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Author for correspondence:
Megan Davies,
E-mail: megan.davies@sund.ku.dk

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The complexities of suicide: a multilevel survival analysis examining individual, familial and neighbourhood determinants of suicide risk using Danish register-based data

Megan Davies[1,2] , Henriette Thisted Horsdal[2,3], Sussie Antonsen[2,3], Torben Sigsgaard[2,4], Chun Chieh Fan[5], Wesley K. Thompson[6], Carsten Bøcker Pedersen[2,3,7] and Clive E. Sabel[2,4,8]

[1]Section of Epidemiology, University of Copenhagen, Copenhagen, Denmark; [2]BERTHA Big Data Centre for Environment and Health, Aarhus University, Aarhus, Denmark; [3]National Centre for Register-based Research, Aarhus BSS, Aarhus University, Aarhus, Denmark; [4]Department of Public Health, Aarhus University, Aarhus, Denmark; [5]Department of Radiology, Population Neuroscience and Genetics Lab, University of California San Diego, La Jolla, CA, USA; [6]Division of Biostatistics and Department of Radiology, Population Neuroscience and Genetics Lab, University of California San Diego, La Jolla, CA, USA; [7]Centre for Integrated Register-based Research, CIRRAU, Aarhus University, Aarhus, Denmark and [8]Health Research Institute, University of Canberra, Canberra, Australia

Abstract

Background. Suicide risk is complex and nuanced, and how place impacts suicide risk when considered alongside detailed individual risk factors remains uncertain. We aimed to examine suicide risk in Denmark with both individual and neighbourhood level risk factors.

Methods. We used Danish register-based data to identify individuals born in Denmark from 1972, with full parental information and psychiatric diagnosis history. We fitted a two-level survival model to estimate individual and neighbourhood determinants on suicide risk.

Results. We identified 1723 cases of suicide in Denmark during the follow-up period from 1982 to 2015. Suicide risk was explained mainly by individual determinants. Parental comorbidities, particularly maternal schizophrenia [incidence rate ratio (IRR): 2.29, 95% CI 1.56–3.16] and paternal death (2.29, 95% CI 1.31–3.72) partly explained suicide risk when adjusted for all other determinants. The general contextual effect of suicide risk across neighbourhoods showed a median incidence rate ratio (MRR) of 1.13 (1.01–1.28), which was further reduced with full adjustment. Suicide risk increased in neighbourhoods with a higher proportion of manual workers (IRR: 1.08; 1.03–1.14), and decreased with a higher population density (IRR: 0.89; 0.83–0.96).

Conclusion. Suicide risk varies mainly between individuals, with parental comorbidities having the largest effect on suicide risk. Suicide risk was less impacted by neighbourhood, though, albeit to a lesser extent than individual determinants, some characteristics were associated with suicide risk. Suicide prevention policies might consider targeting interventions towards individuals more vulnerable due to particular parental comorbidities, whilst taking into account that some neighbourhood characteristics might exacerbate this risk further.

Introduction

Despite a global decline, suicide and suicidal behaviour remains a leading cause of death amongst adults and young people. Suicide is a significant global health issue, and the call to decrease mortality from suicide by 2030 from the World Health Organization emphasises the need to prioritise suicide prevention (World Health Organization, 2021). Preventing suicide however is difficult, as the causes and risk factors associated with suicide vary considerably between individuals (Naghavi, 2019). Some people may experience numerous determinants that extend across multiple different contexts, which could include non-modifiable individual factors, familial events and dynamics, as well as the influence of the wider social environment and neighbourhood characteristics.

The causes of suicide are multifaceted, and several risk factors likely accumulate throughout the life-course. Research has established that various underlying familial factors are seen in individuals who died by suicide in later life. For example, follow up studies examining exposure to childhood adversities, which includes deprivation, parental unemployment and parental or sibling illness, have found an increased risk of suicide in later life (Björkenstam, Kosidou, & Björkenstam, 2017; Rod et al., 2020). A family history of suicidal behaviour predisposes individuals to an increased risk of suicide, and though studies have shown a heritability of suicidal

behaviour itself, the increased risk in individuals whose parents have a history of suicidal behaviour is likely a complex interplay between genetics and the shared environment (Tidemalm et al., 2011). Having a parent with psychiatric comorbidities further increases suicide risk, as a family history of depression can also increase the number of depressive episodes in an individual's lifetime, even without stressful or traumatic events triggering depressive episodes (Monroe, Slavich, & Gotlib, 2014). Additionally, bereavement due to suicide has been found to increase an individual's own risk of suicide, and losing a mother to suicide, but not a father, increases the likelihood of an individual being hospitalised due to depression (Cassidy, 2011; Goodwin, Beautrais, & Fergusson, 2004; Pitman, Osborn, King, & Erlangsen, 2014).

Determining how much different familial comorbidities impact suicide risk requires also exploring the impact of the wider environment. Reports and research from the past several years have drawn significant attention to the effect that both individual and area level factors can have on the trajectories of health and life expectancy (Duncan, Jones, & Moon, 1993; Marmot, 2005, 2009). Many studies have since aimed to understand how place impacts health through disentangling contextual, or area level effects, from compositional, or individual level, effects. Research exploring the effect of place on suicide risk has largely focused on the urban-rural environment, with most studies suggesting urbanicity likely increases the risk of suicide, particularly for women, though rural living poses an increased risk of suicide for men (Andrés, Collings, & Qin, 2010; Von Borczyskowski, Lindblad, Vinnerljung, & Hjern, 2010) Male suicide accounts for approximately two thirds of suicide cases globally (Andrés & Halicioglu, 2010; Bilsker & White, 2011; Whitley, 2021), with a three-fold higher incidence rate for men than women in Denmark (Titelman et al., 2013). Place of residence has been suggested as an underlying explanation to this, as studies indicate men and women experience a differential effect of neighbourhood on the risk of suicide.

Understanding the impact of place on suicide risk entails examining both the general contextual effect, which explains how much suicide varies between neighbourhoods, and the specific effects of characteristics within neighbourhoods (Merlo, Wagner, Austin, Subramanian, & Leckie, 2018). The general contextual effect of neighbourhood on suicide risk remains uncertain, with some research finding very little variation in suicide incidence between neighbourhoods, and others reporting a heightened risk, particularly for younger adults (Jakobsen & Lund, 2022; Zammit et al., 2014). Findings on the specific effects of neighbourhood have also been mixed, with deprivation being linked to a lower risk of suicide in some studies and an increased risk in others (Congdon, 2013; Rezaeian, Dunn, St Leger, & Appleby, 2005). The inclusion of individual covariates overall has been found to attenuate both the general contextual and specific effects of neighbourhood such as deprivation (Jakobsen & Lund, 2022; Zammit et al., 2014). However, most of the studies looking at specific effects included aggregated measures of deprivation and social fragmentation, which may underestimate important nuances within these dimensions. Ngamini Ngui, Vasiliadis, and Préville (2015) for example found that whilst income level did not affect suicide risk in older adults, a higher proportion of unemployment within neighbourhoods increased the risk. In addition, several of the aforementioned studies adjusted only for individual socio-demographic covariates or personal comorbidities, which could overstate the magnitude of neighbourhood specific effects on suicide risk when key risk factors such as parental comorbidities are excluded.

Preventing suicide involves a thorough understanding of the importance of different risk factors to identify individuals that may be more vulnerable, allowing interventions to be targeted appropriately. Given the lack of studies examining the effect of neighbourhood alongside key individual risk factors, the impact of place on suicide risk remains unclear. We aim to explore the effect of more nuanced neighbourhood characteristics alongside risk factors occurring in individuals that are known to increase suicide risk. We further aim to explore which specific familial indicators affect suicide risk by using Danish population registers, that allow us to examine maternal and paternal comorbidities distinctly. We fit a two-level survival model of individuals nested in Danish neighbourhoods, to gain insight into how suicide risk may vary across different contexts and determine which factors are associated with suicide risk when considered at both the individual and neighbourhood level.

Methods

Study population

All individuals living in Denmark are registered in the Danish Civil Registration System (Pedersen, 2011) with a unique personal identification number used in all Danish registries enabling accurate data linkage. Among many other variables, this registry includes information on sex, date of birth, parental personal identification numbers and continuously updated information on vital status and residential address. We included all individuals born in Denmark between 1st January 1972 to 31st December 2005, who resided in Denmark on their 10th birthday and whose mothers were born in Denmark after 1st April 1935, resulting in a study population of 1,906,130 individuals.

Suicide

Death by suicide was defined based on information from the Danish Registry of Cause of Death (Helweg-Larsen, 2011). Since 1970, this registry has recorded information for all residents who die in Denmark. Classification of cause(s) of death is done according to the International Classification of Diseases (ICD), 8th revision (ICD-8) until 1993 and 10th revision (ICD-10) from 1994. We identified all deaths by suicide (ICD-8: 950–959, ICD-10: X60-X84, Y870) during follow-up.

Individual-level covariates

We included age, sex and how often an individual moved to a different municipality (0, 1, or 2 and more moves) from age 5 to age 10 (Webb, Pedersen, & Mok, 2016) We also included maternal and paternal age at the time of the individual's birth categorised into six groups (12–19, 20–24, 25–29, 30–34, 35–39, and 40 years and above). Paternal age was included for known fathers in the data, and a few cases of paternal age were included for unknown fathers where the Civil Registration System could link this information to individuals.

For each parent, we defined somatic illness as any comorbidity based on the comorbidity index score developed by Charlson, Pompei, Ales, & MacKenzie(1987) (ICD-8 and ICD-10 codes used to define the diseases together are shown in online Supplementary eTable S1). We calculated the score based on all discharge diagnoses recorded in the Danish National Patient Registry (Lynge, Sandegaard, & Rebolj, 2011). We also linked to

the Danish Psychiatric Central Registry (Mors, Perto, & Mortensen, 2011) to obtain information on maternal and paternal history of mental health. These were classified hierarchically as any history of schizophrenia (ICD-8: 295.x9 excl.295.79, ICD-10: F20), affective disorder (ICD-8: 296.x9 excl. 296.89, 298.09, 298.19, 300.49, 301.19, ICD-10: F30–F39), other psychiatric illness (ICD-8: 290–315, ICD-10: F00–F99) or no psychiatric illness.

We defined any maternal or paternal suicide attempt based on the previous classification by Nordentoft, Mortensen, and Pedersen (2011), using information from the Danish Psychiatric Central Registry and the Danish National Patient Registry. Maternal and paternal death were also included. Finally, we collected information about parental socioeconomic status from registries at Statistics Denmark (Jensen & Rasmussen, 2011; Petersson, Baadsgaard, & Thygesen, 2011). We defined maternal and paternal income (age, sex and calendar year specific quartiles on the basis of the entire population), cohabiting status (married/cohabiting; single), educational level (primary school; secondary school/vocational training; short cycle higher education (1–2 years); higher education), and employment status (employed; unemployed; outside workforce).

Geographical data zones

Prior to this study, 1885 areas across Denmark were generated to create neighbourhoods, hereafter data zones, of homogenous small area geographic neighbourhoods, containing approximately 2500 residents in each zone (Pedersen et al., 2022). Individual covariates were then aggregated to create data zone level indices of neighbourhood characteristics including measures of material deprivation such as low income, basic education level, unemployment, no car owned, social fragmentation which included lone adult households, residential transience, rented accommodation, social marginalisation including violent offenders, criminality, individuals born abroad, and finally neighbourhood physical illness and population density. These were calculated annually from 1981 to 2014, but averaged in five year bands to reduce uncertainty. We used zone-level data from the calender year before each individuals 10th birthday. Due to a lack of historical data for some of the data zone level indices, we used the weighted average in the 5 year period including the calender year preceding each individuals 10th birthday. All data zone level indices were standardised before analysis.

Statistical analysis

Individuals were followed from their 10th birthday until either death, emigration or 31st December 2015, whichever came first. Data were analysed using multilevel log linear Poisson regression models including individual and neighbourhood level variables, with neighbourhood as a random intercept term. The logarithms of the aggregated person-years were used as an offset variable. Poisson modelling is equivalent to the cox regression model for survival analysis, and allows individual incidence risk ratio (IRR) to be calculated, as well as accounting for the natural clustering of individuals within geographic units. We fitted two models to examine the individual risk factors at different model adjustment levels, (1) age-sex interaction and parental mental health comorbidities and parental previous suicide attempt, (2) full individual level adjustment. To examine the general contextual effect of neighbourhood, we report the median incidence rate

ratio (MRR) for the models above and for each specific neighbourhood indicator added individually. The general contextual effect of neighbourhood was calculated using the MRR based on the formula used by Austin, Stryhn, Leckie, and Merlo (2018). The specific neighbourhood indicators were examined unadjusted initially followed by full adjustment for individual covariates. We also ran sex-stratified analyses to compare neighbourhood specific effects.

Data analyses were carried out using R version 4.0.4. Multilevel Poisson regression was performed using the R2MLwiN package retrieved through R, using IGLS to gain initial starting values followed by MCMC to estimate Bayesian models. Diagnostics including the Raftery Lewis Criteria were used to examine how many iterations the model should run for. We used 4 chains with 250 000 simulations, with a burn-in of 10 000 simulations to fit the model.

Results

Table 1 shows the number of cases of suicide for each individual level covariate and their IRR. Between 1982 and 2015, 1723 individuals died from suicide from the study population of 1,906,130. Age-sex variables were included in all models but not reported in the table. We initially fit a sex only adjusted model (not reported in the table), which showed a 3.42 (95% CI 3.04–3.83) fold increased suicide risk for men compared to women. Maternal schizophrenia diagnosis (IRR 2.29, 1.56–3.16) and paternal death (IRR 2.29, 1.31–3.72) showed the largest increased effect on suicide risk than other individual determinants and parental comorbidities. An increased IRR of suicide was also observed in those whose parents had a history of previous suicide attempt, any maternal and paternal psychiatric illness, maternal and paternal affective disorder, younger maternal age at birth, coming from a single parent household, low paternal income, low paternal education level and paternal unemployment.

Table 2 shows the contextual effect of suicide risk, which indicates the unexplained residual variance at data zone level. We reported both the MRR and random variance estimate between data zones adjusted for sex only, followed by age-sex interaction and parental mental health and suicide attempts, and full individual level adjustment. Both the MRR and random variance show that there is little unexplained variance at data zone level, indicating that there is little additional risk of suicide when comparing two randomly selected individuals from an area with a high incidence rate of suicide compared to a low incidence rate. The MRR and random variance were most attenuated when adjusted for all individual covariates and additionally including the proportion of individuals with basic education.

Table 3 shows the neighbourhood specific effects. The basic analysis showed 10 of the 14 specific effects to be associated with an increased risk of suicide. These were attenuated with the inclusion of individual covariates. Full individual level adjustment showed that suicide risk was greater in neighbourhoods with a higher proportion of individuals with basic education and manual workers, when adjusted for all individual covariates. Suicide risk was lowered in neighbourhoods with a higher proportion of individuals born abroad, and a higher population density.

Figure 1 shows the basic-adjusted stratified models of IRR of neighbourhood effects on suicide risk comparatively by sex. The results show several indicators within material deprivation to increase suicide risk, particularly for men, as well as an increased risk in neighbourhoods with a higher proportion of violent

Table 1. Individual level determinants of suicide risk

	Number of suicides	Model 1: Basic adjustment, parental mental health and suicide attempt[a]	Model 2: Full individual level adjustment[b]
Individual and familial covariates			
Sex			
Female	377		
Male	1346		
Mental health covariates			
Maternal mental health diagnosis			
No psychiatric illness	1555	1.00 (ref)	1.00 (ref)
Any psychiatric illness	97	**1.84 (1.46–2.26)**	**1.54 (1.22–1.90)**
Affective disorder	36	**1.84 (1.27–2.51)**	**1.67 (1.15–2.28)**
Schizophrenia	35	**2.74 (1.88–3.77)**	**2.29 (1.56–3.16)**
Paternal mental health diagnosis			
No psychiatric illness	1560	1.00 (ref)	1.00 (ref)
Any psychiatric illness	93	**1.77 (1.40–2.19)**	**1.31 (1.03–1.64)**
Affective disorder	31	**2.16 (1.44–3.02)**	**1.73 (1.16–2.42)**
Schizophrenia	16	1.62 (0.92–2.53)	1.16 (0.66–1.83)
Maternal suicide attempt			
No	1661	1.00 (ref)	1.00 (ref)
Yes	62	**1.91 (1.42–2.49)**	**1.65 (1.23–2.15)**
Paternal suicide attempt			
No	1654	1.00 (ref)	1.00 (ref)
Yes	46	**1.75 (1.24–2.37)**	**1.43 (1.01–1.93)**
Parental physical illness and death			
Maternal Charlson Comorbidity			
No	1645		1.00 (ref)
Yes	78		1.10 (0.86–1.37)
Paternal Charlson Comorbidity			
No	1617		1.00 (ref)
Yes	83		0.87 (0.68–1.08)
Maternal death			
No	1700		1.00 (ref)
Yes	23		1.72 (0.52–4.11)
Paternal death			
No	1639		1.00 (ref)
Yes	61		**2.29 (1.31–3.72)**
Parental age at birth			
Maternal age (years)			
25–29	550		1.00 (ref)
12–19	131		**1.61 (1.27–1.99)**
20–24	578		**1.30 (1.14–1.48)**
30–34	342		**1.18 (1.02–1.36)**
35–39	112		**1.32 (1.04–1.64)**
40 and older	10		1.06 (0.50–1.85)

(Continued)

Table 1. (*Continued.*)

	Number of suicides	Model 1: Basic adjustment, parental mental health and suicide attempt[a]	Model 2: Full individual level adjustment[b]
Paternal age (years)			
25–29	600		1.00 (ref)
12–19	19		**0.62 (0.36–0.96)**
0–24	320		0.97 (0.83–1.12)
30–34	450		1.07 (0.94–1.22)
35–39	212		1.15 (0.96–1.37)
40 and older	99		1.05 (0.81–1.32)
Family socio-economic factors			
Family cohabiting status			
Married/cohabited	1334		1.00 (ref)
Single	371		**1.21 (1.06–1.37)**
Maternal income quartile (Q)			
Q4 (highest)	389		1.00 (ref)
Q1 (lowest)	484		1.01 (0.86–1.19)
Q2	400		0.94 (0.81–1.10)
Q3	434		1.06 (0.92–1.22)
Paternal income quartile (Q)			
Q4 (highest)	332		1.00 (ref)
Q1 (lowest)	556		**1.18 (1.01–1.39)**
Q2	400		1.09 (0.93–1.26)
Q3	359		1.04 (0.89–1.21)
Maternal education			
Higher education	302		1.00 (ref)
Primary school	471		1.05 (0.88–1.25)
Secondary school or vocational education	870		1.01 (0.87–1.18)
Short cycle higher education	38		1.02 (0.70–1.40)
Paternal education			
Higher education	244		1.00 (ref)
Primary school	448		**1.24 (1.03–1.49)**
Secondary school or vocational education	864		1.02 (0.86–1.20)
Short cycle higher education	42		0.77 (0.54–1.05)
Maternal employment status			
Employed	1246		1.00 (ref)
Unemployed	158		1.15 (0.96–1.36)
Outside workforce	295		1.13 (0.96–1.32)
Paternal employment status			
Employed	1370		1.00 (ref)
Unemployed	123		**1.29 (1.05–1.56)**
Outside workforce	134		**1.35 (1.09–1.64)**
Individual residential moves			

(*Continued*)

Table 1. (*Continued.*)

	Number of suicides	Model 1: Basic adjustment, parental mental health and suicide attempt[a]	Model 2: Full individual level adjustment[b]
Residential changes			
None	1444		1.00 (ref)
1	182		0.96 (0.81–1.11)
2 or more	97		1.13 (0.90–1.38)
Total cases	1723		

[a]Adjusted for basic age-sex interaction and parental mental health.
[b]Adjusted for basic age-sex interaction and all individual level variables.

Discussion

Utilising Danish register-based data, we examined the effect of both individual and neighbourhood level risk factors on suicide. Previous studies have demonstrated a link between broader area characteristics, such as urbanicity or rurality, and suicide risk, though more detailed analyses of neighbourhood effects show an attenuation of the general and specific effect of neighbourhood when individual factors are included. In accordance with other studies, we find little general contextual effect at the neighbourhood level on suicide risk, suggesting that suicide risk variation occurs mainly between individuals rather than between neighbourhoods. We identified several important risk factors at the individual level, as well as smaller but significant associations between some specific neighbourhood effects and suicide risk.

offenders for men and women, and higher proportion of physical illness for men. Some social fragmentation indices were borderline significant, though fewer cases of suicide in women introduces more uncertainty.

Table 2. Contextual effect between data zones on suicide risk

Model	Median incidence rate ratio (95% CI)	Random variance (95% CI)
Adjusted for sex only	1.13 (1.01–1.28)	0.01721 (0.00003–0.06794)
Adjusted for age-sex interaction, parental mental health and suicide attempts	1.13 (1.00–1.27)	0.01607 (0.00002–0.06483)
All Individual covariates	1.11 (1.00–1.25)	0.01297 (0.00002–0.05504)
PI low income[a]	1.12 (1.00–1.25)	0.01306 (0.00002–0.05519)
PI basic education[a]	1.11 (1.00–1.25)	0.01242 (0.00002–0.05283)
PI not employed[a]	1.12 (1.00–1.25)	0.01358 (0.00002–0.05621)
PI manual workers[a]	1.11 (1.00–1.24)	0.01246 (0.00002–0.05275)
PH overcrowded[a]	1.11 (1.00–1.25)	0.01282 (0.00001–0.05416)
PH no car owned[a]	1.12 (1.00–1.25)	0.01323 (0.00002–0.05439)
PH lone adult[a]	1.12 (1.00–1.25)	0.01368 (0.00002–0.05604)
PH rents home[a]	1.12 (1.00–1.25)	0.01313 (0.00002–0.05540)
PI residential transience[a]	1.11 (1.00–1.25)	0.01298 (0.00002–0.05408)
PI violent crime[a]	1.12 (1.00–1.26)	0.01372 (0.00002–0.05686)
PI any criminality[a]	1.12 (1.00–1.25)	0.01362 (0.00002–0.05654)
PI born abroad[a]	1.11 (1.00–1.25)	0.01281 (0.00002–0.05354)
PI physical illness[a]	1.12 (1.00–1.25)	0.01344 (0.00002–0.05580)
Population density[a]	1.11 (1.00–1.25)	0.01269 (0.00002–0.05380)

[a]Adjusted for all individual level covariates.

Table 3. Neighbourhood-level contextual effects

Neighbourhood-level socio-economic indicator[a]	Basic individual level IRR — IRR of neighbourhood per 1 s.d. increase[b]	Full individual level adjusted IRR — IRR of neighbourhood per 1 s.d. increase[c]
Material deprivation		
PI low income	**1.11 (1.05–1.16)**	1.03 (0.98–1.09)
PI basic education	**1.12 (1.07–1.18)**	**1.07 (1.02–1.13)**
PI not employed	**1.13 (1.07–1.19)**	1.03 (0.98–1.09)
PI manual workers	**1.15 (1.09–1.21)**	**1.08 (1.03–1.14)**
PH overcrowded	**1.05 (1.00–1.10)**	1.00 (0.95–1.05)
PH no car owned	1.05 (0.99–1.11)	0.96 (0.90–1.01)
Social fragmentation		
PH lone adult	**1.08 (1.02–1.14)**	0.98 (0.93–1.04)
PH rents home	**1.05 (1.00–1.10)**	0.96 (0.91–1.01)
PI residential transience	1.04 (0.98–1.09)	0.98 (0.92–1.03)
Social marginalisation		
PI violet offending	**1.11 (1.06–1.16)**	1.01 (0.96–1.06)
PI any criminality	**1.06 (1.01–1.11)**	0.99 (0.94–1.04)
PI born abroad	0.98 (0.93–1.04)	**0.92 (0.87–0.97)**
Physical illness		
PI physical illness	**1.09 (1.03–1.14)**	1.02 (0.97–1.08)
Other		
Population density	0.96 (0.89–1.03)	**0.89 (0.83–0.96)**

[a]PI and PH refer to proportion of individuals and proportion of households respectively.
[b]Adjusted for basic age-sex interaction.
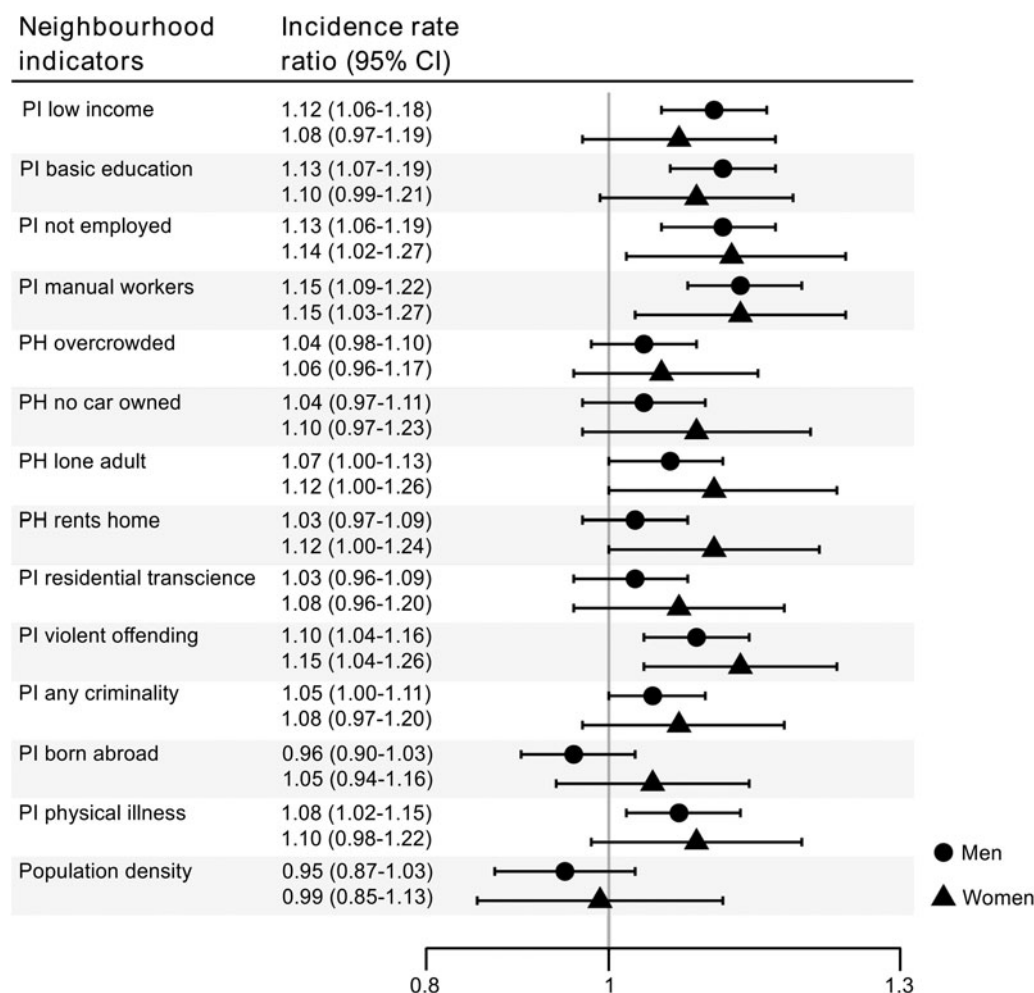[c]Adjusted for basic age-sex interaction and all individual level variables.

Neighbourhood indicators	Incidence rate ratio (95% CI)
PI low income	1.12 (1.06–1.18)
	1.08 (0.97–1.19)
PI basic education	1.13 (1.07–1.19)
	1.10 (0.99–1.21)
PI not employed	1.13 (1.06–1.19)
	1.14 (1.02–1.27)
PI manual workers	1.15 (1.09–1.22)
	1.15 (1.03–1.27)
PH overcrowded	1.04 (0.98–1.10)
	1.06 (0.96–1.17)
PH no car owned	1.04 (0.97–1.11)
	1.10 (0.97–1.23)
PH lone adult	1.07 (1.00–1.13)
	1.12 (1.00–1.26)
PH rents home	1.03 (0.97–1.09)
	1.12 (1.00–1.24)
PI residential transcience	1.03 (0.96–1.09)
	1.08 (0.96–1.20)
PI violent offending	1.10 (1.04–1.16)
	1.15 (1.04–1.26)
PI any criminality	1.05 (1.00–1.11)
	1.08 (0.97–1.20)
PI born abroad	0.96 (0.90–1.03)
	1.05 (0.94–1.16)
PI physical illness	1.08 (1.02–1.15)
	1.10 (0.98–1.22)
Population density	0.95 (0.87–1.03)
	0.99 (0.85–1.13)

● Men
▲ Women

0.8　　　1　　　1.3

Fig. 1. Age-adjusted incidence ratio ratios and 95% CI for neighbourhood indicators on suicide risk by sex.

Research on the general contextual effect of suicide has produced mixed findings. Variation in suicide risk has been mainly observed at the individual level, with little unexplained variation between neighbourhoods remaining when individual covariates are adjusted for (Zammit et al., 2014), and research on other mental health outcomes have shown similar patterns (Fone et al.,- 2014; Zammit et al., 2010). Our study found little variation of suicide risk between neighbourhoods, when looking between newly created homogenous sized areas in Denmark, suggesting that most of the risk of suicide is explained by determinants occurring between individuals. A larger effect of place has been observed in other psychiatric outcomes, with recent research on schizophrenia risk using the same neighbourhoods as the present study finding evidence of unexplained variation between these small area neighbourhoods across Denmark (Pedersen et al., 2022). Studies using geographic areas with a smaller number of residents per neighbourhood have found a greater general contextual effect on suicide risk than we report in the present study, though the stratification of groups in these analyses may explain the larger contextual effects which were seen in some subgroups rather than others, as opposed to the use of smaller geographic neighbourhoods (Jakobsen & Lund, 2022; Kanamori et al., 2020).

Suicide risk may be explained by variability between individuals rather than neighbourhoods, but the determinants within a neighbourhood do appear, albeit to a lesser extent than individual factors, to have an impact on suicide risk. We found that even after individual level adjustment, within the dimension of deprivation, there was a small increased risk of suicide in neighbourhoods with a higher proportion of individuals with basic education and manual workers. The use of an aggregated measure for deprivation in previous research may explain why we find some aspects of deprivation to be associated with suicide risk whilst other studies report null findings (Jakobsen & Lund, 2022; Zammit et al., 2014), as following full adjustment in our analysis, low income and unemployment were not associated with suicide risk. We found a lack of association between suicide risk and social fragmentation, similarly to Hagedoorn, Groenewegen, Roberts, and Helbich (2020) that found no association for the whole sample, whilst stratified analyses revealed an increased risk only for women. Our findings showed a borderline significant increased effect of social marginalisation measures in women, though these results were adjusted for age only, and there were fewer cases of suicide amongst women compared to men. Future studies should further explore these differential neighbourhood effects between men and women, and how suicide risk may be heightened for men or women in neighbourhoods with particularly high material deprivation or social marginalisation.

Characteristics within neighbourhoods may also protect against suicide risk, as we found neighbourhoods with a higher proportion of individuals born abroad and higher population

density decreased the risk of suicide. This substantiates research that finds suicide to be lower amongst ethnic minority populations, possibly due to higher levels of social cohesion in these communities (Neeleman & Wessely, 1999). Living in an area with a lower population density has been linked to an increased risk of suicide in men, suggested to be due to lower social support and access to support services (Vichi, Vitiello, Ghirini, & Pompili, 2020), and a heightened risk of suicide has been shown in rural areas amongst male farmers (Hirsch & Cukrowicz, 2014; Ringgenberg, Peek-Asa, Donham, & Ramirez, 2018). Our stratified analysis did not show an association between population density and suicide risk for men or women, though the basic adjustment effect in the whole sample of population density was also nonsignificant. Though urbanicity has been shown to have a detrimental effect on mental health, it appears urban and higher population density areas impact the risk of psychiatric disorders more so than suicide (Vassos, Agerbo, Mors, & Pedersen, 2016). Population density and suicide risk may also be more nuanced not only between men and women, but between age groups. Low population density has been found to increase suicide risk in older women, but conversely younger women experience an increased risk in higher population density areas (O'farrell, Corcoran, & Perry, 2016). A lack of inclusion of individual level risk factors in these studies however indicates that more research is needed to determine if the effect of population density and suicide risk across different groups remains when other risk factors are accounted for.

Individual risk factors were shown to have a greater effect on suicide risk than neighbourhood specific effects in our study. Previous studies have shown that having a parent with a mental health disorder strongly predicts suicide risk in individuals. We found that having a mother or father with any psychiatric disorder or an affective disorder diagnosis increased the risk of suicide. The mechanisms for parental mental health impacting suicide risk could be due to a complex gene-environment interaction that increases suicidal tendencies at both a biological and behavioural level (Tidemalm et al., 2011). Having a mother with schizophrenia had the largest increased effect on suicide risk, whereas paternal schizophrenia was not significantly associated with suicide. Maternal mental health has also previously been found in other research to be more indicative of suicide risk than paternal mental health (Stenager & Qin, 2008; Wilkinson, Harris, Kelvin, Dubicka, & Goodyer, 2013). Having a mother with schizophrenia may be related to a greater increased risk due to the detrimental impact of schizophrenia on quality of life and family dynamics, which often involves other family members taking on caregiving roles (Caqueo-Urízar et al., 2017). It may also be that suicide risk is higher amongst those whose mothers have poor mental health and particularly a more severe psychiatric disorder, due to mothers being more likely to be the primary caregiver. A parental history of schizophrenia is also the biggest predictor of an individual developing the disorder, and suicide is the leading cause of death amongst individuals with schizophrenia (Mortensen, Pedersen, & Pedersen, 2010; Pompili et al., 2007). Though we did not include personal comorbidities, as these are on the causal pathway rather than confounders of suicide risk, future studies might consider including such mediating factors. Early interventions for individuals with a maternal history of schizophrenia should be considered, even in the absence of an individual diagnosis of schizophrenia, to ensure these potentially more vulnerable individuals receive early suicide prevention interventions and support.

Previous maternal suicide attempt showed a slightly larger effect on suicide risk than paternal suicide attempt, corroborating previous findings about the impact of maternal mental health on suicide risk (Geulayov, Gunnell, Holmen, & Metcalfe, 2012; Stenager & Qin, 2008). We also found, as well as maternal schizophrenia, the death of a father had the greatest impact on suicide risk. In contrast to other studies that found losing a mother had a greater impact on suicide risk, we did not find any association between maternal death and suicide risk (Guldin et al., 2015). The death of a parent has been found to increase the risk of suicide in children only of the same-sex, and with men being more likely to die from suicide, it could be that losing a father increases the risk of suicide in men, who already experience a heightened risk. We also found several other paternal factors to have a smaller but significant effect on suicide risk, including low income, unemployment and being outside of the workforce. Adversities accumulated throughout childhood have been shown to have a dose-response effect on suicide risk (Björkenstam et al., 2017; Rod et al., 2020). It may be the accumulation of these factors in our study that increases the risk of suicide, though more research on the interaction of these adversities and their effect on suicide risk is necessary.

Strengths and limitations

This is the first study to our knowledge to examine detailed individual and neighbourhood level risk factors together on the risk of suicide using register-based data across Denmark. The use of register data from a large national Danish cohort enabled us to estimate suicide risk in individuals with full parental history on both the maternal and paternal side. Our research extends other work by using multilevel survival methods to estimate the effect of the shared impact of both familial comorbidities and socio-economic factors alongside detailed neighbourhood indicators. The importance of childhood residence has previously been shown across other adverse outcomes, and as we define neighbourhood indicators at age 10 (Webb et al., 2016), we were able to prospectively show the impact of neighbourhood on suicide risk, as opposed to previous studies that look at the neighbourhood an individual lived in when they died. We were also able to get a greater understanding of the impact of several specific neighbourhood effects on suicide risk, that might have been overstated previously due to a lack of inclusion of important individual level risk factors. The use of homogenous small area neighbourhoods also extends research that has examined the effect of larger geographical areas on suicide risk, enabling us to examine more detailed variation of suicide risk and neighbourhood level constructs.

Despite our use of register data and robust analytical methods, potential limitations should be noted. The uneven distribution of suicide cases and small case numbers for several individual variables between men and women meant we were only able to examine suicide risk stratified by sex for neighbourhood factors. The rarity of suicide means that examining detailed individual level factors by sex is difficult, and future studies extending this research must take this into account. Our use of data zones to examine neighbourhood effects, whilst providing a better understanding of small area variation in suicide risk in Denmark, might not have revealed variation as much as larger aggregated areas may have, or indeed even smaller geographic areas. Despite several variables occurring within family units, we were unable to analyse these at an additional household level, due to some households containing very few individuals. Finally, we

focused on death by suicide as our outcome, which although captures a more clearly defined outcome compared to other measures of suicidal behaviour such as suicide attempts, could still underestimate true rates of suicide due to the associated stigma (Palmer, 2020; Tøllefsen, Hem, & Ekeberg, 2012).

Conclusion

Using a large national Danish population-based sample, we examined the risk of suicide in the context of detailed individual and neighbourhood determinants. Individual factors such as having a mother with schizophrenia, the death of a father and suicide attempt history of both parents increased the risk of suicide. Multilevel survival analysis revealed suicide risk was mainly explained by individual factors, with little variation occurring between small area neighbourhoods across Denmark. Some specific neighbourhood characteristics however revealed both increased and decreased risks of suicide, such as neighbourhoods with higher deprivation measures, and those with a higher population density, respectively. Interventions for preventing suicide should be targeted towards those individuals at a higher risk of suicide due to particular parental comorbidities, with the consideration that some neighbourhood characteristics can play a smaller but still significant role in suicide risk alongside these important risk factors.

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