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Opening the black box of the relationship between neighborhood socioeconomic status and mental health: Neighborhood social-interactive characteristics as contextual mechanisms

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ABSTRACT

Previous studies have linked low neighborhood socioeconomic status (NSES) to mental health problems. However, few studies have investigated the mechanisms underlying this association and most focused on the association with negative indicators of mental health, such as symptoms of depression or anxiety. This paper investigated whether neighborhood social characteristics (social interaction, trust, safety, organization participation, and attachment) mediate the association between NSES and mental health. We combined Danish register data with survey data from the North Denmark Region Health Survey 2017. Mental health was assessed with the Rand 12-item Short-form Survey (SF-12). The sample consisted of 14,969 individuals nested in 1047 neighborhoods created with an automated redistricting algorithm. We fitted multilevel structural equation mediation models and used a Monte Carlo simulation method to estimate confidence intervals for the indirect effects. NSES was positively associated with mental health. Neighborhood trust significantly mediated this relationship, accounting for 34% of the association after controlling for other mediators. These results indicate that higher levels of mental health in more affluent neighborhoods are partially explained by higher levels of trust. Improving neighborhood trust could mitigate sociogeographic inequalities in mental health.

1. Introduction

In recent decades, the number of studies linking neighborhood factors to health has grown exponentially, indicating a shift from focusing solely on individual health determinants to recognition of the importance of the surrounding neighborhood environment (Diez Roux, 2016). Although neighborhood factors have been suggested to affect the mental and physical health of individuals, only a few studies have focused on the challenge of opening the 'black box' of neighborhood effects (Galster, 2013; Jivraj et al., 2019; Rose et al., 2021; van Ham et al., 2012). Instead, previous studies have often identified correlations between individual outcomes and neighborhood characteristics without explicitly identifying specific causal mechanisms (van Ham et al., 2012).

One type of mechanisms that possibly explain the link between neighborhood context and mental health are social-interactive mechanisms (Galster, 2013), referring to social processes in neighborhoods such as social cohesion and collective efficacy (Sampson et al., 1997). Exposure to different types of social-interactive factors may 'get under the skin' of residents and influence mental health in various ways. For example, neighborhood disorder including assault and trouble caused by young people or street gangs, may lead to chronic stress responses in residents that cause adverse physiological changes; in the long run, these changes may impair health (Van Deurzen et al., 2016). In contrast, social-interactive characteristics such as social cohesion might promote mental health due to greater positive affect and by buffering the effects of daily stressors (Robinette et al., 2013) and negative life events such as economic crises (Loureiro et al., 2019).

Many previous studies have focused on structural factors such as neighborhood socioeconomic status (NSES) with several review studies concluding that socioeconomically deprived neighborhoods were associated with symptoms of depression (Julien et al., 2012; Mair et al., 2008; Richardson et al., 2015) as well as other various mental health and well-being outcomes (Silva et al., 2016; Visser et al., 2021). In addition to structural factors, a more holistic perspective is needed, to integrate multiple contextual factors, to capture in more detail different characteristics of various neighborhoods (Loureiro et al., 2019, 2022).

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Nevertheless, according to multiple reviews, the question of how NSES may affect the mental health status of residents through social-interactive mechanisms often remains unanswered (Aneshensel, 2010; Blair et al., 2014; Kim, 2008; Mair et al., 2008; Paczkowski and Galea, 2010; Visser et al., 2021). A few studies have examined this question with perceived neighborhood disorder (Greene et al., 2020; Kim, 2010; Ross, 2000; Schmidt et al., 2020), neighborhood social cohesion (Bassett and Moore, 2013; Erdem et al., 2015; Rios et al., 2012), network social capital (Haines et al., 2011), neighborhood social contacts (Drukker and van Os, 2003), worry about crime (Jonsson et al., 2020) and neighborhood violence (Joshi et al., 2017) as mediating factors. Most of these studies investigated how disadvantaged and socioeconomically deprived neighborhoods might influence symptoms of depression or anxiety. However, the use of such measures as indicators of overall population mental health has drawbacks, as mental health is more than just the absence of mental illness (Keyes, 2007). To our knowledge, only three of the abovementioned studies use mental health instruments that cover positive and negative as well as hedonic and eudemonic aspects of mental health (Drukker and van Os, 2003; Greene et al., 2020; Jonsson et al., 2020). However, it is important to study mental health from this perspective as well, as the mechanisms that influence ill-being may not be the same as the mechanisms of well-being (Huppert, 2009).

Another shortcoming associated with most studies in this area is the use of predefined administrative/census-based areas to delineate neighborhoods (Mair et al., 2008; Richardson et al., 2015; Truong and Ma, 2006; Visser et al., 2021). Such areas rarely correspond to theoretical concepts or residents' understandings of neighborhoods; thus, the use of such areas is potentially problematic for the study of social processes (Sampson et al., 2002). Instead, the areas used should correspond to the hypothesized mechanisms under study (Visser et al., 2021). This may lead to different results when the use of administrative areas is compared to alternative theoretically based neighborhoods due to the so-called modifiable areal unit problem (Chaix et al., 2006; Flowerdew et al., 2008; Franzini and Spears, 2003; Jakobsen, 2021; Messer et al., 2012; Parenteau and Sawada, 2011).

In an effort to further this area of research, the aim of this study was to analyze various possible contextual social-interactive mechanisms explaining the association between NSES and mental health. Instead of relying on administrative units as neighborhoods, we used neighborhoods created with an automated redistricting algorithm with the use of physical boundaries such as larger roads as neighborhood dividers. The use of physical barriers as dividers stems from findings that such barriers can also function as social dividers and thereby promote or hinder social interaction (Feld, 1981; Grannis, 1998) and result in high within-group sociodemographic homogeneity (Foster and Aaron Hipp, 2011; Lund, 2018). Furthermore, residents may use such major physical barriers to help identify their own neighborhood from distinct areas (Campbell et al., 2009; Grannis, 2009).

Thus, we investigated the indirect effects of multiple contextual mechanisms related to the social-interactive environments of neighborhoods. We hypothesized that (i) higher levels of NSES are positively associated with mental health and (ii) that one or more neighborhood social-interactive characteristics, in the form of neighborhood social interaction, trust, organization participation, attachment, and safety, mediate the relationship between NSES and mental health.

2. Theory of neighborhood social-interactive mechanisms

Social-interactive mechanisms include complex multifaceted concepts, such as social capital (e.g., resources from social networks including trust and norms of reciprocity) (Putnam, 2000), social cohesion (e.g., strength of social relationships, sense of belonging, shared values, common identity, trust, and the existence of equal opportunities versus social exclusion within a community) (Berger-Schmitt, 2002), and the related concept of collective efficacy (social cohesion, trust and informal social control) (Sampson et al., 1997). Despite the differences between these concepts, they share key similarities. In addition, social capital can be separated into structural and cognitive components characterized as what people 'do' and what people 'feel', respectively (Harpham et al., 2002). We focused on social interactions as well as neighborhood organization participation (NOP) as examples of specific structural dimensions, and trust, attachment, and safety as examples of cognitive dimensions.

Social ties and interaction have been well established as generally beneficial for mental health (Kawachi and Berkman, 2001; Santini et al., 2015). In addition, living in disadvantaged neighborhoods has been linked to smaller social networks (York Cornwell and Behler, 2015) and loneliness (Algren et al., 2020). However, structural characteristics of a neighborhood may not always be a strong determinant of social ties and interactions within the neighborhood itself (Berg and Timmermans, 2015; Jørgensen, 2010).

Another structural component of social capital is the level of civic engagement, in the form of NOP, which can help build relationships of trust and reciprocity with others (Collins et al., 2014). Participation in organizations has been linked to higher quality of life and fewer depressive symptoms (Anderson et al., 2014; Santini et al., 2020; Takagi et al., 2013); furthermore, residents in less affluent areas are more likely to have low levels of social participation (Bowling and Stafford, 2007).

When focusing on the quality of the social interactions taking place in neighborhoods, one of the key cognitive aspects is the particularized interpersonal trust between people in the neighborhood (Garoon et al., 2016). Drawing on the work by Simmel and Luhmann, Lewis and Weigert define trust as "a functional alternative to rational prediction for the reduction of complexity" that "allows social interactions to proceed on a simple and confident basis" (Lewis and Weigert, 1985). Previous studies have linked lower levels of trust to neighborhood deprivation (Corcoran et al., 2018; Franzini et al., 2005; Nettle et al., 2014) depression (Fahmi et al., 2019; Fujiwara and Kawachi, 2008) and well-being (Helliwell and Putnam, 2004).

Place attachment, defined as a positive affective bond or association between individuals and their residential environment (Shumaker and Taylor, 1983), has also been linked to better mental health (Scannell and Gifford, 2017; Young et al., 2004). Attachment to places can be considered a fundamental human need based on the emotional significance that geographic spaces evoke in humans, thereby transforming into meaningful "places" (Giuliani, 2003). Moreover, place attachment can occur at both the individual and group levels and thereby be shared by group members such as neighbors (Scannell and Gifford, 2010). Feelings of place attachment may be lower in deprived neighborhoods due to circumstances such as higher levels of crime and lower safety (Bailey et al., 2012).

From a biological perspective, the feeling of being in a safe environment is linked to an optimal bodily state and social engagement behaviors, while feelings of unsafety are linked to defensive stress responses (Porges, 2007). Consistent with these findings, living in less safe neighborhoods has been associated with psychological distress and depression (Booth et al., 2012; Choi and Matz-Costa, 2018; Cromley et al., 2012; Wilson-Genderson and Pruchno, 2013). Moreover, deprived neighborhoods have been linked to lower perceived safety (Franzini et al., 2005; Mouratidis, 2020) and higher levels of crime (Benson et al., 2003; Sampson et al., 1997; Zimmerman and Messner, 2010).

To summarize, previous research has shown that these abovementioned neighborhood characteristics are related to various aspects of mental health but are unequally distributed across neighborhoods with different NSESs, which makes these characteristics theoretically plausible mediators in the pathway between NSES and mental health.

3. Methods

3.1. Study area

The study area includes the North Denmark Region which is one of five Regions in Denmark. These regions are administrative entities above the municipality level, and below the central government. The North Denmark Region covers an area of 7,933 km^2 with a population of 587,335 and a population density (inhabitants per km^2) of 74.5 in 2017 (Statistics Denmark, 2017).

3.2. Data sources

This study used three different types of data: 1) survey data from the North Denmark Region Health Survey 2017 to measure mental health and neighborhood contextual mechanisms; 2) register data for the population from age 16 living in the North Denmark Region in 2017 derived from various registers by Statistics Denmark (Baadsgaard and Quitzau, 2011; Jensen and Rasmussen, 2011; Pedersen, 2011) to measure individual-level sociodemographic characteristics and NSES; and 3) georeferenced micro-areas developed by Lund (2018) to divide individuals into different neighborhoods.

The North Denmark Region Health Survey is a population-based survey designed to be representative of the adult population aged 16 and above in the North Denmark Region. The questionnaire includes a broad range of questions related to morbidity and health, focusing on aspects not available in registers, e.g., questions about neighborhoods. Individuals were randomly sampled from the Danish Civil Registration System and invited by postal or electronic mail. The survey was conducted by the North Denmark Region from February to May 2017, and reminders were sent to nonrespondents. A total of 22,583 individuals completed the questionnaire (60.1%), providing an overall margin of error of <1% at a 95% confidence level. The sample was restricted to respondents from neighborhoods with a minimum of five observations due to discretionary criteria and with no missing data on all variables used in the analyses, resulting in a final sample of $N = 14{,}969$ individuals nested in 1047 neighborhoods.

Missing data were omitted from the analysis as the final sample showed no major differences from the full sample on key demographic variables (gender, age and marital status) as well as on mental health status and NSES.

3.3. Neighborhoods

Neighborhoods were measured using micro-areas created by Lund (2018), which have been used in previous studies to investigate neighborhood characteristics in a Danish context Jakobsen, 2021; Kristiansen and Lund, 2022; Lund, 2018, 2020; Lund et al., 2019). The areas were constructed with an automated redistricting algorithm that formed the smallest areas possible that contained at least 100 inhabitants and were separated by large physical barriers. To run the algorithm, the National Square Grid that assigned addresses in Denmark to 'hectare cells' (100 m x 100 m) in 2000, 2005, 2010, and 2015 was used as georeferenced data. The algorithm works in two overall steps. First, initial areas were delineated with the use of physical barriers such as highways, roads broader than 6 m, rivers and streams broader than 3 m, railways, lakes, forests, coastlines, and intakes. In this step, the square grid was applied with the grids dissolved into areas where the largest part of the square was located with borders formed after the grid was applied. Thus, the straight borders were replaced with the borders of the squares in each area. After this step, the areas were further clustered to ensure that there were at least 100 inhabitants in each area according to discretionary criteria of Statistics Denmark. Further criteria were set to ensure the least possible number of merges and the smallest possible number of inhabitants. These criteria ensure that the algorithm consistently generates the same areas if the process is repeated (Lund, 2018). For a more detailed description of the micro-areas, see Lund (2019, 2018).

3.4. Mental health

Mental health was measured using the mental component score (MCS-12) of the Rand 12-item Short Form questionnaire (SF-12) (Ware John et al., 1996). The SF-12 is a multipurpose generic assessment of health status that covers eight health concepts: physical function, limitations due to physical health and emotional problems, bodily pain, general health, vitality, social function and psychological distress and well-being over the last 4 weeks. From these items, a physical component score (PCS-12) and a mental component score (MCS-12) can be constructed (Ware et al., 1998). All 12 items are used to construct the MCS-12, but the scale places added emphasis on items covering the concepts of emotional problems, vitality, social function and psychological distress and well-being. The MCS-12 is considered a valid measure of mental health in health research (Cheak-Zamora et al., 2009) and has previously been used to measure mental health in various countries, including Denmark (Christensen et al., 2014, 2020; Fong et al., 2010; Kontodimopoulos et al., 2007; Peterson et al., 2009).

In this study, the 12 items were summed and converted into the MCS-12. After the subscale scores were calculated, they were weighted according to population norms. Weights from the North Denmark Region population were calculated and used as population norms instead of the originally proposed population norms from the scoring algorithms (Bjørner et al., 1997). Using this weighting emphasizes population and time adequacy over the possibility of comparing scale scorings to other studies, which corresponds to the aim of the present study (Tucker et al., 2016). Furthermore, we used an exploratory factor analysis with oblique rotation instead of a principal component analysis with orthogonal rotation, since the latter can cause inconsistencies between the subscales and summarized scales and assumes zero correlation between the mental and physical health factors (Blanchard et al., 2004; Fleishman et al., 2010; Jakobsson et al., 2012; Tucker et al., 2016).

3.5. Neighborhood socioeconomic status

A composite index to measure NSES was created based on the full Danish population above age 16 in 2017 (Jakobsen, 2021). Based on previous contextual socioeconomic deprivation scores, the index was created with the following three indicators: the proportion of the population between 30 and 64 years of age that was unemployed for at least half of the year, including recipients of sickness benefits, persons on leave and recipients of cash benefits (Bender et al., 2015; Juhász et al., 2010; Meijer et al., 2013); proportion of the population between 30 and 64 years of age with a disposable income in the lowest quartile (Bender et al., 2015; Meijer et al., 2013); and proportion of the population between 30 and 64 years of age with basic education (UNESCO Institute for Statistics, 2012) as the highest attained educational level (Bender et al., 2015; Juhász et al., 2010; Lund, 2020).

All three indicators were standardized to z-scores and used to create an index, with principal component analysis (PCA). The index was reversed and standardized to a z-score, with higher scores indicating higher NSES.

3.6. Neighborhood social characteristics

Neighborhood social interaction was measured with the question "How often are you in contact with friends, acquaintances and family that you do not live with (specifically neighbors or residents in your local area)?" with the response categories (Daily or almost daily, 1 or 2 times a week, 1 or 2 times a month, Less than once a month, or Never) coded from 5 to 1. *Neighborhood trust* was measured with the question "To what extent do you trust people from your settlement/neighborhood/local area?" with response options (Trust them completely, Trust them a lot, Do not trust them very much, or Do not trust them at all). *NOP* was measured with

the question "Do you participate in associations or volunteer work in one or more of the following areas?" and providing a wide range of options ranging from housing and community organizations to youth work such as scouts or youth clubs with response options (Yes, daily; Yes, weekly, but not every day; Yes, monthly, but not every week; Yes, but rarely participates/is a member; or No, never participates/is not a member). This measure was summed into a composite index, with higher scores indicating a higher degree of participation in various organizations. *Neighborhood attachment* was measured with the question "Do you feel attached to your local area?" with the response categories (Yes, strongly attached; Yes, partly attached; No, not particularly attached; or No, not at all attached). *Neighborhood safety* was measured with the question "How safe do you feel walking alone in your local area after dark?" with response options (Very safe, Fairly safe, Fairly unsafe, or Very unsafe).

To capture the mechanisms at a collective neighborhood level and further reduce same-source bias, the individual scores were used to construct ecological average scores at the neighborhood level. Due to variation in observations across neighborhoods, which ranged from 5 to 217, we used empirical Bayes estimates (EBEs). These estimates borrow strength across neighborhoods and shrink estimates for neighborhoods with few observations toward the overall mean (Mujahid et al., 2007) with a shrinkage factor calculated as follows:

$$\text{Shrinkage factor} = \frac{\sigma_u^2}{\sigma_u^2 + \sigma_e^2/n_j}$$

where σ_u^2 is the level-2 variance and σ_e^2 is the level-1 variance, and n_j is the number of observations in neighborhood j in the sample (Hox et al., 2018). The less precise the group-specific estimate and the less variability observed across groups, the greater the shift toward the overall group mean. The strength of this approach is that it uses information from other neighborhoods to improve estimates for unreliable neighborhoods (Diez Roux, 2002; Mujahid et al., 2008). Finally, for interpretational purposes, the scores were standardized to z-scores, with higher scores indicating a higher degree of neighborhood social interaction, trust, organization participation, attachment, and safety.

3.7. Individual-level variables

Gender, age, marital status, education, personal income, employment status and ethnicity were included as individual-level variables. Age was grand-mean centered. Marital status was measured as married, cohabiting or living alone. Education was measured as the highest attained education according to the ISCED collapsed into three categories: 'Basic education' (levels 0–2), 'Medium education' (levels 3–5) and 'High education' (levels 6–8) (UNESCO Institute for Statistics, 2012). Income was measured as the total annual personal income (except for any rental income from one's own accommodation and before deducting labor-market contributions and pension contributions) and categorized into quartiles. Employment status was collapsed into four categories: employed, unemployed, student and pensioner. Ethnicity was dichotomized to Danish or other.

3.8. Statistical analysis

To open the black box of the mechanisms by which NSES influences mental health, we used a structural equation multilevel mediation (MSEM) approach with a 2-2-1 design (as illustrated in Fig. 1), given that individuals were nested in neighborhoods; NSES and neighborhood social characteristics were measured at level 2 and individual mental health was measured at level 1 (Preacher et al., 2010; Zhang et al., 2009).

The basic idea of simple mediation is when the relationship between two variables is fully or partially accounted for by a third variable that conceptually lies on the causal pathway between the exposure and the outcome (Baron and Kenny, 1986). In mediation terminology, the

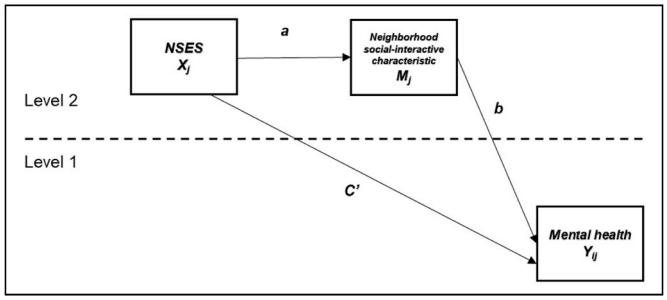

Fig. 1. Illustration of a simple 2-2-1 multilevel mediation model.

relations between the variables can be divided into distinct paths: the path between the predictor and mediator (path *a*), the path between the mediator and outcome (path *b*) and the path between the predictor and the outcome, also called the total effect (path *c*). Finally, the path between the predictor and outcome, once intervening mediated relations have been accounted for is c-ab (path *c'*), also called the direct path. The indirect effect of the predictor through the mediator that measures the amount of mediation can then be quantified as the product of a and b (i.e., *ab*). (Preacher and Hayes, 2008).

Due to the skewness and nonnormality of the sampling distribution of the indirect effect, common methods for estimating the confidence interval of the indirect effect, such as the *delta method* (Sobel, 1982), can result in a conservative, underpowered test that fails to detect a true indirect effect (MacKinnon et al., 2004; Preacher and Selig, 2012). To solve this problem, we used the Monte Carlo simulation method to construct confidence intervals for the indirect effects (MacKinnon et al., 2004). The Monte Carlo simulation method has been shown to produce results comparable to those of bootstrap methods; furthermore, this method is much faster and less computationally demanding to implement in a multilevel context (Preacher and Selig, 2012). To construct the confidence interval for the indirect effect, we first estimated the effects of $\widehat{a}$ and $\widehat{b}$ and their standard errors of $\widehat{\sigma}_{\widehat{a}}$ and of $\widehat{\sigma}_{\widehat{b}}$ from the sample. Next, we generated a simulated sampling distribution of the indirect effect *ab* by generating a distribution of 100,000 random samples with population values equal to the sample values of $\widehat{a}$, $\widehat{b}$, $\widehat{\sigma}_{\widehat{a}}$ and $\widehat{\sigma}_{\widehat{b}}$. Finally, percentiles of the sampling distribution were used as limits for a 95% confidence interval of the sample $\widehat{a}\widehat{b}$.

To estimate the overall variance in mental health between neighborhoods, also known as the general contextual effect (GCE) (Merlo et al., 2018) we first modeled an "empty" multilevel model that only included a random intercept with no predictors. From this model the intraclass correlation coefficient (ICC) was calculated as follows:

$$\text{ICC} = \frac{\sigma_u^2}{\sigma_u^2 + \sigma_e^2}$$

where σ_u^2 is the level-2 variance and σ_e^2 is the level-1 variance. The ICC is the percentage of the total variance attributable to the area-level variance (Snijders and Bosker, 1999). Second, we estimated the crude associations between mental health and NSES, social interaction, trust, NOP, attachment and safety as contextual mechanisms, with each predictor in a separate model. Third, we included the individual-level covariates to estimate the adjusted associations between mental health and each predictor separately, with the estimate of NSES corresponding to the total effect of NSES. Finally, we estimated a model that included all predictors concurrently. Indirect effects were estimated with the use of both single and multiple mediation models. The single mediation models allowed us to investigate if the various potential mechanisms acted as mediators, and the multiple mediation model allowed us to study the possible mediating effect of the potential mechanisms when controlling for all other mediators and thereby the mechanism's unique

ability to mediate the relationship between NSES and mental health (Preacher and Hayes, 2008). Based on the recommendations of Preacher and Hayes (2008), we allowed the residuals associated with the mediators to covary. To quantify the strength of mediation, we calculated the ratio of the indirect effect to the total effect as $\widehat{P}_M = (\widehat{a} \times \widehat{b})/\widehat{c}$ (Shrout and Bolger, 2002).

Before conducting the multilevel models, we estimated variance inflation factors (VIFs) to identify possible multicollinearity due to positive zero-order correlations between the neighborhood characteristics. The VIFs for the neighborhood characteristics and mean VIF were below 2.5, indicating no serious problems with multicollinearity.

To account for potential differences in selection probabilities and response rates, we used calibrated weights constructed by Statistics Denmark for the analyses.

4. Results

Fig. 2 shows the micro-areas mapped with the EBEs for mean mental health scores divided into four classes using Jenks Natural Breaks (Jenks, 1967) with darker colors indicating higher levels of mental health, and with no clear geographic or urban-rural pattern identified. The zero-order correlations at the ecological level with NSES and EBEs for mental health and neighborhood characteristics are presented in Table 1. Results indicated that neighborhoods with higher levels of NSES, social interaction, trust, NOP, attachment, and safety were associated with higher ecological levels of mental health; NSES had the strongest correlation with mental health ($r = 0.36$), followed by trust ($r = 0.35$) and safety ($r = 0.34$). Furthermore, neighborhoods with higher levels of social interaction, trust, NOP, attachment, and safety were associated with higher levels of NSES; trust ($r = 0.32$) and safety ($r = 0.35$) had the strongest associations with NSES. Significant correlations were observed between all neighborhood social characteristics. Neighborhoods with higher levels of attachment were particularly strongly associated with higher levels of social interaction ($r = 0.58$) and trust ($r = 0.49$). In addition, neighborhoods with higher levels of trust were moderately associated with higher levels of social interaction ($r = 0.48$). For descriptive statistics of all study variables, see the Supplementary Material.

The ICC for mental health was 2.5% (SE = 0.004). This is comparable to other similar studies using the SF-12 or SF-36 (Fone and Dunstan, 2006; Peterson et al., 2009) and shows a relatively small GCE of neighborhoods.

Table 2 shows the model results for the association between the neighborhood characteristics and individual mental health. For the crude estimates, the models showed significantly higher mental health of individuals in neighborhoods with higher levels of all neighborhood characteristics, with NSES being the strongest predictor of mental health. After adjusting for individual characteristics, the associations were largely attenuated, but all neighborhood characteristics were still significant predictors of mental health. In the fully adjusted models (adjusted for both individual-level characteristics and all neighborhood characteristics), only neighborhood trust remained a significant predictor of mental health (Coef: 0.25, 95% CI: 0.05, 0.45).

Before conducting the mediation analysis, we tested for exposure-mediator interactions for all neighborhood characteristics (Valeri and VanderWeele, 2013). We identified a significant interaction between NSES and NOP (see Supplementary Material), showing that the relationship between NSES and mental health was less pronounced in neighborhoods with high NOP than in neighborhoods with low NOP. In the full model that controlled for all other neighborhood characteristics, the interaction was no longer significant and did not improve model fit; therefore, it was not included in the mediation models. We further tested for interactions between all neighborhood mediators but found no significant interactions.

Table 3 shows the indirect effects of the neighborhood characteristics from the separate single mediation models and the indirect effects from a multiple mediation model with all neighborhood mediators entered concurrently. In the single mediation models, social interaction, trust, attachment, and safety were significant mediators. Neighborhood trust showed the largest mediation effect, accounting for 43% of the association between NSES and mental health, followed by neighborhood safety, which accounted for 31%. In the multiple mediation model, only neighborhood trust was a significant mediator of this relationship (Coef: 0.13, 95% CI: 0.03, 0.24) accounting for 34% of the association between NSES and mental health when controlling for the other neighborhood mediators.

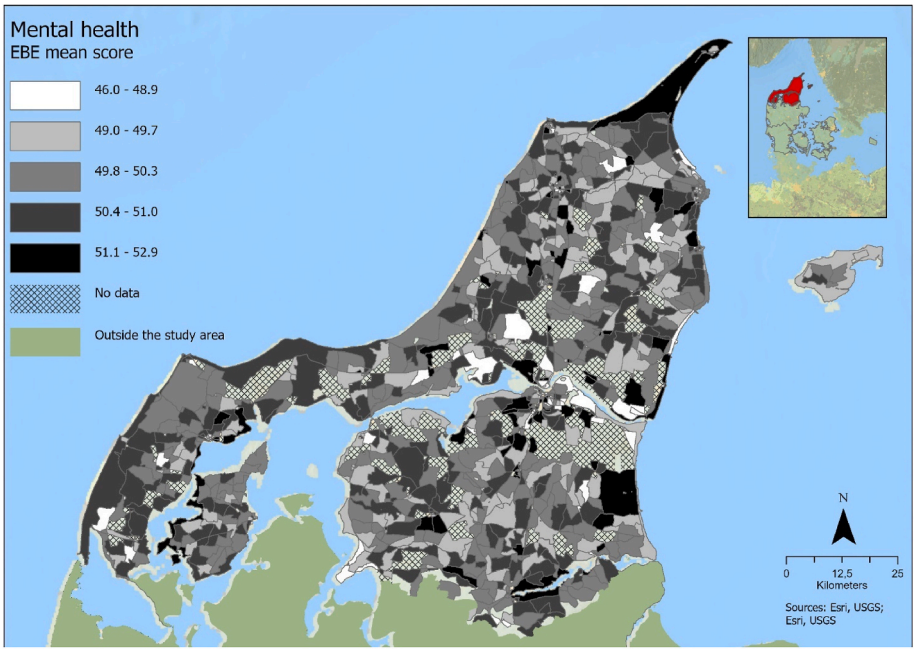

Fig. 2. Map of North Jutland, Denmark mapped with neighborhood EBEs of mean mental health scores..

Table 1
Ecological correlation matrix with EBEs for mental health, neighborhood characteristics and NSES.

	1.	2.	3.	4.	5.	6.	7.
1. Mental health	1.00						
2. NSES	0.36***	1.00					
3. Social interaction	0.22***	0.13***	1.00				
4. Trust	0.35***	0.32***	0.48***	1.00			
5. NOP	0.24***	0.16***	0.28***	0.22***	1.00		
6. Attachment	0.22***	0.16***	0.58***	0.49***	0.24***	1.00	
7. Safety	0.34***	0.35***	0.24***	0.36***	0.13***	0.29***	1.00

(N = 1047 neighborhoods) ***p < 0.001, **p < 0.01, *p < 0.05.

Table 2
Model results predicting mental health.

	Crude estimates[a]		Adjusted estimates[b]		Full model estimates[c]	
	Coef	(95% CI)	Coef	(95% CI)	Coef	(95% CI)
NSES	0.88***	(0.72, 1.05)	0.37***	(0.22, 0.52)	0.17	(-0.01, 0.35)
Social interaction	0.46***	(0.28, 0.63)	0.26***	(0.11, 0.42)	0.01	(-0.20, 0.22)
Trust	0.77***	(0.61, 0.93)	0.41***	(0.27, 0.55)	0.25*	(0.05, 0.45)
NOP	0.44***	(0.24, 0.64)	0.24**	(0.09, 0.39)	0.09	(-0.06, 0.24)
Attachment	0.50***	(0.31, 0.68)	0.29***	(0.13, 0.45)	0.01	(-0.20, 0.21)
Safety	0.76***	(0.58, 0.93)	0.36***	(0.21, 0.51)	0.14	(-0.04, 0.31)

Coef = path coefficient. [a] Crude estimates from separate models. [b] Adjusted estimates from separate models. [c] Adjusted estimates from the full model containing all predictors concurrently. Adjusted = adjusted for individual-level gender, age, marital status, education, personal income, employment status and ethnicity. (N = 14,969) ***p < 0.001, **p < 0.01, *p < 0.05.

Table 3
Monte Carlo indirect effect estimates.

	Single mediation[a]			Multiple mediation[b]		
	Coef	(95% CI)	$\widehat{P}_M$	Coef	(95% CI)	$\widehat{P}_M$
Social interaction	0.05*	(0.01, 0.09)	0.13	0.01	(-0.05, 0.06)	–
Trust	0.17***	(0.09, 0.25)	0.43	0.13*	(0.03, 0.24)	0.34
Attachment	0.06*	(0.01, 0.12)	0.16	0.00	(-0.06, 0.07)	–
Safety	0.12**	(0.04, 0.20)	0.31	0.07	(-0.02, 0.16)	–

Coef = path coefficient. [a] Estimates from separate single mediation models. [b] Estimates from full multiple mediation model.
$\widehat{P}_M$ = indirect effect/total effect. All models adjusted for individual-level gender, age, marital status, education, personal income, employment status and ethnicity. (N = 14,969) ***p < 0.001, **p < 0.01, *p < 0.05.

5. Discussion

In this study, we aimed to open the "black box" of neighborhood effects concerning the relationship between NSES and mental health by empirically testing various potential contextual mechanisms related to the social-interactive environment of neighborhoods. We found that higher levels of NSES, social interaction, trust, NOP, attachment, and safety were significantly associated with higher levels of mental health, even when controlling for individual-level factors. Furthermore, we found an interaction between NSES and NOP, indicating that a high degree of participation in organizations in neighborhoods may buffer the impact of NSES on mental health. However, this interaction was no longer significant after controlling for other neighborhood characteristics. In the single mediation models, neighborhood social interaction, trust, attachment, and safety significantly mediated the relationship between NSES and mental health. In a multiple mediation model, only neighborhood trust was a significant mediator of the relationship between NSES and mental health and accounted for 34% of the association. These results indicate that higher levels of mental health associated with living in more affluent neighborhoods is partially explained by higher levels of mutual trust among neighbors when taking other social-interactive neighborhood characteristics into account.

Our finding that neighborhood social characteristics can mediate the association between NSES and mental health is in line with previous studies (Bassett and Moore, 2013; Drukker and van Os, 2003; Erdem et al., 2015; Haines et al., 2011; Rios et al., 2012). Rios et al. (2012) reported that neighborhood social cohesion accounted for 10% of the association between NSES and individual psychological distress. In that study, neighborhood social cohesion was measured using the social cohesion dimension of the Collective Efficacy Scale (Sampson et al., 1997), in which mutual trust was one of the core indicators (Rios et al., 2012). In addition, other studies show that neighborhood social cohesion mediates the association between NSES and depressive symptoms (Bassett and Moore, 2013) as well as psychological distress (Erdem et al., 2015). In the present study, we did not investigate composite measures of neighborhood social cohesion, but our finding that neighborhood trust was the strongest and only significant mediator and predictor of mental health in the full models is not surprising, since trust is normally understood to be a key indicator of social cohesion and social capital and is sometimes used as a single indicator (Delhey and Newton, 2003). A study from the UK found generalized trust to be the only social capital indicator showing a positive and significant association with psychological health overtime, where social participation in local groups and the frequency of talking to neighbors showed no such effect (Giordano and Lindström, 2011). A review by Ehsan and De Silva (2015) concluded that both individual and ecological measures of cognitive social capital,

e.g., mutual trust, were associated with a reduced risk of common mental disorders, while there was no overall association with structural social capital at either the individual or ecological level. As one possible explanation for the importance of trust, a trusting neighborhood environment might be characterized by positive and supportive personal relationships beneficial for mental health, while this may not necessarily be the case in neighborhoods with high levels of attachment, safety, or social interaction. In addition, attachment, safety, and social interaction might lead to higher levels of trust, with trust acting as a mediator. However, further studies are needed to clarify how these factors may be causally related.

Even though social capital has been positively linked to mental health, there is a lack of controlled trials determining a causal effect (Flores et al., 2018). Nevertheless, a few intervention studies have shown promising results. For example, a quasi-experimental study that investigated an ecological intervention with the objectives of promoting community participation in urban renewal and engaging residents in the construction of attractive urban places showed improvements in mental health, sense of community and social capital (Semenza et al., 2007).

In our study, neighborhood trust was measured at the ecological level. However, there is disagreement on whether neighborhood social characteristics should be measured individually or collectively (Ehsan et al., 2019; Sampson, 2011; Sampson et al., 2002). Both Sampson (2011) and Kawachi and Berkman (2015) argue that collective efficacy and social capital should be seen as social and collective phenomena; therefore, they simply cannot be captured through individual responses alone. We believe that this is also the case with trust: trusting social environments should be seen as the result of mutual trust among residents and not just as a single resident's degree of trust in his neighbors. When neighborhood trust was measured at the individual level, sensitivity analyses showed that it was a stronger predictor of individual mental health than the ecological measure but with a weaker mediating effect, accounting for 27% of the association between NSES and mental health. This indicates that ecological measures of neighborhood social characteristics, in addition to individual responses, are important to consider when investigating the social mechanisms of place. One explanation of the biosocial link between NSES and mental health was proposed by Prior et al. (2018), who found that allostatic load, a biological response to chronic stress, acted as a biological mediator between neighborhood deprivation and both physical and mental health. The complete pathway between NSES and mental health is likely complex and potentially includes individual, social, structural, cognitive, and biological factors. Future studies should investigate more complex pathways and different types of mediators to provide important insights that allow for a better understanding of the link between neighborhoods and mental health.

5.1. Study strengths and limitations

One key strength of this study lies in our ability to use micro-areas designed by an automated redistricting algorithm that accounts for physical barriers in the landscape to function as social dividers (Lund, 2018), instead of relying on administrative delineations as neighborhood units. Sensitivity analyses showed that when using parishes, the smallest administrative area in Denmark, we found no mediation effect of any of the neighborhood characteristics. Furthermore, the ICC for mental health was lower when using parishes (ICC = 1.5%, SE = 0.003). Together with previous research, this indicates that micro-areas are better at capturing relevant neighborhood effects when focusing on mental health-related outcomes (Jakobsen, 2021). In addition, we included a variable at the municipality level with four categories — 1) urban, 2) semi urban, 3) rural and 4) outer municipality (The Danish Ministry of Food, Agriculture and Fisheries and The Danish Ministry of the Interior and Health, 2011) - to account for the potential contextual confounder of living in an urban or rural area. However, this did not change the results substantially.

As previously mentioned, physical barriers can serve as barriers to social interaction (Feld, 1981; Grannis, 1998) and may reflect individuals' own perceptions of neighborhoods (Campbell et al., 2009; Grannis, 2009; Lynch, 1971). If neighborhood trust matters for mental health, it is clear why the use of larger administrative boundaries may lead to different results, as the average level of trust in these areas can be only marginally expected to reflect the socially interactive environment that individuals experience and participate in on a daily basis. Physical barriers may however not always function as barriers between neighborhoods. It is possible that people who live close to various attractive blue and green space barriers may form social clusters separated from those who live further away from these barriers (Schüle et al., 2019).

One major limitation of this study was the cross-sectional design, which prevents a determination of temporal order in the association between NSES and mental health. However, previous studies using experimental and cohort designs have found evidence for a temporal causal link between NSES and subsequent mental health conditions (Crump et al., 2011; Galea et al., 2007; Leventhal and Brooks-Gunn, 2003; Ludwig et al., 2013; White et al., 2017).

Regarding the association between NSES and the self-reported neighborhood characteristics, we consider reverse causation more unlikely, as this would mean that NSES is affected by characteristics such as perceived safety and trust. However, the path between the different neighborhood characteristics and mental health is more likely to be reversed, as it is highly possible that a person's mental health may affect their perception of trust, etc. in a neighborhood (Echeverria et al., 2004). Thus, one strength of this study was the use of ecological measures instead of individual responses as measurements of neighborhood characteristics; this method also reduced same-source bias (Mujahid et al., 2007). In addition, we included several individual characteristics to control for various potential exposure-outcome, mediator-outcome and exposure-mediator confounders (VanderWeele, 2016). Another limitation of this study concerns our inability to include both individual and micro-area-level weights, as the available weights designed for this study by Statistics Denmark were combined weights of the individual and municipality levels, which may have biased our results. However, sensitivity analyses showed that when running the mediation models without weights, neighborhood trust was still the only significant mediator in the multiple mediation model.

5.2. Conclusion

This study adds to the existing literature as we used a new method of automatically generated neighborhoods, which accounts for physical barriers in the landscape, to study whether social characteristics of neighborhoods (social interaction, trust, safety, NOP, and attachment) mediate the association between NSES and mental health. We found evidence that neighborhood trust is a mediator of the association between NSES and mental health. Thus, the higher mental health levels of residents in more affluent neighborhoods can be partially explained by higher levels of neighborhood trust. Improvements in trust between neighborhood residents could potentially mitigate geographic and socioeconomic inequalities in mental health. However, further studies are needed to test the effect of specific public health interventions targeted at the neighborhood level on mental health.

Data availability

The authors do not have permission to share data.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.healthplace.2022.102905.

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