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published in
Social Science and Medicine
2017

DOI (link to publisher)
10.1016/j.socscimed.2017.05.052

document version
Publisher's PDF, also known as Version of record

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Link to publication in VU Research Portal

citation for published version (APA)
Wörn, J., Ellwardt, L., Aartsen, M., & Huisman, M. (2017). Cognitive functioning among Dutch older adults: Do neighborhood socioeconomic status and urbanity matter? *Social Science and Medicine*, *187*, 29-38. https://doi.org/10.1016/j.socscimed.2017.05.052

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Download date: 14. Jan. 2025

Social Science & Medicine 187 (2017) 29–38

Contents lists available at ScienceDirect

Social Science & Medicine

journal homepage: www.elsevier.com/locate/socscimed

Cognitive functioning among Dutch older adults: Do neighborhood socioeconomic status and urbanity matter?

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A R T I C L E I N F O

Article history:
Received 7 December 2016
Received in revised form
24 May 2017
Accepted 29 May 2017
Available online 3 June 2017

Keywords:
The Netherlands
Older adults
Cognition
MMSE
Neighborhood socioeconomic status
Urbanity
Growth model
Multilevel modeling

A B S T R A C T

Positive associations of neighborhood socioeconomic characteristics and older adults' cognitive functioning have been demonstrated in previous studies, but overall results have been mixed and evidence from European countries and particularly the Netherlands is scarce. We investigated the effects of socioeconomic status (SES) and urbanity of neighborhoods on four domains of cognitive functioning in a sample of 985 Dutch older adults aged 65–88 years from the Longitudinal Aging Study Amsterdam. Besides cross-sectional level differences in general cognitive functioning, processing speed, problem solving and memory, we examined cognitive decline over a period of six years. Growth models in a multilevel framework were used to simultaneously assess levels and decline of cognitive functioning. In models not adjusting for individual SES, we found some evidence of higher levels of cognitive functioning in neighborhoods with a higher SES. In the same models, urbanity generally showed positive or inversely U-shaped associations with levels of cognitive functioning. Overall, effects of neighborhood urbanity remained significant when adjusting for individual SES. In contrast, level differences by neighborhood SES were largely explained by the respondents' individual SES. This suggests that neighborhood SES does not influence levels of cognitive functioning beyond the fact that individuals with a similar SES tend to self-select into neighborhoods with a corresponding SES. No evidence of systematically faster decline in neighborhoods with lower SES or lower degrees of urbanity was found. The findings suggest that neighborhood SES has no independent effect on older adults cognitive functioning in the Netherlands. Furthermore, the study reveals that neighborhood urbanity should be considered a determinant of cognitive functioning. This finding is in line with theoretical approaches that assume beneficial effects of exposure to complex environments on cognitive functioning. We encourage further investigations into the effect of urbanity in other contexts before drawing firm conclusions.

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1. Introduction

Recent years have seen a strong interest in the effects of neighborhood environments – typically understood as relatively small areas surrounding a person's place of residence as defined by administrative, geographical or subjective boundaries – on health. A sizeable amount of findings indicating better health (as assessed in terms of self-rated health, depression, cardiovascular and cardiometabolic risk factors, and mortality) in socioeconomically better off neighborhoods is challenged by many studies reporting null-findings (Julien et al., 2012; Kim, 2008; Leal and Chaix, 2011; Mair et al., 2008; Pickett and Pearl, 2001; Richardson et al., 2015; Riva et al., 2007). Especially for older adults, maintaining cognitive functioning is an important health outcome, influencing their quality of life, and costs of care (Hertzog et al., 2009). It has been argued that the neighborhood context is especially meaningful for older adults because of their higher vulnerability and because they presumably spend more time in their neighborhoods than younger people, especially after retirement (e.g. Robert and Li, 2001).

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http://dx.doi.org/10.1016/j.socscimed.2017.05.052
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A recent review concludes that the majority of studies report that older adults in neighborhoods with a higher socioeconomic status or lower levels of deprivation show better cognitive functioning (Wu et al., 2015). However, while many cross-sectional studies examined effects of neighborhood socioeconomic status (NSES) on the *levels* of cognitive functioning, very few studies examined cognitive *decline* over time (but see Boardman et al., 2012; Sheffield and Peek, 2009; Zeki Al Hazzouri et al., 2011). We thus aim to examine effects of NSES not only on levels but also on decline of cognitive functioning. To get a broader and more detailed picture, we investigate four different aspects of cognitive functioning, particularly general cognitive functioning, processing speed, problem solving, and memory, instead of using a general measure only. We expect all four domains of cognitive functioning to be associated with NSES. While the different domains may vary in their susceptibility to neighborhood characteristics, we do not explicitly theorize on domain-specific variations in this study. Instead, we include the different domains in our empirical analysis to facilitate a broader test where findings can be cross-validated across domains. Reliance on multiple outcomes rather than a sole measure seems especially important in light of the rather poor discriminatory power of MMSE in well-functioning individuals.

We further examine the effect of another key neighborhood characteristic, i.e. the effect of neighborhood urbanity, on older adults' cognitive functioning. Like NSES, neighborhood urbanity may affect access to opportunity structures that benefit cognitive functioning. Given the potential contribution of neighborhood urbanity to the understanding of interindividual differences in cognitive functioning, the scarcity of previous research on this issue signifies the need for our study.

We start by outlining theoretical considerations and empirical findings that propose effects of NSES and urbanity on older adults' cognitive functioning. Subsequently, we use growth models in a multilevel framework to examine the effect of both neighborhood characteristics on levels of and decline in cognitive functioning in a sample of 985 older adults from the Longitudinal Aging Study Amsterdam (LASA; Aartsen and Huisman, 2016). At the beginning of our study in 1995/6, the respondents were aged 65–88 years and did not show cognitive impairment. They were followed up for up to six years.

2. Theory and hypotheses

Associations of NSES and neighborhood urbanity with cognitive functioning could base on two different mechanisms. Firstly, the neighborhood context may have a causal influence on the cognitive functioning of its older inhabitants by affecting opportunity structures that influence behaviors associated with cognitive functioning. For example, neighborhoods with a higher (vs. lower) NSES may provide their older inhabitants with more and higher quality resources that encourage engagement in physical activities (e.g. parks, gyms, sidewalks of good quality), social activities (e.g. attractive shopping areas, social clubs, neighborhood organizations), and cognitively stimulating activities (e.g. bookstores, libraries) (Wight et al., 2006; also see Sheffield and Peek, 2009; Wu et al., 2015). This assumption is supported by theoretical approaches like the cognitive-enrichment hypothesis arguing that within age-related biological constraints, “behaviors of an individual (including cognitive activity, social engagement, exercise, and other behaviors) have a meaningful positive impact on the level of effective cognitive functioning in old age” (Hertzog et al., 2009). Other theories state more explicitly that cognitive decline may similarly be affected by cognitive, physical, and social activities (e.g. Use It or Lose It Hypothesis (Hultsch et al., 1999), Environmental Complexity Hypothesis (Schooler, 1984), Revised Scaffolding Theory of Aging and Cognition (Reuter-Lorenz and Park, 2014)).

Besides differential access to opportunities, neighborhoods may influence their inhabitants’ motivation to engage in cognitively enhancing activities: Older adults' neighbors in better off neighborhoods are more likely to be well educated and occupationally successful and might stimulate upward comparison. This may in turn motivate older adults' engagement in activities that enhance cognitive functioning (Sisco and Marsiske, 2012).

In view of neighborhood urbanity, we assume that more urban neighborhoods represent more complex environments, as understood by the higher diversity of stimuli and the requirement to make decisions in which a larger amount of information needs to be considered and processed (see Schooler, 1984). For example, moving in busy traffic, not getting sidetracked by distractions along the way, and choosing from a larger number of options when it comes to shopping and leisure time activities characterize complex urban environments, offering cognitive stimulation (Cassarino and Setti, 2015). In line with this, Crowe et al. (2008) assumed that a greater life-space (i.e. the spatial range within which people move regularly) with its “greater diversity of experiences and greater demands in terms of decision making” represents a component of environmental complexity. They found that older adults who used a greater life-space showed a weaker decline in cognitive functioning over a 4-year period, controlling for baseline cognition and the effect of physical function. Furthermore, urban neighborhoods supposedly offer a high density of mentally stimulating offers like museums and theatres. Also by means of dense public transportation systems, access to a variety of offers should be facilitated for older adults (St. John et al., 2016; also see Wu et al., 2015).

We thus expect higher levels of and slower decline in cognitive functioning for older adults residing in neighborhoods with a higher NSES (hypothesis H1a/H1b) or a higher degree of urbanity (H2a/H2b), respectively.

Secondly, better cognitive functioning in neighborhoods with a higher NSES or higher urbanity can be caused by the selection of individuals based on their individual socioeconomic status (SES) into specific neighborhoods. E.g., individual education and income have been shown to be related to cognitive functioning in cross-sectional studies (Opdebeeck et al., 2016; Zhang et al., 2015) (longitudinal findings have been more mixed though, see Anstey and Christensen, 2000; Valenzuela and Sachdev, 2006). Thus, individuals with higher SES and associated better cognitive functioning more likely live in neighborhoods with a higher (vs. lower) NSES or a higher (vs. lower) degree of urbanity. In such case, cognitive differences are not necessarily caused by the neighborhood context but by the mingling of certain individuals in the respective neighborhoods. We thus test the alternative explanation that statistical effects of NSES and urbanity dissolve once individual socioeconomic status is considered (H3).

3. Previous research

3.1. Findings on neighborhood socioeconomic status

Cross-sectional empirical findings on the effect of NSES in older populations are mixed. On the one hand, studies found NSES (defined here as (proxy-)measures of at least one dimension of socioeconomic status, i.e. education, occupation, and/or income) to be positively associated with the level of cognitive functioning (Clarke et al., 2012; Lang et al., 2008; Lee et al., 2011; Rosso et al., 2016; Shih et al., 2011; Sisco and Marsiske, 2012; Wight et al., 2006; Zeki Al Hazzouri et al., 2011) or negatively associated with cognitive impairment (Basta et al., 2008; Wee et al., 2012). Partly, studies found that the effect of NSES on cognitive functioning depended on individual demographic (Lang et al., 2008), socioeconomic (Aneshensel et al., 2011; Basta et al., 2008; Deeg and Thomése, 2005; Wight et al., 2006) or genetic (Lee et al., 2011) factors. On the other hand, a range of studies found no or attenuated effects of measures of NSES when adjusting for individual SES (Clarke et al., 2012; Lee et al., 2011; Rosso et al., 2016; Sheffield and Peek, 2009; Sisco and Marsiske, 2012; Wee et al., 2012; Wight et al., 2006). The lack of associations between measures of NSES and cognitive functioning or impairment in models accounting for individual SES is more in line with the selection mechanism than with the causal explanation. Yet, not all findings can undoubtedly be attributed to the former, partly because other factors (e.g. health) where controlled simultaneously.

The available evidence on effects of NSES on cognitive decline is equally mixed. Some studies find associations of higher NSES with reduced rates of cognitive decline, at least for some of the investigated indicators of NSES (Sheffield and Peek, 2009) or cognitive functioning. In one study, these effects showed in white but not black people (Rosso et al., 2016). Taken together, this provides at least some evidence for a causal effect. The NSES-measures in two other studies were however not related to change in cognitive functioning over time when individual SES was controlled (partly simultaneously with additional factors), questioning the existence of a causal effect and supporting the possibility of a selection mechanism (Boardman et al., 2012; Zeki Al Hazzouri et al., 2011).

3.2. Findings on urbanity

To the best of our knowledge, little is known about effects of urbanity on normal cognitive functioning. Findings from related fields however give reason to expect that higher neighborhood urbanity might be beneficial for cognitive functioning. E.g., a recent study using brain imaging measures found that urbanity as measured by dwelling density is cross-sectionally associated with better brain health (see online supplements in Cerin et al., 2017). Conclusions from research looking into dementia and cognitive impairment are however mixed. Either no association (Klich-Rączka et al., 2014; St. John et al., 2016) or a negative association is reported between urbanity (partly measured at larger scales than neighborhoods) and risks of dementia and cognitive impairment after adjustment for at least age and education (Arslantas et al., 2009; Gavrila et al., 2009; also see the review by Russ et al., 2012). Given the potentially stimulating effect of urban neighborhoods, the lack of empirical studies on its effects on normal cognitive functioning illustrates the need for further investigations of this issue.

4. Data and methods

4.1. Participants

We used data from the Longitudinal Aging Study Amsterdam (LASA), an ongoing study on the cognitive, social, emotional and physical functioning of older adults in the Netherlands (Aartsen and Huisman, 2016). The first wave of data was collected in 1992/3, with follow-ups approximately every three years. The population-based sample was selected from eleven municipalities within three culturally distinct regions of the country and aimed to represent urban as well as rural inhabitants within each of these regions. Ethics approval was obtained from the medical ethics committee of the VU University Medical Center (IRB numbers: 92/138 and 2002/141). In the present study, we analyzed data from 985 older adults who were aged 65–88 years at the start of our study period, which was only in the second wave in 1995/6 (T_1) due to availability of neighborhood data. Respondents were followed up for the two subsequent waves in 1998/9 (T_2) and 2001/2 (T_3), i.e. for up to approximately six years, with reduced sample sizes caused by missing values (see Table 1).

4.2. Measures

4.2.1. Cognition

Firstly, the Mini Mental State Examination (MMSE) was a general measure of cognition, including orientation in time and space, registration, attention, recall, language and visuospatial abilities (Folstein et al., 1975). The maximum score is 30, with higher values indicating better cognitive functioning (see Table 1 for descriptive statistics of all variables).

Secondly, processing speed was assessed with the Coding Task (Piccinin and Rabbitt, 1999). Respondents were presented with a key of two rows of letters in which a letter from the upper row and the lower row belong together. The test consisted of an upper row containing letters and an empty lower row. Within three trials of 1 min, respondents had to match as many letters as possible to the upper row by orally naming the corresponding letter from the key. We analyzed the mean number of matches made by the respondents in up to three trials per wave.

Thirdly, problem solving was measured with Raven Colored Progressive Matrices (RCPM; Raven, 1995). In this non-verbal visual test of abstract reasoning, respondents were presented with 24 patterns, in each of which one part was missing. Respondents were asked to pick the pattern that correctly fits into the incomplete pattern from six alternatives.

Fourthly, episodic memory was assessed with the 15 words test (15WT), a Dutch version of the Auditory Verbal Learning Test (Rey, 1964; Saan and Deelman, 1986). Respondents were asked to learn 15 words and recall them immediately during the learning phase, which was repeated three times. We analyzed the delayed recall score, i.e. the number of words correctly recalled by the respondent after a distraction period of 20 min.

4.2.2. Individual level control variables

We adjusted for individual sex and age to account for potential differences in cognitive functioning as well as for demographic differences in the composition of neighborhoods. Individual education, income and employment status were used to examine whether differences in cognitive functioning by NSES and urbanity remain after accounting for selection based on individual SES. Education was measured in years typically needed to achieve a certain educational level. Our income measure is based on the categorical report of monthly net household income of the respondent and, if applicable, its partner. Following a procedure suggested by Broese van Groenou (2003), we generated a continuous measure of net monthly household income by replacing income categories with the median income of each category. For reasons of comparability between respondents with and without a co-residing partner, we divided net monthly household income by 1.5 if the respondent co-resided with a partner, as suggested by the modified OECD-scale (Hagenaars et al., 1994). We controlled for employment status because employment can be an additional source of cognitive stimulation and the likelihood of being employed may differ by NSES and neighborhood urbanity. Our measure assessed whether the respondent was currently in paid work for at least 1 h per week. We did not control for individual health because it might be a mechanism linking neighborhood characteristics and cognitive functioning, hiding existing effects of NSES and urbanity. However, we present models including health indicators in a robustness check (Online Supplement 2).

All cognitive outcomes were assessed at T_1, T_2, and T_3, while age, income and employment status were assessed at baseline T_1 in

Table 1
Descriptive statistics for cognitive functioning, individual controls and neighborhood characteristics.

Variable	$n_{respondents}$	Mean or %	SD	Range
Cognition				
MMSE (T_1)	985	27.69	1.63	24–30
MMSE (T_2)	833	27.24	2.45	10–30
MMSE (T_3)	645	26.79	3.04	5–30
Coding Task (T_1)	985	24.15	6.68	7.00–42.67
Coding Task (T_2)	777	23.75	6.61	3.00–40.00
Coding Task (T_3)	570	23.40	6.80	3.33–40.67
RCPM (T_1)	985	17.99	3.76	4–24
RCPM (T_2)	787	17.49	3.93	4–24
RCPM (T_3)	575	17.51	3.87	4–24
15WT (T_1)	985	6.13	2.89	0–15
15WT (T_2)	773	5.56	2.94	0–15
15WT (T_3)	579	5.89	3.22	0–14
Individual controls				
Male (Ref. female)	985	48.93	n.a.	n.a.
Age (T_1)	985	74.75	6.30	64.76–88.33
Education	985	9.20	3.36	5–18
Income (1000 Euro/month; T_1)	985	0.97	0.43	0.34–2.61
Employed (Ref. not employed; T_1)	985	4.37	n.a.	n.a.
Neighborhood variables (T_1)				
NSES 1st quartile	985	14.72	n.a.	6,534€–7,7737€[a]
NSES 2nd quartile	985	34.82	n.a.	7,760€–8,395€[a]
NSES 3rd quartile	985	25.38	n.a.	8,440€–9,348€[a]
NSES 4th quartile	985	25.08	n.a.	9,393€–12,229€[a]
Neighborhood urbanity	985	2.03	1.46	0–4[a]

Note. SD = standard deviation; MMSE = Mini Mental State Examination; RCPM = Raven Colored Progressive Matrices; 15WT = 15 Words Test; NSES = neighborhood socioeconomic status; Ref. = reference category; n.a. = not applicable.
[a] Range of the original variable within the respective category.

1995/6. Information on sex and education were assessed at the first collection of LASA data in 1992/3. We treat the latter two variables as if they were measured at T_1 because they rarely change in older adults. Since we tested for quadratic effects of continuous variables, age, education and income were centered to their respective sample means to reduce multicollinearity.

4.2.3. Neighborhood socioeconomic status and urbanity

Neighborhood information for baseline T_1 in 1995 stem from Statistics Netherlands. A neighborhood is represented by a so-called *wijk*, which is an area in a community that consists of one or more adjoining homogenous sub-areas, which are again delineated by historical or built characteristics (Statistics Netherlands, n.d.). At baseline, the respondents in our analytical sample lived in 63 different neighborhoods, corresponding to an average number of 15.63 respondents per neighborhood ($SD = 15.27$, $min = 1$, $max = 62$).

NSES was operationalized as the average net income per inhabitant in the neighborhood in the previous year, i.e. 1994, provided that they had income the whole year (Statistics Netherlands, 2016). In our analyses, we used quartiles of average neighborhood income, calculated on the basis of 63 neighborhoods in which the respondents constituting our sample resided.

To obtain a measure of neighborhood urbanity, the number of addresses within a radius of 1 km around an address was determined. The average of this measure of address density over all addresses in a neighborhood constitutes our indicator of neighborhood urbanity (reported as the number of addresses/km^2). This measure of neighborhood urbanity was developed to measure human activity in an area and thus includes residential addresses as well as addresses of shops, workplaces etc. (den Dulk et al., 1992). Statistics Netherlands differentiates between areas that are not urbanized (<500 addresses/km^2), little urbanized (500 to <1000 addresses/km^2), somewhat urbanized (1000 to <1500 addresses/km^2), highly urbanized (1500 to <2500 addresses/km^2), and very highly urbanized (>2500 addresses/km^2). We used a continuous measure ranging from 0 (not urbanized) to 4 (highly urbanized), mean-centered at the neighborhood level.

4.2.4. Analytical approach

We restricted the sample to respondents with valid information on all independent variables and the baseline assessment of all four cognitive functioning measures. Out of 1367 respondents with complete cognitive baseline information, we excluded 135 respondents with cognitive impairment (MMSE-score ≤ 23, Tangalos et al., 1996), 191 respondents who moved since 1992 (i.e. during approximately three years before the baseline measurement T_1 in 1995/6), one respondent with missing neighborhood information, and 55 respondents with missing information on independent variables. Respondents with missing values on cognitive functioning measures at T_2 and/or T_3 were retained in the sample and maximum likelihood estimation was applied to deal with missing data (Baraldi and Enders, 2010). Information on at least one cognitive functioning measure was provided by 833 and 646 respondents at T_2 and T_3, respectively. Those providing information on cognitive functioning at T_3 were more likely to be female, were younger on average and had higher average scores on cognitive measures at T_1. For each domain of cognitive functioning, we estimated growth curve models in a multilevel framework, which allowed us to assess simultaneously the level of cognitive functioning at baseline and the rate of decline during the subsequent six years. In a multilevel approach to growth curves, typically a hierarchical two-level data structure is assumed: Assessments of the same respondent at different time points (level 1) are nested within the respective respondent (level 2). We added a third level for neighborhoods to account for the clustering of respondents living in the same neighborhood at T_1. The temporal dimension of decline is represented by the survey waves at T_1, T_2, and T_3, which were recoded to 0, 3, and 6 years, respectively, so cognitive decline is reported as the yearly rate of change. The effects of individual and neighborhood variables on the levels of cognitive functioning are then indicated by the conditional effects of the respective variables, while their effects on cognitive decline are represented by interaction terms of the respective variable with time. We used the xtmixed-command in Stata version 14.0 and tested for random slopes of time at the individual level and for random slopes of time and individual-level independent variables at the neighborhood level. When testing the joint significance of or differences between fixed effects, we applied Wald χ^2-tests.

5. Results

Neighborhood effects from the multilevel linear regressions predicting baseline levels and growth rates over six years for all cognitive outcomes are shown in Table 2 (see Online Supplement 1

Table 2
Multilevel linear regression models predicting baseline levels (T_1) and growth rates (T_1–T_3) for four cognitive functioning outcomes among 985 respondents aged 65 and older at T_1. Independent variables refer to T_1. Unstandardized regression coefficients (*p*-values in parentheses).

	MMSE		Coding Task		RCPM		15WT	
	M1	M2	M1	M2	M1[a]	M2	M1	M2[b]
Fixed Effects								
Baseline								
Intercept	27.58***	27.81***	22.98***	25.21***	16.89***	17.69***	6.37***	6.66***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
NSES (Ref. 1st quartile)								
2nd quartile (T1)	0.03	−0.04	1.32*	0.71	0.60	0.28	0.43	0.30
	(0.865)	(0.854)	(0.040)	(0.257)	(0.113)	(0.438)	(0.134)	(0.318)
3rd quartile (T1)	0.26	0.08	2.11**	0.92	0.88*	0.26	0.50	0.26
	(0.192)	(0.703)	(0.003)	(0.180)	(0.026)	(0.495)	(0.101)	(0.410)
4th quartile (T1)	0.30	0.05	2.89***	1.16	0.97*	0.10	0.55	0.28
	(0.126)	(0.802)	(0.000)	(0.077)	(0.013)	(0.789)	(0.066)	(0.373)
Neighborhood urbanity	0.15***	0.10*	0.69***	0.35*	0.17*	0.03	0.18**	0.14*
	(0.001)	(0.024)	(0.000)	(0.013)	(0.042)	(0.736)	(0.004)	(0.036)
Neighborhood urbanity^2	n.a.	n.a.	−0.33*	−0.28*	n.a.	n.a.	n.a.	n.a.
	n.a.	n.a.	(0.011)	(0.032)	n.a.	n.a.	n.a.	n.a.
Growth rate (linear)								
Time (years)	−0.23***	−0.18**	−0.25**	−0.28**	−0.26***	−0.25***	−0.34*	−0.36*
	(0.000)	(0.003)	(0.003)	(0.001)	(0.000)	(0.000)	(0.014)	(0.010)
NSES (Ref. 1st quartile)								
2nd quartile (T1) × years	0.01	−0.01	−0.03	−0.02	0.06	0.06	−0.15	−0.14
	(0.913)	(0.888)	(0.680)	(0.770)	(0.361)	(0.404)	(0.337)	(0.386)
3rd quartile (T1) × years	0.03	0.01	0.02	0.04	0.12	0.12	−0.23	−0.19
	(0.641)	(0.852)	(0.854)	(0.668)	(0.091)	(0.093)	(0.157)	(0.235)
4th quartile (T1) × years	−0.03	−0.06	−0.02	0.01	0.10	0.10	−0.06	−0.06
	(0.691)	(0.371)	(0.850)	(0.937)	(0.152)	(0.164)	(0.705)	(0.738)
Neighborhood urbanity × years	−0.01	−0.02	−0.03	−0.02	0.01	0.01	−0.04	−0.03
	(0.355)	(0.154)	(0.116)	(0.193)	(0.441)	(0.524)	(0.308)	(0.346)
Neighborhood urbanity^2 × years	n.a.	n.a.	−0.01	−0.01	n.a.	n.a.	n.a.	n.a.
	n.a.	n.a.	(0.536)	(0.544)	n.a.	n.a.	n.a.	n.a.
Growth rate (quadratic)								
Time^2 (years^2)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.04	0.04
	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	(0.097)	(0.069)
NSES (Ref. 1st quartile)								
2nd quartile (T1) × years^2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.02	0.01
	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	(0.508)	(0.584)
3rd quartile (T1) × years^2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.03	0.02
	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	(0.342)	(0.476)
4th quartile (T1) × years^2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.01	0.01
	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	(0.609)	(0.647)
Neighborhood urbanity × years^2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.00	0.00
	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	(0.517)	(0.570)
Random Variance Components								
Neighborhood level								
Intercept	0.04***	0.06***	0.33	0.53	0.08	0.10*	0.08*	0.12
Respondent level								
Intercept	0.96	0.81	30.00***	24.09***	7.59***	6.06***	4.26***	3.81***
Slope (years)	0.18***	0.17***	0.18***	0.18***	n.a.	n.a.	0.04***	0.04***
Residual	2.08***	2.08***	4.76***	4.75***	5.63***	5.60***	2.57***	2.57***
$n_{observations}$	2463	2463	2332	2332	2347	2347	2337	2337
$n_{respondents}$	985	985	985	985	985	985	985	985
$n_{neighborhoods}$	63	63	63	63	63	63	63	63
Wald χ^2-tests for time trends								
p_{NSES}	0.80	0.61	0.92	0.86	0.34	0.34	0.36	0.40
$p_{Urbanity}$	0.35	0.15	0.22	0.34	0.44	0.52	0.38	0.40

Note. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.
Models M1 control for age and sex and their effects on time. Models M2 additionally control for education, income and employment status. If implied by the data, curvilinear effects of continuous control variables were estimated. Details are shown in Online Supplement 1.
MMSE = Mini Mental State Examination; RCPM = Raven Colored Progressive Matrices; 15WT = 15 Words Test; NSES = neighborhood socioeconomic status; Ref. = reference category; n.a. = not applicable.
[a] To achieve model convergence, a restricted maximum likelihood instead of a maximum likelihood algorithm had to be used.
[b] Model included a random slope for income at the neighborhood level (Slope (income) = 1.14, $p = .814$) based on a Likelihood Ratio-Test (χ^2 (1) = 9.24, $p = .002$).

for full models). Models M1 were adjusted for sex and age to examine whether NSES and urbanity were associated with cognitive functioning when taking into account differences in neighborhood composition by these demographic variables. Models M2 additionally account for individual SES, i.e. respondents' education, income at baseline and employment status at baseline. This was done to see if potential neighborhood effects in models M1 mainly reflect self-selection of individuals rather than a neighborhood effect. Self-selection describes a situation in which apparent neighborhood effects are explained by the gathering of individuals with certain socioeconomic and cognitive characteristics in certain neighborhoods and thus largely reflect an association at the individual level. For example, individuals with a higher individual SES would have higher cognitive levels and slower rates of decline and would simultaneously be more likely to live in neighborhoods with higher NSES or urbanity (and vice versa). The estimation of curvilinear effects for education (Coding Task) and income (MMSE, Coding Task) was implied by the data.

5.1. Levels at baseline

We observed a pattern of increasing levels of cognitive functioning across NSES-quartiles for all outcomes (models M1, Table 2). The difference between the first and fourth quartile was statistically significant for Coding Task ($B_{Q4\text{-}Q1} = 2.89$, $p \leq .001$) and RCPM ($B_{Q4\text{-}Q1} = 0.97$, $p = .013$), but not MMSE ($B_{Q4\text{-}Q1} = 0.30$, $p = .126$) and 15WT ($B_{Q4\text{-}Q1} = 0.55$, $p = .066$). For Coding Task, also the third and second NSES-quartile had higher average levels than the first ($B_{Q3\text{-}Q1} = 2.11$, $p = .003$; $B_{Q2\text{-}Q1} = 1.32$, $p = .040$), and the level of the fourth was also higher than that of the second ($B_{Q4\text{-}Q2} = 1.57$, $p = .005$). For RCPM, also the third NSES-quartile differed significantly from the first ($B_{Q3\text{-}Q1} = 0.88$, $p = .026$). When accounting for selection into neighborhoods by individual SES in models M2, no significant differences between NSES-quartiles remained (all $p \geq 0.077$).

Degree of urbanity was positively associated with levels of MMSE ($B_{URB} = 0.15$, $p = .001$), RCPM ($B_{URB} = 0.17$, $p = 0.042$), and 15WT ($B_{URB} = 0.18$, $p = .004$). For Coding Task, an inversely U-shaped association was found ($B_{URB\ linear} = 0.69$, $p \leq .001$; $B_{URB\ squared} = -0.33$, $p = .011$; Wald $\chi^2(2) = 27.19$, $p \leq .001$). Accounting for individual SES in models M2, the coefficients were somewhat reduced but the linear association with MMSE and 15WT and the inversely U-shaped association with Coding Task remained statistically significant (all $p \leq 0.036$).

5.2. Decline over time

In models accounting for sex and age (and their effects on cognitive change over time), we found cognitive decline in all four outcomes (MMSE: $B_{Years} = -0.23$, Coding Task: $B_{Years} = -0.28$, RCPM: $B_{Years} = -0.18$, all $p < 0.001$; 15WT: $B_{Years} = -0.47$, $B_{Years\ squared} = 0.05$; Wald $\chi^2(2) = 70.61$, $p < .001$, corresponding to a change of −0.96 points after three years and −1.02 points after six years, obtained by replacing Years = 3 and Years = 6 in $\Delta 15WT = B_{Years\ linear}{}^*Years + B_{Years\ squared}{}^*Years^2 = -0.47\ {}^*Time + 0.05{}^*Time^2$, respectively; coefficients refer to female respondents of average age; models not shown). A curvilinear change for 15WT was estimated since descriptive analyses hinted at a non-linear development of 15WT scores over time. Causes might be the re-use of the same set of words at T_1 and T_3, practice effects and measurement inequivalence between T_2 vs. T_1 and T_3.

Findings on differences in cognitive decline by neighborhood characteristics hardly differed between partly and fully adjusted models. None of the models showed a pattern of systematically slower decline of cognitive functioning in higher NSES-quartiles and differences in change did not differ significantly between quartiles (all $p \geq 0.091$; Table 2 and additional analyses, considering also the curvilinear trend for 15WT). Similarly, rates of decline did not significantly depend on urbanity (all $p \geq 0.116$, considering also the curvilinear effect of urbanity on Coding Task) (see Fig. 1 and Fig. 2).

5.3. Random components and intraclass correlation coefficients (ICCs)

Two things should be noted when evaluating random components. Firstly, the variation of cognitive functioning at the neighborhood level was relatively small in random intercept models where only sex, age, and the linear decline (plus quadratic term of time for 15WT) and the effects of sex and age on decline were accounted ($ICC_{MMSE} = 0.02$, $ICC_{Coding\ Task} = 0.06$, $ICC_{RCPM} = 0.02$, $ICC_{15WT} = 0.02$; models not shown). This implies that after taking into account these predictors, a much larger part of variation in cognitive functioning is located at the individual compared to the neighborhood level. Secondly, adding random slopes for time at the neighborhood level did not significantly improve these models, indicating that variation in cognitive decline between neighborhoods was rather small.

5.4. Robustness checks

We ran several checks to evaluate the robustness of our findings. Firstly, we added health indicators (number of functional limitations, number of chronic diseases, number of depressive symptoms (CES-D)). The results are reported in Online Supplement 2. Due to missing values on the added variables, this sample consists of 974 individuals from 62 neighborhoods. Overall, these analyses support our conclusions from the original models. The most notable deviations were that the level-difference in MMSE between the second and fourth NSES-quartile and the effect of urbanity on linear change in Coding Task became statistically significant in the partly adjusted model M1.

Secondly, we checked whether findings have been affected by respondents who moved between T_1 and T_3. We re-ran our analyses with a subsample including only respondents of the initial sample who did not move between T_1 and T_3 (n = 506), excluding 136 movers (64 movers between T_1 and T_2, 63 movers between T_2 and T_3, 9 respondents moved between both periods) and 343 respondents with missing information on at least one of the moving periods. The results of this robustness-check (see Online Supplement 3) are generally in accord with the results from the initial sample. A notable difference was that the robustness check showed significantly higher levels of MMSE in the fourth (vs. second) quartile and higher levels of 15WT for the second, third and fourth (vs. first) quartile in partly adjusted models M1, which were however no longer significant in the fully adjusted models M2. Furthermore, for MMSE, Coding Task and 15WT, the level difference by urbanity was not statistically significant in the fully adjusted models M2 of the robustness check. However, for Coding Task and 15WT, the coefficients were of similar size, so their non-significance can be attributed to the smaller sample size. Finally, decline of MMSE was significantly slower in the second and third (vs. first), but not in the fourth NSES-quartile, and the U-shaped trend of 15WT differed significantly between the third vs. fourth quartile of NSES, indicating faster initial decline in the third quartile. Nevertheless, these differences did overall not imply systematically slower decline in neighborhoods with a higher NSES. Instead, this robustness check showed again that differences in cognitive functioning by NSES can be attributed to selection on individual SES and that level differences by urbanity are relatively

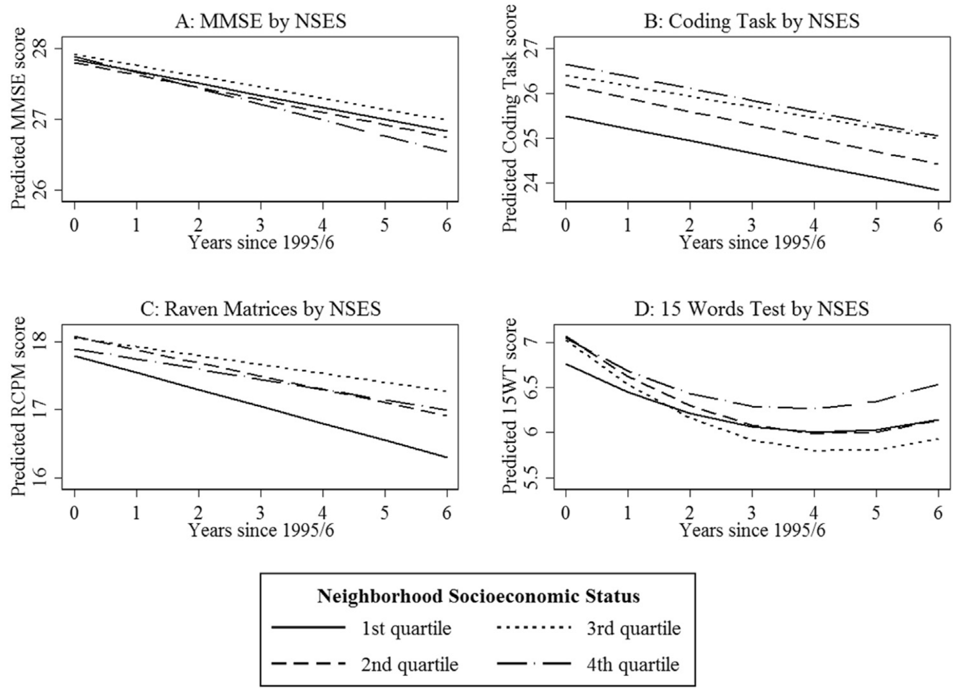

Fig. 1. Predicted growth curves by neighborhood socioeconomic status for all four cognitive outcomes in the observed period T_1 to T_3. Graphs depict results from models M2 (see Table 2) for women of average age, education and income who were not employed at T_1.

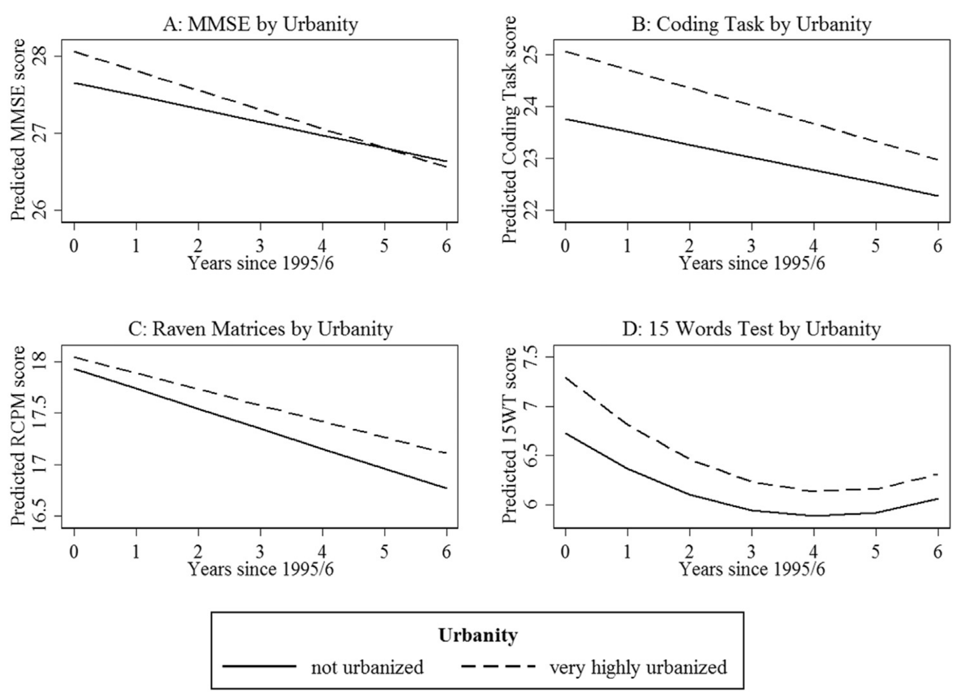

Fig. 2. Predicted growth curves for the most extreme values of neighborhood urbanity for all four cognitive outcomes in the observed period T_1 to T_3. Graphs depict results from models M2 (see Table 2) for women of average age, education and income who were not employed at T_1.

robust to selection on individual SES. Both neighborhood characteristics hardly systematically affected decline in cognitive functions.

Thirdly, due to the negative skewness of MMSE-scores, we additionally re-ran the original models with a log(31-MMSE)-transformation to achieve a more normal distribution of model residuals. Overall, the conclusions from these models support the original conclusions (higher levels in more urban neighborhoods in both partly and fully adjusted models, no significant differences in levels by NSES, and no differences in decline by neither NSES nor urbanity).

Fourthly, respondents might improve on cognitive tests due to practice effects when their cognitive functioning is assessed repeatedly. Similar to a procedure described by Vivot et al. (2016), we added a dummy variable to identify the first observation in our study. Practice effects would then be represented by a negative deviation at T_1 from the general pattern of cognitive decline. We found evidence of a practice effect for MMSE but not for Coding Task, RCPM, and 15WT. Accounting for practice effects did not change our substantial conclusions (see Online Supplement 4).

6. Discussion

Our study is among the first to examine neighborhood effects on levels of and decline in cognitive functioning among Dutch older adults. We used official statistics on neighborhoods to avoid same source bias and employed a longitudinal design to allow for the study of cognitive decline. According to H1a, we expected higher levels of cognitive functioning in neighborhoods with a higher NSES. We found partial support for H1a, indicating higher levels of processing speed and problem solving, but not general cognitive functioning and memory, in neighborhoods with higher NSES. No support was found for H1b, predicting cognitive decline to be slower in neighborhoods with higher NSES. For all cognitive outcomes, levels were positively associated with urbanity, supporting H2a. However, the inversely U-shaped association for processing speed showed that this association might be reversed at high levels of urbanity. The lack of significant effects of urbanity on decline lead us to reject H2b, predicting slower cognitive decline in urban neighborhoods. The selection mechanism (H3) found partial support because controlling for individual SES largely reduced the associations that we previously found between NSES and levels of processing speed and problem solving, respectively (note that NSES was not associated with cognitive decline and levels of general cognitive functioning and memory). However, observed effects of urbanity on levels were overall relatively robust to controlling for individual SES (except for problem solving; note that no effects of urbanity on decline were found), giving little additional support for H3.

The findings show that if neighborhood differences in levels by NSES are observable, these can be explained by the selection of individuals into neighborhoods based on their individual SES. The lack of systematic differences in cognitive decline as a function of NSES does not support the idea that more opportunities for stimulating activities in the neighborhood slow down decline. An explanation for the findings on NSES may be that access to supposedly relevant opportunity structures was not worse in neighborhoods with lower NSES (Pearce et al., 2007). Alternative explanations might be that average income in the neighborhood is a rather indirect measure of neighborhood characteristics that are assumed to be relevant (e.g. parks, conditions of sidewalks, shopping areas, or libraries) or that these concepts are unrelated to cognitive functioning (Clarke et al., 2012). The findings imply that individuals with lower SES who might only afford living in neighborhoods with lower NSES are not additionally disadvantaged by the NSES of their neighborhood when it comes to cognitive functioning. Nevertheless, it should be noted that levels of processing speed and problem solving were higher in neighborhoods with higher NSES in partly adjusted models, indicating that older adults with lower cognitive functioning gather in neighborhoods with a lower NSES.

We found higher levels of cognitive functioning in more urban neighborhoods, findings that were overall robust to our tests of the selection mechanism, with the exception of problem solving. Thus, results for levels of cognitive functioning by urbanity largely comply with the assumed stimulating effect of urban neighborhoods. However, the inversely U-shaped association for processing speed shows that very high urbanity may be less beneficial, e.g. because the environment is too stressful or too challenging and discourages older adults from using opportunity structures. The finding of level differences by urbanity is in line with the idea that access to stimulating resources may well differ between more and less urban neighborhoods in the Dutch context, while it may differ less by NSES. The lack of an effect of urbanity on decline implies that level differences by urbanity are not due to urbanity differences in decline in old age, but might rather arise already earlier in life.

Besides the merits of our study, there are some limitations. Firstly, neighborhood effects earlier in the life-course might well have effects on cognitive functioning in older adults. Our findings may also be biased by respondents moving during the observed period. We addressed both issues by restricting the sample to people who did not move within three years before the start of our study and by conducting a robustness-check with a non-mover subsample.

Secondly, the ICCs and random components from models accounting only for sex, age, and time showed little variation in cognitive functioning at the neighborhood level, also – although not directly comparable – in comparison to studies on cognitive functioning in older populations from the American context, which report neighborhood level ICCs ranging from 0.19 to 0.29 in intercept only models (Aneshensel et al., 2011; Clarke et al., 2012; Wight et al., 2006). This implies that investigating determinants at the individual level, which might include differential use of opportunity structures in the neighborhood as a function of individual characteristics, seems more promising to understand the determinants of cognitive functioning in our sample of Dutch older adults.

Thirdly, further research is necessary before generalizing our findings. This refers to different aspects: (1) Although the data were collected from a population-based sample to depict a good representation of older adults in the Netherlands, the findings of our study cannot be generalized to the population of older adults in the Netherlands. To do so, using sample weights or census data would be necessary. (2) Neighborhood effects can be expected to depend on country characteristics (e.g. strength of differences between neighborhoods and buffering effects of welfare states) and thus our findings can also not be generalized to other country contexts. Also, the Netherlands are a highly urbanized country, yielding little variation in the degree of urbanity. Thus, neighborhood urbanity might be more important in understanding interindividual differences in cognitive functioning in countries with more variation in urbanity. (3) Although neighborhood characteristics can be assumed to change slowly, it is conceivable that characteristics of some neighborhoods may have changed since our data had been collected. Yet, we believe that the theoretical mechanisms linking NSES and urbanity with cognitive functioning are as valid today as they were in the 1990s and early 2000s. Consequently, we assume that one would find similar associations with more recent data. To empirically assess the transferability of our conclusions to more recent times, replication with newer data would be desirable.

We conclude that in the Dutch context, individual SES is more relevant than NSES to understand level differences in cognitive functioning. Thus, interventions should target individuals based on their individual risk profile instead of their residence in a neighborhood with certain NSES. Simultaneously, it should be highlighted that change in cognitive functioning overall was not systematically associated with individual SES or NSES. The study also reveals that neighborhood urbanity should be considered as a determinant of levels of cognitive functioning. This is in line with theoretical approaches that assume beneficial effects of exposure to complex environments on cognitive functioning. However, since rates of decline in our sample of older adults did not differ by urbanity, we assume that urbanity differences in cognitive functioning arise already earlier in life. Future research might follow up on our findings and test if urbanity makes a bigger difference in contexts that are less homogenously urbanized than the Netherlands.

Acknowledgments

This research was conducted while Jonathan Wörn received a scholarship from the research training group SOCLIFE (University of Cologne, Germany). The Longitudinal Aging Study Amsterdam is supported by a grant from the Dutch Ministry of Health, Welfare and Sports (321175).

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.socscimed.2017.05.052.

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