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Disabilities Moderate the Association between Neighbourhood Urbanity and Cognitive Health: Results from the Irish Longitudinal Study on Ageing

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Disabilities Moderate the Association between Neighbourhood Urbanity and Cognitive Health: Results from the Irish Longitudinal Study on Ageing

Abstract

Background – Geographical variations in cognitive health have been extensively explored, but the evidence on adult individuals with disabilities is inconclusive. While urban living is suggested as more cognitively stimulating than rural dwelling in epidemiological research, both rurality and urbanity can present barriers that may negatively impact cognitive health, the former due to limited accessibility to stimulation, and the latter because presenting environmental stressors.

Objective – To bridge this gap in the literature, we investigated geographical variations in multiple cognitive skills in adult age based on neighbourhood urbanity and having disabilities.

Methods - Data on global cognition, memory, speed of processing and executive functions, as well as reported functional limitations, was taken from 4,127 individuals aged 50+ participating in the first wave of The Irish Longitudinal Study on Ageing (TILDA). Neighbourhood urbanity was measured using Census data on population density. Multivariate regression analyses controlled for socio-demographic, health and lifestyle covariates.

Results - Residence in medium-high densely populated areas was significantly associated with better cognitive performance across all measures, after controlling for covariates. However, having disabilities was linked to worse global cognitive functioning (MoCA, p = .005), immediate recall (p = .022) and executive functions (CTT2, p = .009) in the least and most densely populated areas.

Conclusions –Living in urbanised areas may provide more mental stimulation than rural places; however, functional limitations moderate this association, suggesting potential environmental challenges both in rural and urban areas. Considering both individual and environmental circumstances can enrich investigations of geographical variations in cognitive health.

Keywords: cognitive aging, urbanization, population density, disabilities.

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1. Introduction

Increasing ageing and urbanisation worldwide have informed accumulating evidence on how lived environments contribute to health inequalities in ageing, and on the environmental factors that can sustain healthy and independent living in ageing, defined as "age-friendly" (1–3). Along age-friendly initiatives, there is growing interest in investigating which places can support cognitive health in ageing, or "cognitive-friendly" (4,5), given rising rates of dementia and cognitive impairment experienced in older age (6) and the evidence that stimulating and enabling environments can protect against cognitive decline (7,8).

Considering a "person-environment fit" perspective (9) ageing comes with higher dependency on the level of support received from the surrounding environment, especially if experiencing disabilities. Adult individuals with functional limitations are in fact more at risk than others of facing environmental barriers and limitations to the engagement in outdoor activities (10,11) - a well-established protective factor for cognitive health in ageing (12) -, and are thus more susceptible than others to the presence of supportive and accessible places to age well. Despite rising proportions of individuals with disabilities worldwide (13), it is yet unclear how the lived environment contributes to health inequalities for adult people with disabilities (14), especially in relation to geographical variations in cognitive health.

Several epidemiological studies have indicated a cognitive advantage of living in urban rather than rural areas (5,15–17). However, the moderating role of disabilities has been investigated in very few studies. These have shown that on one hand rural living can impact negatively on health because of geographical isolation and limited accessibility to resources (18,19), but on the other hand, an overcrowded urban environment presents stressors and barriers (e.g., noisy traffic) that can cause withdrawal from outdoor activities (20,21). In line

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with these studies, investigations looking at the proximal environment of residence suggest a nonlinear association between neighbourhood urbanity and cognitive outcomes in older age, for instance in terms of residential density (22), or land-use mix (23). Going beyond a cognitive focus, a study in Scotland found a nonlinear association between population density and suicide rates (24), suggesting a detrimental effect on mental health of living in areas with very low or very high levels of urbanisation.

These findings support ecological models of ageing (9) and theories of environmental design (25) which suggest that the level of stimulation coming from the surrounding environment has to be within a certain “optimal” range in order to promote adaptive cognitive responses, especially if functional limitations make us more susceptible to environmental demands. From a cognitive, information-processing viewpoint, an older person living in a more urbanised area is exposed to a more dynamically complex environment which stimulate cognitive skills that deal with novelty (7), multi-tasking, and making sense of complex perceptual information (5,22,26). On the other hand, animal and human studies suggest that overpopulation and crowding are associated with reduced cognitive control and impaired spatial memory because increasing distractibility and mental fatigue (27–29). Within this perspective, low levels and, on the opposite, very high levels of urbanisation, should be the least supportive of cognitive functioning, the former being not stimulating enough, whereas the latter potentially overloading and cognitively detrimental (25,26), especially for an individual with limited functionality.

The present study tested this nonlinear association between urbanity and cognitive health by exploring geographical variations in multiple measures of cognition for a nationally representative sample of adult individuals based on neighbourhood urbanity, and by examining the moderating effect on such variations of having a disability.

Based on the literature discussed above, we hypothesised better cognitive performance for medium-high levels of neighbourhood urbanity, whereas we expected worse performance for very low or very high levels. We also predicted this nonlinear pattern of variation to be exacerbated by the presence of disabilities.

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2. Methods

2.1. Participants

The sample for this study included 4,127 community-dwelling Irish people aged 50 and older who completed a physical and cognitive health assessment in the first wave (2009 - 2011) of The Irish Longitudinal Study on Ageing (TILDA), a large cohort study on the health, well-being and socioeconomic circumstances of Irish older people (30,31). Ethical approval was obtained before data collection, and all respondents provided signed informed consent (31); no individuals with severe cognitive impairment took part in the First Wave (32). Further details on the design and methodology of TILDA, as well as the comparability with other longitudinal studies are available elsewhere (32,33).

2.2. Design

Cross-sectional analyses were conducted on variations in performance for a comprehensive set of cognitive skills based on neighbourhood urbanity, and in interaction with the presence of disabilities, while controlling for individual-level covariates. An anonymised released version of the dataset for the first wave of TILDA (see http://www.ucd.ie/issda/data/tilda/) was used to maintain data confidentiality.

2.3. Measures

2.3.1. Neighbourhood urbanity

Neighbourhood urbanity was measured in terms of population density of the electoral division of residence of each TILDA participant as derived from the Irish Census 2006 (34). Population density was defined as the average number of inhabitants per hectare (1 hectare is equivalent to 2.47 acres). Electoral divisions were the smallest legally defined administrative areas in Ireland with an average size of 20 km^2 (or 2,000 hectares). For reasons of anonymity,

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the variable was categorised in six groups of increasing population density adopting categories used in the Irish Census:

(1) Very low: Less than 0.5 persons per hectare (i.e., less than one person every two hectares);

(2) Low: Between 0.5 and 1 person per hectare;

(3) Medium Low: Between 1 and 10;

(4) Medium High: Between 10 and 25;

(5) High: Between 25 and 50;

(6) Very High: More than 50 persons per hectare.

By matching the above categories with broad urban-rural classifications provided in the Irish Census, we found that over 98% of participants in rural settlements (defined in the Irish Census as having fewer than 1,500 inhabitants) lived in electoral divisions with very-low to medium-low population density (Groups 1-3), whereas 92% of urban participants (i.e., living in settlements with a population of 200,000 or more) resided in electoral divisions with medium-high to very-high population density (Groups 4-6). Participants living in settlements with a population going from 1,500 to less than 200,000 inhabitants (an intermediated category provided by the Census) were instead more spread across electoral divisions of varying population density, although 74% lived in areas with medium-low to high population density (Groups 3-5). A detailed account of the distribution of electoral divisions by urban-rural Census categories is presented in Supplementary Table 1.

It is to note that the adopted categorisation of neighbourhood urbanity is relative to the Irish context, which has a high number of settlements with low and very low population density, and very few highly populated areas.

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2.3.2. Disabilities

Participants were asked to report whether they experienced issues with abilities of daily living (ADLs) and/or with instrumental abilities of daily living (IADLs). These are commonly used measures of functional status: ADLs include the basic tasks of everyday life, such as eating, bathing, dressing, toileting, and walking, whereas IADLs are the activities needed to live independently in a community setting, such as managing money, shopping, using the telephone, housekeeping, preparing meals, and taking medications correctly (31). Given that 89% (N = 3,712) of our sample reported no disabilities (either in ADLs or IADLs), we coded the responses into a binary measure indicating the absence or presence of any disability (ADLs and/or IADLs) rather than using separate categories for each type.

2.3.3. Cognitive Measures

Cognitive health was assessed in terms of global cognition, memory, processing speed, and executive functions. Measures of global cognition included the Montreal Cognitive Assessment Test (MoCA) and the Mini Mental State Examination (MMSE), this one recoded as number of errors. Memory was measured in terms of immediate and delayed recall of a list of 10 words. Processing speed was assessed through the mean completion time (seconds) for the Colour Trail Making Test Part 1 (CTT1). Measures of executive functions included a verbal fluency (animal naming) test, the mean completion time (seconds) for the Colour Trail Making Test Part 2 (CTT2), and the mean change in completion time from CTT1 to CTT2 (CTT delta). CTT errors were not analysed due to the very low error rate (less than 10% for one error and less than 2% for two or more errors). Detailed description of these measures and relative references are provided elsewhere (31).

2.3.4. Covariates

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Covariates included: sex; age; educational attainment (primary, secondary, or third/higher); employment status ("employed", "retired", or "other", this last including for example individuals in training or looking after the house); the number of chronic conditions (see details below); clinical symptoms of depression measured through the Center for Epidemiologic Studies Depression Scale (CES-D); the perceived frequency of loneliness ("Rarely/Never", "Some of the time", "Moderate/Most of the time"); fear of falling (yes or no); the engagement in physical activity as measured through the International Physical Activity Questionnaire (IPAQ) Short form; and the frequency of engagement in social activities ("Rarely/Never", "Yearly", "Monthly", "Weekly"). Detailed description of these measures and relative references are provided elsewhere (31).

Number of chronic conditions was a composite score ranging from 0 (no conditions) to 11 (total number of conditions), created by adding up the total number of conditions reported by the participant when answering the question "Has a doctor ever told you that you have any of the conditions on this card?", and including any of the following: high blood pressure or hypertension, angina, heart attack, congestive heart failure, diabetes or high blood sugar, stroke, mini-stroke or transient ischemic attack (TIA), high cholesterol, heart murmur, abnormal heart rhythm, other heart trouble, chronic lung disease, asthma, arthritis, osteoporosis, cancer or malignant tumour, Parkinson's disease, emotional/nervous/psychiatric problem, alcohol or substance abuse, stomach ulcers, varicose ulcers, cirrhosis or serious liver damage.

Engagement in social activities was generated by adding up the frequency of engagement in activities including the following: going to the cinema, traveling for leisure, participating in classes and training, engaging in hobbies, taking part in games (e.g., bingo, cards), going to the pub, dining out, taking part in sport or exercise, visiting friends and family, doing charity work. Each of the 10 subcomponents was scored as 1 ("Rarely/Never"),

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2 ("Yearly"), 3 ("Monthly"), or 4 ("Weekly"), thus the total composite score ranged from 10 to 40, with higher scores indicating a higher frequency of engagement.

2.4. Statistical analyses

Statistical analyses were performed using Stata version 12 (StataCorp LP, Texas). Sampling weights were calculated for each participant in TILDA as the inverse of the probability that an individual in the Irish older population selected at random with same age, sex and educational attainment would have completed the health assessment (31,35); participants from groups less likely to participate received a higher weight. Linear regression was used for continuous variables (MoCA, CTT 1, fluency, CTT 2, CTT delta), and Poisson regression for count variables (MMSE errors, immediate and delayed recall). Regression models explored variations in cognitive performance across the six groups of neighbourhood urbanity in univariate analyses, and in multivariate analyses controlling for all covariates, including disabilities. We conducted a Wald test of the null hypothesis that the coefficients across the groups of population density were equal. We then looked at the moderating effects of having disabilities by building regression models including the interaction between neighbourhood urbanity and disabilities in both univariate and multivariate analyses. *P*-values for the interaction are presented. Statistical significance was indicated by a *p*-value lower than .05. While our initial sample included 4,303 participants, 176 observations (4%) were excluded from the analyses because missing data in relation to either cognitive performance, neighbourhood urbanity, disabilities, or the level of engagement in outdoor activities (a key covariate for our analyses), leaving a total of 4,127 valid observations. .

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3. Results

3.1. Sample characteristics

In our sample (Mean age 62.5, standard deviation = 8.8, median age = 61; 49.8% female), 35.6% of participants lived in the least populated areas (Group 1), 10.2% lived in the most populated areas (Group 6), and between 11% and 16% of participants lived in any of the intermediate areas of neighbourhood urbanity. Table 1 shows the distribution of participants with or without disabilities across the groups of population density: Overall, 88.9% of the sample reported no disabilities, however, group 4 (14%) and group 6 (16%) had higher proportions of people with disabilities than other groups, and significantly higher than Group 1 (Group 4: $p = .03$; Group 6: $p = .005$).

[Table 1 here]

Participants' characteristics are provided in detail in the Supplementary Table 2. Overall, the sample was healthy: Participants reported on average 1.93 chronic conditions ($SD = 1.65$), 74% of them had none or mild symptoms of depression, and over 78% reported no fear of falling. The participants indicated on average a medium-low frequency of engagement in social activities (mean = 23.8, $SD = 4.68$, range: 10-40), and over 70% of them engaged in moderate or vigorous physical activity. Over 46% had a secondary school educational attainment and 20% had a degree or higher qualification. Approximately 40% of the sample was employed at the time of the interview, whereas 34% was retired and the remaining 25% was unemployed. Considering the distribution of demographic characteristics across groups of neighbourhood urbanity, participants' average age was increasingly higher in more urbanised areas, with Group 6 being the oldest (Mean age = 64.05, $SD = 8.45$), the most likely to be retired (42%), to have a higher number of chronic conditions (Mean = 2.27, $SD = 1.71$), and to report fear of falling (28%). Although almost 70% of the total sample had

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achieved secondary or higher education, the least and most urbanised areas had relatively higher proportions of participants with primary education (Group 1 = 36%; Group 2 = 37%; Group 6 = 47%). Similarly, participants in groups 1, 2 and 6 reported lower engagement in social activities than those in groups 3-5.

In terms of cognitive performance (see Table 2), the overall sample showed very good scores in the MMSE (Mean number of errors = 1.62, *SD* = 1.88) but less than optimal performance at the MoCA (*M* = 24.8, *SD* = 3.4), in line with the fact that the MoCA includes more difficult tasks than the MMSE. The participants recalled around seven out of 10 words immediately after presentation and approximately six words after a delay. Part 1 of the Coloured Trail Making Test (CTT1) was completed on average in less than a minute (*M* = 58.1, *SD* = 26.8, range: 17.7-231.03 seconds), whereas Part 2 (CTT2) required almost the double of time (*M* = 114.5, *SD* = 44.8, range: 30.1-415.2 seconds). Participants named on average 20 animals in the fluency task (range: 0-50). Comparisons between groups in terms of cognitive abilities (see Table 2) showed a pattern of significantly better performance across all measures for participants in Groups 3-5 (medium-low to high population density), although the differences were of small magnitude.

[Table 2 here]

3.2. Performance by neighbourhood urbanity

Multivariate analyses adjusted for all covariates (see Figure 1, detailed estimates of the regression analyses are provided in Supplementary Table 3) confirmed better performance for groups 4 and 5 (as compared to the least densely populated areas) and showed that, accounting for socio-demographic, health and lifestyle circumstances, differences in score emerged also between group 1 and 6 (respectively the least and most densely populated areas). As it can be noted in Figure 1, groups 1-3 appeared to have overall

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lower scores than groups 4-6 for all measures except CTT1 (Figure 1e) and CTT2 (Figure 1f). These two measures showed instead better performance for groups 2-6 when compared to group 1. Neighbourhood urbanity contributed to approximately 2% of the variance in the cognitive measures.

[Figure 1 here]

3.3. Performance by neighbourhood urbanity and disability

We then analysed whether having or not disabilities would moderate the variations in cognitive performance emerged in Figure 1, and found a significant interaction between disabilities and neighbourhood urbanity after controlling for all the covariates for MoCA ($F_{5,617}$ = 3.40, p = .005), immediate recall ($F_{5,617}$ = 2.64, p = .022) and CTT2 ($F_{5,617}$ = 3.09, p = .009), as shown in Figure 2. The analyses indicated that, while living in electoral divisions with higher population density was associated with higher scores for participants with no disabilities (solid line in Figure 2), when considering participants with disabilities (dashed line in Figure 2), those living in the least and most densely populated areas had the worst performance. The interaction explained 5.5% of variance for MoCA scores, 5% for immediate recall, and 7% for CTT2. This pattern of results emerged also for MMSE errors, CTT1, and CTT delta but the interaction did not reach statistical significance for these measures (data not shown).

[Figure 2 here]

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4. Discussion

Our study investigated variations in cognitive performance in community-dwelling healthy Irish adults aged 50 and older based on neighbourhood urbanity, and the moderating effects on these variations of having or not functional limitations. Although our sample was overall healthy and relatively young, after controlling for socio-demographic, health and lifestyle covariates participants living in areas (i.e., electoral divisions) with medium to very high neighbourhood urbanity had better cognitive performance than those living in areas with very low neighbourhood urbanity, with variations noted for global cognition (MoCA, MMSE errors), immediate and delayed recall, processing speed (CTT1) and executive functions (CTT2, CTT delta, verbal fluency).

In terms of overall variations in cognitive performance based on neighbourhood urbanity, the distribution of scores resembled a possible step or sigmoid form for most of the investigated cognitive measures, with Groups 1-3 being worse than Groups 4-6. This might be indicative of a threshold of urbanity over which the lived environment offers more opportunities for cognitive stimulation, partially in line with previous epidemiological studies looking at land-use mix (36). Interestingly, demographic covariates did not appear to explain these results, as participants in more densely populated areas were older and reported more chronic conditions as well as more fear of falling. This pattern of results points at the potential role of aspects of neighbourhood quality (e.g., presence of green) or other environmental measures influencing cognition which deserve further investigation.

Our findings do not fully support the initial hypothesis that very high levels of neighbourhood urbanity (Group 6), which we expected to be a proxy of crowding, would be associated with worse cognitive performance than living in medium-high densely populated areas. One reason for these results might be that highly populated areas in the most urbanised

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environments in Ireland do not present the same level of crowding as areas in bigger metropolis in other countries. Nonetheless, Group 6 showed smaller differences in performance from Group 1 than Groups 4-5 did, in line with a nonlinear dose-response relationship between levels of urbanisation and cognition in ageing found in previous studies (23,36). Notably, participants in areas with medium to high population density (Groups 3-5) engaged more (although to a small degree) in social activities than those living in the least and most densely populated areas, but the pattern of variations was not affected when controlling for social engagement.

Our second hypothesis was that a nonlinear pattern of variation in cognitive performance based on neighbourhood urbanity would emerge particularly for participants reporting disabilities, because this group would be more likely to experience issues of isolation in rural areas and potential issues of crowding in densely populated areas. This hypothesis was confirmed for MoCA, immediate recall and CTT2, with poorer performance for participants with disabilities living in the least and most densely populated electoral divisions. These cognitive skills are involved in the executive control of complex activities (e.g., multitasking, time management, problem solving), and that benefit the most from interacting with a stimulating and enabling environment (7). Notably, both groups 1 and 6 had among the lowest levels of educational attainment and of engagement in social activities. Education and social engagement are well-established protective factors for cognitive health in ageing (37), and previous studies have shown that urban-rural variations in cognitive functioning could be ascribed to differences in mental stimulation received through education (16) or through social engagement (38). However, the interactions remained significant even after controlling for educational attainment or social engagement in our multivariate models, suggesting that socioeconomic circumstances did not fully account for the association between neighbourhood urbanity and disabilities in our sample. This conclusion is in line

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with previous studies exploring the association between neighbourhood urbanity and cognitive skills in older age (22). Furthermore, our results cannot be ascribed to similarities in the participants' age between Group 1 and Group 6, as the latter was significantly older than the rest of the sample (including Group 1).

Our findings support previous epidemiological investigations that indicate a positive association between living in a more urbanised environment and better cognitive health in an adult sample. However, when considering functional limitations, living in places with very low or very high population density can become less supportive of cognitive health, possibly because the former afford fewer opportunities for cognitive stimulation in the local environment whereas the latter present a higher number of environmental barriers or stressors. Having measures of environmental accessibility or stressors would have enabled to reach a conclusion on the potential mechanisms through which individuals with disabilities are more cognitively disadvantaged in isolated or crowded environments. Our findings are in this sense preliminary and inform future empirical investigations of cognitive correlates of neighbourhood characteristics other than crowding. Nonetheless, the results of the present study extend previous findings on urban-rural variations in cognitive health in adult samples (17) by showing more refined variations thanks to the use of a measure of urbanisation at the level of the local environment of residence, and by highlighting the importance of considering how these variations are moderated by individual circumstances. Importantly, our study, together with previous findings, stimulates to consider the environment of residence across multiple environmental levels (26) by incorporating an exploration of characteristics of the local area of residence (in this study, neighbourhood urbanity) into broader measures of urbanisation.

Longitudinal studies will clarify potential causal relationships as well as the clinical relevance of our results. While the variations in scores were of small magnitude given the

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health and young-old sample, they may indicate a disadvantage which could potentially increase over time and become of clinical importance. This cannot be elucidated by the cross-sectional data due to potential cohort effects.

Population density of the area of residence has been recommended in the epidemiological literature to clarify broad urban-rural variations in cognitive health (39). However, given that levels of urbanity and rurality in Ireland can differ from those of other, more urbanised, countries, cross-national investigations are needed to clarify the generalisability of the categories of neighbourhood urbanity used for this study. Comparisons across countries would enable to understand whether it is possible to determine an optimal level of population density to support healthy cognitive ageing in an absolute sense, or whether cultural and associated lifestyle differences may indicate that a relative measure of urbanisation is more appropriate.

This study is, to our knowledge, the first to identify variations in a comprehensive set of cognitive skills in adult age in relation to neighbourhood urbanity and disabilities. As supporting the cognitive health of an increasing ageing population with multi-morbidities is currently a global priority, it is important to understand whether an insufficiently stimulating or over-stimulating environment could amplify functional limitations in older age. Issues of accessibility can arise for adult people with disabilities both in rural and highly urbanised areas, but they can be of a different nature (isolation in one case, environmental stress in the other) and therefore need to be addressed differently. This type of investigation, considering the individual as well as contextual circumstances of a person who is growing old, is crucial to clarify how lived places contribute to health inequalities.

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Figure legends

Figure 1 caption: Estimated marginal cognitive performance by neighbourhood urbanity level for the Montreal Cognitive Assessment (a, MoCA), the Mini Mental State Examination (b, MMSE errors), immediate (c) and delayed recall (d), the Colour Trail Making Test Part 1 (e, CTT1), Part 2 (f, CTT2) and Delta measure (g, CTT delta), and verbal fluency (h). All covariates are controlled for. Data are weighted. Neighbourhood urbanity: (1) very low (reference); (2) low; (3) medium-low; (4) medium-high; (5) high; (6) very high. Error bars represent 95% confidence intervals. Significant differences in score from Group 1 are indicated at the level * $p < .05$, ** $p < .01$ and *** $p < .001$. Data source: The Irish Longitudinal Study on Ageing (TILDA).

Figure 2 caption: Estimated marginal cognitive performance by neighbourhood urbanity level and presence of disabilities for the Montreal Cognitive Assessment (a, MoCA), immediate recall (b) and the Colour Trail Making Test Part 2 (c, CTT2) All covariates are controlled for. Data are weighted. Neighbourhood urbanity: (1) very low (reference); (2) low; (3) medium-low; (4) medium-high; (5) high; (6) very high. Error bars represent 95% confidence intervals. Significant differences between participants with and without disabilities for Groups 2-6, as compared to differences for Group 1, are indicated at the level * $p < .05$, ** $p < .01$ and *** $p < .001$. Data source: The Irish Longitudinal Study on Ageing (TILDA).

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Table 1

Disabilities by Neighbourhood Urbanity, n (%)

Neighbourhood urbanity group	Presence of disabilities	
	No *n* = 3,712 (88.9%)	Yes *n* = 415 (11.1%)
1 (x < 0.5)	1,285 (90.3)	127 (9.7)
2 (0.5 <= x < 1)	401 (90.4)	38 (9.6)
3 (1 <= x < 10)	537 (89.3)	60 (10.7)
4 (10 <= x < 25	486 (85.7)	72 (14.3)
5 (25 <= x < 50)	669 (90.3)	67 (9.7)
6 (x >= 50)	334 (83.7)	51 (16.3)

Data source: The Irish Longitudinal Study on Ageing (TILDA).

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Table 2

Estimates of Cognitive Performance for Total Sample and by Neighbourhood Urbanity Level (Groups 2-6 as compared to Group 1)

Cognitive measure	Total sample (*N* = 4,127)	Neighbourhood Urbanity Level						*P*-value
		1 (*n* = 1,412, 35.6%) Ref.	2 (*n* = 439, 11.2%)	3 (*n* = 597, 13.7%)	4 (*n* = 558, 12.9%)	5 (*n* = 736, 16.5%)	6 (*n* = 385, 10.2%)	
MoCA, mean ± SD	24.8 ± 3.4	24.4 ± 3.5	24.3 ± 3.5	24.9 ± 3.3	25.3 ± 3.4	25.5 ± 3.3	24.8 ± 3.2	<.000
MMSE errors[a], median (IQR)	1 (2-0)	1 (3-0)	1 (3-0)	1 (2-0)	1 (2-0)	1 (2-0)	1 (2-0)	<.000
Immediate recall, median (IQR)	7 (8-5.5)	6.5 (7.5-5.5)	6.5 (7.5-5.5)	7 (8-6)	7 (8-6)	7 (8-6)	7 (8-5.5)	<.001
Delayed recall, median (IQR)	6 (8-4)	6 (7-4)	6 (7-4)	6 (8-5)	6 (8-5)	6 (8-5)	6 (8-4)	<.000
CTT1[a] (sec), mean ± SD	58.1 ± 26.8	60.7 ± 27.3	57.9 ± 27.8	54.4 ± 25.3	55.3 ± 26.2	56.5 ± 26.1	59.7 ± 25.7	<.001
Verbal fluency, mean ± SD	20.9 ± 6.8	20.3 ± 6.5	19.7 ± 6.3	21.5 ± 6.6	21.3 ± 6.9	22.3 ± 7.7	20.9 ± 6.5	.002
CTT2 [a] (sec), mean ± SD	114.5 ± 44.8	121.1 ± 46.7	116.5 ± 44.9	110.1 ± 43.4	106.7 ± 42.4	107.4 ± 41.1	116.7 ± 42.6	<.000
CTT delta [a], mean ± SD	56.5 ± 29.3	60.4 ± 30.6	58.6 ± 28.3	55.7 ± 28.9	51.5 ± 26.9	50.9 ± 27.7	57.0 ± 28.2	<.000

Note. MoCA = Montreal Cognitive Assessment, MMSE = Mini Mental State Examination, CTT = Colour Trail Making Test, SD = standard deviation, IQR = interquartile range. *P*-values correspond to a Wald test of the null hypothesis that the coefficients across the population density categories were equal. Data are weighted. Data source: The Irish Longitudinal Study on Ageing (TILDA).

[a] Higher values for these measures indicate worse performance.

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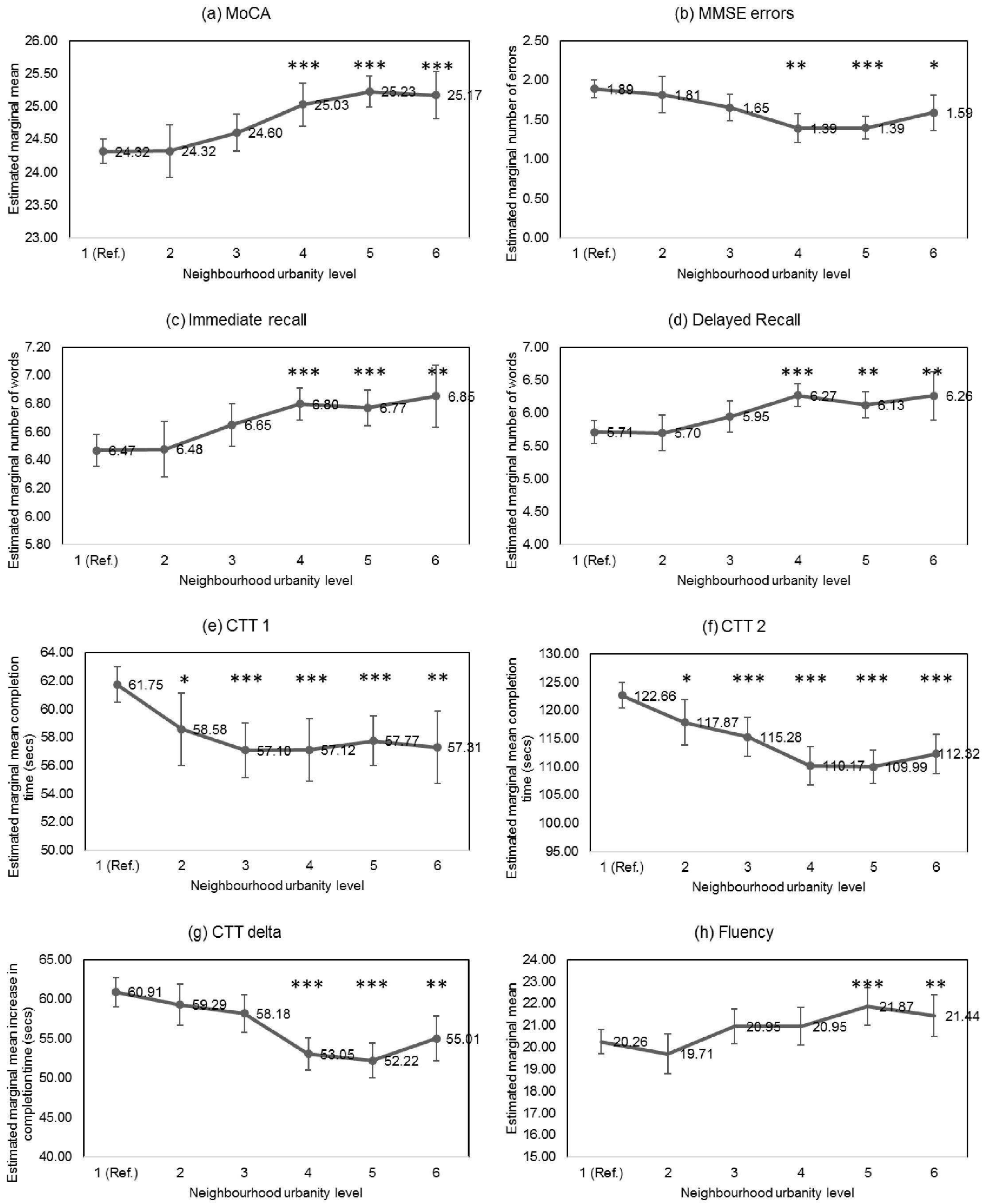
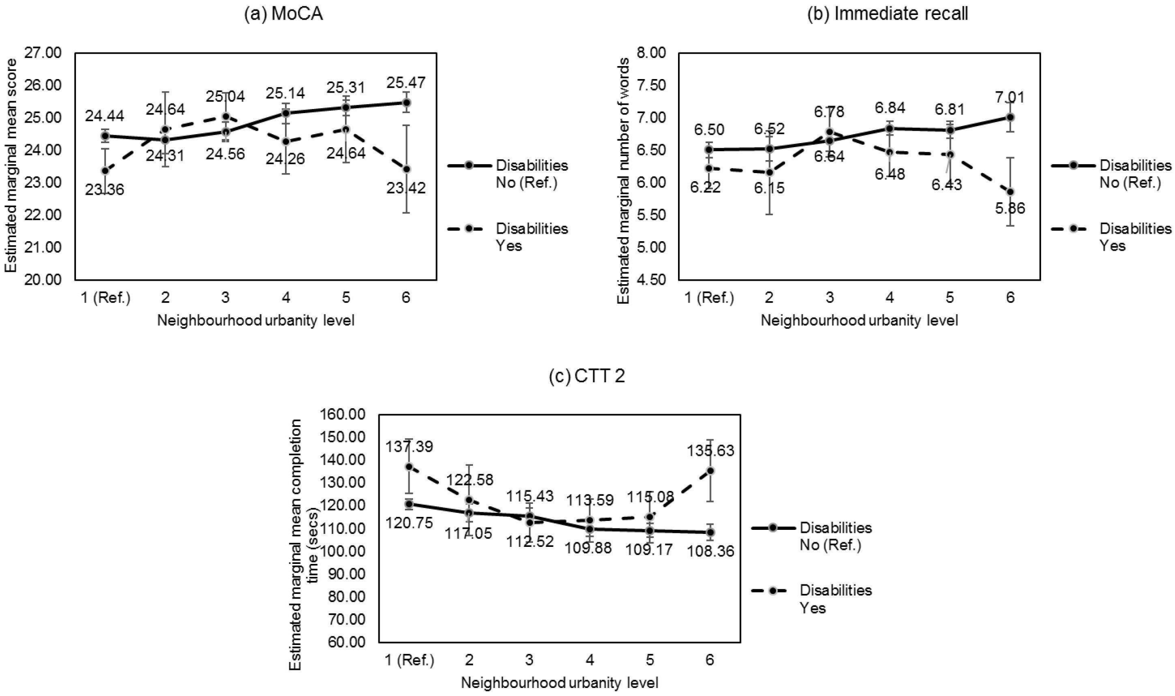


(a) MoCA
Estimated marginal mean
Neighbourhood urbanity level
1 (Ref.)
24.32
24.32
24.60
25.03
25.23
25.17
***
***
***
(b) MMSE errors
Estimated marginal number of errors
1.89
1.81
1.65
1.39
1.39
1.59
**
***
*
(c) Immediate recall
Estimated marginal number of words
6.47
6.48
6.65
6.80
6.77
6.85
***
***
**
(d) Delayed Recall
5.71
5.70
5.95
6.27
6.13
6.26
***
**
**
(e) CTT 1
Estimated marginal mean completion time (secs)
61.75
58.58
57.10
57.12
57.77
57.31
*
***
***
***
**
(f) CTT 2
122.66
117.87
115.28
110.17
109.99
112.32
*
***
***
***
***
(g) CTT delta
Estimated marginal mean increase in completion time (secs)
60.91
59.29
58.18
53.05
52.22
55.01
***
***
**
(h) Fluency
20.26
19.71
20.95
20.95
21.87
21.44
***
**


(a) MoCA
Estimated marginal mean score
Neighbourhood urbanity level
1 (Ref.)
24.44
23.36
24.64
24.31
25.04
24.56
25.14
24.26
25.31
24.64
25.47
23.42
Disabilities No (Ref.)
Disabilities Yes
(b) Immediate recall
Estimated marginal number of words
6.50
6.22
6.52
6.15
6.78
6.64
6.84
6.48
6.81
6.43
7.01
5.86
(c) CTT 2
Estimated marginal mean completion time (secs)
137.39
120.75
122.58
117.05
115.43
112.52
113.59
109.88
115.08
109.17
135.63
108.36

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Data statement

The data associated with this manuscript are property of The Irish Longitudinal Study on Ageing (TILDA, www.tilda.tcd.ie) and for reasons of confidentiality can only be accessed after receiving permission from the TILDA data management team.

For further details on how to access TILDA data, please visit http://www.ucd.ie/issda/data/tilda/ or contact tilda@tcd.ie

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