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A solid start for the Dutch first thousand days-approach: insights into program adoption, monitoring and cross- sectoral collaboration

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Defining vulnerability subgroups among pregnant women using pre-pregnancy information: a latent class analysis

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ABSTRACT

Background

Early detection of vulnerability during or before pregnancy can contribute to optimizing the first thousand days, a crucial period for children's development and health. We aimed to identify classes of vulnerability among pregnant women in the Netherlands using pre-pregnancy data on a wide range of social risk and protective factors, and validate these classes against the risk of adverse outcomes.

Methods

We conducted a latent class analysis based on 42 variables derived from nationwide observational data sources and self-reported data. Variables included individual, socioeconomic, lifestyle, psychosocial and household characteristics, self-reported health, healthcare utilization, life-events and living conditions. We compared classes in relation to adverse outcomes using logistic regression analyses.

Results

In the study population of 4172 women, we identified five latent classes. The largest 'healthy and socioeconomically stable'-class [n = 2040 (48.9%)] mostly shared protective factors, such as paid work and positively perceived health. The classes 'high care utilization' [n = 485 (11.6%)], 'socioeconomic vulnerability' [n = 395 (9.5%)] and 'psychosocial vulnerability' [n = 1005 (24.0%)] were characterized by risk factors limited to one specific domain and protective factors in others. Women classified into the 'multidimensional vulnerability'-class [n = 250 (6.0%)] shared multiple risk factors in different domains (psychosocial, medical and socioeconomic risk factors). Multidimensional vulnerability was associated with adverse outcomes, such as premature birth and caesarean section.

Conclusions

Co-existence of multiple risk factors in various domains is associated with adverse outcomes for mother and child. Early detection of vulnerability and strategies to improve parental health and well-being might benefit from focussing on different domains and combining medical and social care and support.

INTRODUCTION

The first thousand days of life, from preconception to the child's second birthday, are crucial to children's further physical, mental and social development. This critical and sensitive period is an important determinant of health and well-being in adulthood, as supported by the well-evidenced Developmental Origins of Health and Disease (DOHaD) concept (1, 2). The DOHaD concept explains how experiences and exposures during early life, such as stress and nutrition, influence susceptibility to disease in later life and across generations, arguably through epigenetic mechanisms of foetal programming (1, 2). Because of this intergenerational aspect, parents are the central focus to improve child health and advance health equity (3).

To indicate subgroups of parents and their unborn or newborn children who are at higher risk of poor health or have lower access to healthcare, the concept of vulnerability is often used (4-6). Vulnerability reflects a complex and dynamic process. Simplified, various stressors at individual or contextual level (e.g. unemployment or living in a deprived neighbourhood) can act as risk factors to vulnerability, while protective factors (e.g. stable social network) might reduce or prevent vulnerability (4, 5, 7, 8).

Whether the presence of risk factors increases vulnerability and thereby hinder achieving one's optimal health potential depends on the balance and interaction between risk and protective factors (4, 8). While research on perinatal health has traditionally focussed on risk factors of a medical nature, there is now indisputable evidence for direct and indirect influences of social factors as well (9-14). The social, economic, cultural and environmental living conditions (i.e. social determinants of health) that shape parents' and children's daily experiences and thereby influence their health and development, are embedded in larger systems and structures such as policies and laws (3, 15).

There is an international growing professional and political focus on early detection of vulnerability during the first thousand days and development of effective strategies to improve parental health and well-being (3, 16). For instance in the Netherlands, the government launched a nationwide 'Solid Start'-programme in 2018 with the aim of providing each child the best start in life by strengthening collaboration between medical and social services, with a specific focus on families in vulnerable situations (16). Detecting vulnerability during pregnancy with the preventive purpose of countering suboptimal child health is challenging and can benefit from in-depth knowledge into vulnerability.

However, currently, little is known about the combination of different risk and protective factors to vulnerability and its influence on health outcomes. There seems to be few studies that consider protective factors to vulnerability and there is limited insight into clustering and underlying interactions, while it is recognized that especially the co-existence of risk factors can lead to adverse birth outcomes (11, 17, 18). Previous studies frequently explored the association between a limited number of predetermined, single risk factors

and adverse birth outcome, but neglected co-existence of both protective- and risk factors that can influence outcomes (12, 18, 19).

The aim of this study was to identify classes of vulnerability among pregnant women based on a wide range of social risk and protective factors in a latent class analysis (LCA). We conducted the LCA using Dutch observational nationwide data sources and self-reported data prior to pregnancy. In addition, we validated these classes by studying the association between latent class membership and various maternal and perinatal health outcomes and care utilization.

METHODS

Data sources

This study utilized data from the nationwide population-based data infrastructure DIAPER (acronym for Data-InfraStructure for ParEnts and childRen). DIAPER integrates routinely collected observational data from three Dutch nationwide data sources (Perined, Vektis and Statistics Netherlands) at individual level. The Dutch Perinatal Registry 'Perined' collects routine care data on pregnancy after 22 weeks of gestation, birth and the first 28 days after birth, as supplied by midwives, gynaecologists and paediatricians (20). Healthcare information centre 'Vektis' collects claims data under the Dutch Healthcare Insurance Act and provides data on healthcare utilization and spending (21). 'Statistics Netherlands' collects and publishes data on societal matters and provides access to data through their System of Social Statistical Datasets (SSD) (22, 23). This linkable SSD-data covers nearly 20 themes, including health, welfare, income, education and labour.

We enriched DIAPER with self-reported data on health, well-being and lifestyle of the Public Health Monitor 2016 (PHM-2016) (24). This is a health survey among a varying sample of the Dutch population aged 19 years and older, carried out every 4 years by the Community Health Services, Statistics Netherlands and the National Institute for Public Health and the Environment. The PHM-2016 had 457.153 participants and was mainly conducted from September-December 2016. Appendix A provides more information about the data sources.

Study population

To ensure that information was not influenced by pregnancy itself, women were eligible for inclusion if these criteria were met: (i) they participated in the PHM-2016 (pre-pregnancy), (ii) they gave birth (livebirth or stillbirth) or had a termination of pregnancy before 1 January 2019, and (iii) pregnancy data in 2017 or 2018 were recorded within Perined. In case women had multiple pregnancies or births during the study period, only data on the first observation was included, to avoid duplication of women's characteristics.

Variables

The selection of variables for the LCA started with compiling a list of all possible risk and protective factors to vulnerability based on the framework of the National Academies of Sciences, Engineering, and Medicine (3), other scientific studies and definitions of vulnerability (4, 5, 8), and expertise of the research team. Based on this list, 42 variables were available and selected in our data sources. These were divided into nine themes: individual characteristics, socioeconomic characteristics, lifestyle factors, household characteristics, self-reported health, healthcare expenditures and utilization, psychosocial characteristics, life-events and living conditions. The timing of the PHM-2016 was decisive in the choice for 1 October 2016 as baseline to include information. If data were available only on yearly basis, we included data from 2016. To increase interpretability, variables were categorized into two or three categories with the first category representing the risk factor to vulnerability. Appendix 1 provides a detailed overview of the variables, including definitions, categories and sources.

Outcomes

We studied the association between latent class membership and perinatal and maternal health outcomes and care utilization to validate classes. Perinatal health outcomes comprised: preterm birth (<37 weeks), small for gestational age (SGA, <10th percentile corrected for gestational age and foetal sex), preterm birth and/or SGA, and admission to a neonatal intensive-care unit (NICU) after birth. Maternal health outcomes comprised: primary and secondary caesarean section, pre-eclampsia/hypertension and postpartum haemorrhage (≥ 1000 ml). Outcomes regarding healthcare utilization included: not having the first antenatal care appointment (i.e., booking visit) before the 10th week of pregnancy and not receiving postpartum care (at home) after birth. Appendix 1 provides more information.

Statistical analyses

Latent class analysis

LCA is a data-driven analysis technique that aims to structure heterogeneity in a population by classifying individuals into unobserved – or latent – homogeneous classes (25). Structuring is based on included variables. Each class is denoted by conditional probabilities for each variable to take on a certain response value (e.g. 1 or 0), with the objective to categorize individuals into the smallest possible set of distinct and interpretable latent classes.

Using R version 3.6.2 (package *poLCA*), we estimated latent class models using all 42 variables with no prior assumptions about the optimal number of classes (26). Missing data were imputed through Multiple Imputation using Chained Equations (MICE) (Appendix 2). We started with a one-class model and stepwise increased to a 15-class model. Parameters of the latent class models were estimated by maximum likelihood. We considered both statistical fit as well as parsimony and interpretability to select the optimal model (25). To compare the competing models' relative fit, we used the Akaike Information Criterion (AIC) (27) and sample-size adjusted Bayesian Information Criterion (aBIC) (28). Lower values

indicate better fit of the model to the data. We also considered the fit-indices' relative decrease, as done in previous studies (29), because a continuous decrease in the AIC is common with large sample sizes and the aBIC also may indicate towards a model with more classes than useful (30). We additionally reviewed the models' entropy, which reflects how clearly the classes can be distinguished with scores ranging from 0 to 1 (optimum) (31). We selected three preferred models based on their fit statistics and compared their item-response probabilities. The final model was selected based on parsimony and interpretability and women were classified into one of the identified classes based on predicted class membership (largest posterior probability). Further, to evaluate the LCA's robustness, we performed two additional analyses. First, to unravel the impact of previous pregnancies, we excluded nullipara and conducted a LCA with additionally previous perinatal and pregnancy outcomes. Second, to evaluate whether similar vulnerability classes can be distinguished across women in the entire reproduction age, we repeated the LCA with a different study population consisting of all women between 19 and 44 years old.

Regression analysis

We studied the association between class membership and adverse outcomes by means of unadjusted logistic regression analysis. Results are reported as odds ratios (ORs) with 95% confidence interval (CI). A p -value of <0.05 was considered statistically significant.

RESULTS

The study population consisted of 4172 women, of whom 1129 had missing data (Table 1). A five-class model was considered best (see Appendix 3 for fit-indices). The aBIC reached a minimum in the 12-class model, but did not show considerable improvement after models beyond seven classes when reviewing the relative fit (elbow shape). The AIC continuously decreased as expected. Entropy values were regarded best for models with two to five classes. We compared the interpretation of models with four, five and six classes and chose the five-class model for its interpretative and distinctive classes.

Table 1. Characteristics of the study population (including missing data)

		n (%)
Individual characteristics		
Age	19-23	306 (7.3)
	24-35	3528 (84.6)
	>35	338 (8.1)
Ethnicity	Non-Western	420 (10.1)
	Western	343 (8.2)
	Native Dutch	3409 (81.7)
Parity*	Nullipara	1755 (42.1)
	Primipara, multipara	2410 (57.8)
	Missing	<10 (<0.2)
Asylum seeker status	Yes	39 (0.9)
	No	4133 (99.1)
Socioeconomic characteristics		
Educational level	Low	328 (7.9)
	Moderate	1513 (36.3)
	High	2303 (55.2)
	Missing	28 (0.7)
Household income	Low	202 (4.8)
	Moderate	3348 (80.2)
	High	591 (14.2)
	Missing	31 (0.7)
Socioeconomic position	No income/ receiving benefits	532 (12.8)
	Student	82 (2.0)
	Paid work	3502 (83.9)
	Missing	56 (1.3)
Debts and payment arrears	Yes	45 (1.1)
	No	4127 (98.9)
Insufficient financial resources	Yes	524 (12.6)
	No	3267 (78.3)
	Missing	381 (9.1)
Permanent contract	No	1929 (46.2)
	Yes	2243 (53.8)
Full-time contract	No	1925 (46.1)
	Yes	2247 (53.9)
Lifestyle factors		
Smoking	Yes	661 (15.8)
	No	3315 (79.5)
	Missing	196 (4.7)
Alcohol use	Yes (excessive)	418 (10.0)
	No	3503 (84.0)
	Missing	251 (6.0)
Physical activity	Less than recommended	1696 (40.7)
	As recommended or more	2158 (51.7)
	Missing	318 (7.6)
Body Mass Index (BMI)	Unhealthy BMI	1386 (33.2)
	Healthy BMI	2641 (63.3)
	Missing	145 (3.5)
Household characteristics		
Type of household	One-person/ parent household	353 (8.5)
	Other	3819 (91.5)
Marital status	Unmarried	2147 (51.5)
	Married	2025 (48.5)
Dissolution of marriage	Yes	58 (1.4)
	No	4114 (98.6)

Table 1. Continued.

		n (%)
Household size	≥6 persons	93 (2.2)
	<6 persons	4079 (97.8)
Youth support uptake	Yes	102 (2.4)
	No	4070 (97.6)
Self-reported health		
Perceived health status	Negative	465 (11.1)
	Positive	3653 (87.6)
	Missing	54 (1.3)
Long-term illness	Yes	747 (17.9)
	No	3362 (80.6)
	Missing	63 (1.5)
Restricted by health	Yes	724 (17.4)
	No	3330 (79.8)
	Missing	118 (2.8)
Healthcare expenditures and utilization		
Overall healthcare expenditures	High	824 (19.8)
	Low-average	3297 (79.0)
	Missing	51 (1.2)
General practitioners' (GP) expenditures	High	827 (19.8)
	Low-average	3308 (79.3)
	Missing	37 (0.9)
Hospital expenditures	High	413 (9.9)
	Low or none	3708 (88.9)
	Missing	51 (1.2)
Medication use	High	428 (10.3)
	Low or none	3744 (89.7)
Addiction related care uptake	Yes	23 (0.6)
	No	4149 (99.4)
Psychosocial characteristics		
Mental healthcare uptake	Yes	228 (5.5)
	No	3907 (93.6)
	Missing	37 (0.9)
Risk of depression or anxiety disorders	Moderate – high risk	1716 (41.1)
	No or low risk	2256 (54.1)
	Missing	200 (4.8)
Loneliness	Feeling lonely	1100 (26.4)
	Not feeling lonely	2719 (65.2)
	Missing	353 (8.5)
Feelings of control over life	Low	144 (3.5)
	Moderate	2741 (65.7)
	High	1006 (24.1)
	Missing	281 (6.7)
Mild intellectual disability	Yes	13 (0.3)
	No	4159 (99.7)
Life-events		
Crime suspect	Yes	95 (2.3)
	No	4077 (97.7)
Crime victim	Yes	874 (20.9)
	No	3298 (79.1)
Having been detained*	Yes	not shown
	No	not shown
History of frequent moving	Yes	1250 (30.0)
	No	2900 (69.5)
	Missing	22 (0.5)

Table 1. Continued.

		n (%)
Loss of a family member	Yes	147 (3.5)
	No	4025 (96.5)
Living conditions		
Home ownership	Rented	990 (23.7)
	Owner occupied	3099 (74.3)
	<i>Missing</i>	83 (2.0)
Motorized vehicle ownership	No	494 (11.8)
	Yes	3678 (88.2)
Proximity to general practitioners' (GP) office	>3 km	265 (6.4)
	<3 km	3847 (92.2)
	<i>Missing</i>	60 (1.4)
Liveability neighbourhood	Low-mediocre	273 (6.5)
	High	3695 (88.6)
	<i>Missing</i>	204 (4.9)
Outcomes		
Preterm birth	Yes	277 (6.6)
	No	3895 (93.4)
Small for gestational age (SGA)	Yes	324 (7.8)
	No	3814 (91.4)
	<i>Missing</i>	25 (0.6)
Preterm birth and/or SGA	Yes	557 (13.4)
	No	3590 (86.0)
Admission to neonatal intensive care unit (NICU)	Yes	130 (3.1)
	No	4042 (96.9)
Primary caesarean section	Yes	318 (7.6)
	No	3854 (92.4)
Secondary caesarean section	Yes	303 (7.3)
	No	3869 (92.7)
Pre-eclampsia/hypertension	Yes	250 (6.0)
	No	3922 (94.0)
Postpartum haemorrhage	Yes	265 (6.4)
	No	3907 (93.6)
No postpartum care (at home)	No postpartum care	258 (6.2)
	Postpartum care	3914 (93.8)
No antenatal care before week 10	No antenatal care before week 10	563 (13.5)
	Antenatal care before week 10	3236 (77.6)
	<i>Missing</i>	373 (8.9)

* Following guidelines of Statistics Netherlands, the data of some variables were rounded (parity) or not shown (having been detained) to prevent disclosure of information about individuals. Detailed definitions of variables and categories are provided in Appendix 1. Missing data are shown in italic.

The five-class model divided the study population into one class characterized by vulnerability in various domains, three classes characterized by vulnerability predominantly in one specific domain and one class with mainly protective factors (see Table 2 for all class proportions and characteristics). Figure 1 provides a visual representation.

Table 2. Class proportions and descriptives of the final 5-class model

Class		1	2	3	4	5
Label		Multi-dimensional vulnerability	High care utilization	Socio-economic vulnerability	Psycho-social vulnerability	Healthy and socio-economically stable
Class proportions		0.06 (n=250)	0.11 (n=485)	0.09 (n=395)	0.24 (n=1005)	0.49 (n=2040)
Individual characteristics						
Age	19-23	0.14	0.03	0.16	0.13	0.03
	24-35	0.74	0.84	0.75	0.76	0.92
	>35	0.12	0.13	0.09	0.10	0.05
Ethnicity	Non-Western	0.26	0.02	0.44	0.13	0.02
	Western	0.06	0.08	0.13	0.11	0.06
	Native Dutch	0.68	0.90	0.43	0.76	0.91
Parity	Nullipara	0.38	0.39	0.23	0.55	0.41
	Primipara, multipara	0.60	0.61	0.77	0.45	0.59
Asylum seeker status	Yes	0.00	0.00	0.09	0.00	0.00
	No	0.98	1.00	0.91	1.00	1.00
Socioeconomic characteristics						
Educational level	Low	0.30	0.04	0.30	0.09	0.01
	Moderate	0.54	0.31	0.39	0.50	0.29
	High	0.16	0.65	0.30	0.41	0.70
Household income	Low	0.16	0.00	0.30	0.05	0.00
	Moderate	0.82	0.75	0.66	0.90	0.80
	High	0.00	0.25	0.03	0.05	0.20
Socioeconomic position	No income/receiving benefits	0.62	0.03	0.87	0.00	0.02
	Student	0.06	0.00	0.06	0.04	0.00
	Paid work	0.30	0.97	0.06	0.96	0.98
Debts and payment arrears	Yes	0.12	0.00	0.03	0.00	0.00
	No	0.88	1.00	0.97	1.00	1.00
Insufficient financial resources	Yes	0.60	0.07	0.35	0.27	0.02
	No	0.38	0.93	0.65	0.73	0.98
Permanent contract	No	0.92	0.32	0.99	0.45	0.34
	Yes	0.08	0.68	0.01	0.55	0.66
Full-time contract	No	0.74	0.45	0.96	0.31	0.40
	Yes	0.26	0.55	0.04	0.69	0.59
Lifestyle factors						
Smoking	Yes	0.36	0.16	0.14	0.25	0.12
	No	0.64	0.84	0.86	0.75	0.88
Alcohol use	Yes (excessive)	0.14	0.10	0.04	0.11	0.12
	No	0.86	0.90	0.96	0.89	0.88
Physical activity	Less than recommended	0.52	0.47	0.48	0.45	0.42
	As recommended or more	0.48	0.54	0.52	0.55	0.58
Body Mass Index (BMI)	Unhealthy BMI	0.64	0.30	0.49	0.42	0.26
	Healthy BMI	0.36	0.70	0.51	0.58	0.74
Household characteristics						
Type of household	One-person/parent household	0.38	0.03	0.10	0.15	0.03
	Other	0.62	0.97	0.90	0.85	0.97
Marital status	Unmarried	0.66	0.45	0.30	0.47	0.46
	Married	0.34	0.55	0.70	0.42	0.54

Table 2. Continued.

	Class	1	2	3	4	5
	Label	Multi-dimensional vulnerability	High care utilization	Socio-economic vulnerability	Psycho-social vulnerability	Healthy and socio-economically stable
	Class proportions	0.06 (n=250)	0.11 (n=485)	0.09 (n=395)	0.24 (n=1005)	0.49 (n=2040)
Dissolution of marriage	Yes	0.08	0.02	0.00	0.02	0.00
	No	0.92	0.99	1.00	0.98	1.00
Household size	≥6 persons	0.04	0.02	0.10	0.01	0.01
	<6 persons	0.96	0.98	0.90	0.98	0.99
Youth support uptake	Yes	0.18	0.01	0.04	0.03	0.00
	No	0.80	0.99	0.96	0.97	1.00
Self-reported health						
Perceived health status	Negative	0.70	0.12	0.10	0.20	0.00
	Positive	0.30	0.88	0.90	0.80	1.00
Long-term illness	Yes	0.68	0.32	0.09	0.28	0.06
	No	0.32	0.68	0.91	0.72	0.94
Restricted by health	Yes	0.76	0.28	0.16	0.29	0.04
	No	0.24	0.72	0.84	0.71	0.96
Healthcare expenditures and utilization						
Overall healthcare expenditures	High	0.66	1.00	0.16	0.05	0.04
	Low-average	0.34	0.00	0.84	0.95	0.96
General practitioners' (GP) expenditures	High	0.68	0.33	0.23	0.21	0.10
	Low-average	0.30	0.67	0.77	0.79	0.90
Hospital expenditures	High	0.30	0.69	0.08	0.00	0.00
	Low or none	0.70	0.31	0.92	1.00	1.00
Medication use	High	0.54	0.23	0.06	0.10	0.03
	Low or none	0.46	0.77	0.94	0.90	0.97
Addiction related care uptake	Yes	0.06	0.00	0.00	0.00	0.00
	No	0.94	1.00	1.00	0.99	1.00
Psychosocial characteristics						
Mental healthcare uptake	Yes	0.32	0.12	0.01	0.06	0.01
	No	0.68	0.88	0.99	0.94	0.99
Risk of depression or anxiety disorders	Moderate – high risk	0.86	0.46	0.56	0.71	0.21
	No or low risk	0.12	0.54	0.44	0.28	0.79
Loneliness	Feeling lonely	0.68	0.22	0.56	0.57	0.14
	Not feeling lonely	0.32	0.78	0.44	0.43	0.86
Feelings of control over life	Low	0.24	0.03	0.11	0.10	0.00
	Moderate	0.72	0.75	0.76	0.81	0.63
	High	0.02	0.22	0.13	0.09	0.37
Mild intellectual disability	Yes	0.02	0.00	0.01	0.00	0.00
	No	0.98	1.00	0.99	1.00	1.00
Life-events						
Crime suspect	Yes	0.14	0.01	0.03	0.03	0.01
	No	0.86	0.99	0.97	0.97	0.99
Crime victim	Yes	0.34	0.24	0.11	0.23	0.20
	No	0.66	0.77	0.89	0.77	0.80
Having been detained	Yes	0.02	0.00	0.00	0.00	0.00
	No	0.98	1.00	1.00	1.00	1.00
History of frequent moving	Yes	0.42	0.36	0.20	0.30	0.29
	No	0.56	0.64	0.80	0.70	0.71

Table 2. Continued.

Class		1	2	3	4	5
Label		Multi-dimensional vulnerability	High care utilization	Socio-economic vulnerability	Psycho-social vulnerability	Healthy and socio-economically stable
Class proportions		0.06 (n=250)	0.11 (n=485)	0.09 (n=395)	0.24 (n=1005)	0.49 (n=2040)
Loss of a family member	Yes	<i>0.06</i>	0.05	0.01	0.03	0.03
	No	0.92	0.96	<i>0.99</i>	0.97	0.97
Living conditions						
Home ownership	Rented	0.64	0.10	0.58	0.36	0.10
	Owner occupied	0.34	<i>0.90</i>	0.42	0.64	<i>0.90</i>
Motorized vehicle ownership	No	0.32	0.07	0.29	0.13	0.06
	Yes	0.66	0.93	0.71	0.87	<i>0.94</i>
Proximity to general practitioners' (GP) office	>3 km	0.02	<i>0.08</i>	0.05	0.04	<i>0.08</i>
	<3 km	<i>0.98</i>	0.92	0.95	0.96	0.92
Liveability neighbourhood	Low-mediocre	0.18	0.03	<i>0.22</i>	0.09	0.03
	High	0.82	<i>0.97</i>	0.78	0.91	<i>0.97</i>

Proportions of risk factors (first category) >0.6 are shown in bold to indicate the higher occurrence of certain risk factors per class. For each category, the class with the highest proportion is shown in italic. Totals may not add up to 1.0 because of rounding. Following guidelines of Statistics Netherlands, the observed numbers in each category were rounded to five before calculating proportions in order to prevent the disclosure of information about individuals.

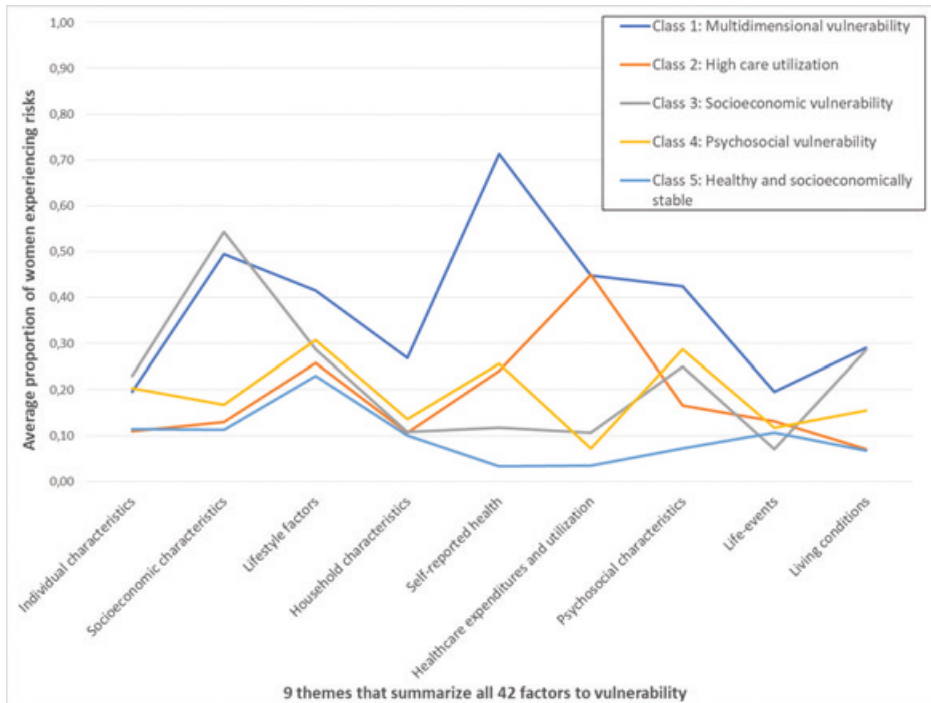


Figure 1. A visual representation of the five latent classes, described across the nine themes that summarize all 42 factors related to vulnerability. The vertical axis displays for each theme the average proportion of women within the categories that represent the risk factors (each first category in Table 2). A higher score means that a higher proportion of women in a class have risk factors to vulnerability. An example: the theme 'self-reported health' consists of three factors: perceived health, long-term illness and restriction by health. For Class 1 (multidimensional vulnerability), the average proportion of women with a negative perceived health (0.7), long-term illness (0.68) and feelings of being restricted by health (0.76), is 0.71. This average proportion is displayed.

Class 1 ($n = 250$; 6.0%), was characterized by high proportions of almost all risk factors to vulnerability. Women in this class were likely to receive social benefits or to have no income (proportion of 0.62) and to live in a rented house (0.65). Related to health, Class 1 was characterized by high GP healthcare expenditures (0.67), long-term illness (0.68) and negative perceptions of health (0.70). These women had a high probability of feeling lonely (0.87) and a moderate to high risk of depression or anxiety (0.87). Considering the vulnerabilities in different areas (including psychosocial, medical and socioeconomic risk factors), Class 1 was named 'multidimensional vulnerability'.

Class 2 ($n = 485$; 11.6%) was characterized by high healthcare expenditures. All women classified in this class had total healthcare expenditures in the highest quintile. Also, they frequently experienced high hospital care expenditures (0.69). Simultaneously, women in this class were likely to have protective factors including a healthy BMI (0.68), positive perception of health (0.87), high educational level (0.65), paid work (0.96), low probability of

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feeling lonely (0.78) and an owner-occupied house (0.90). Based on the dominant features, Class 2 was named 'high care utilization'.

Class 3 (n = 395; 9.5%) was characterized in particular by high proportions of socioeconomic risk factors. Women in this class were likely to receive social benefits or have no income prior to pregnancy (0.87). They frequently lived in a rented house (0.58), had a non-Dutch background (0.56) and a low (0.30) or moderate (0.39) educational level. The probability of living in a neighbourhood with a low liveability score was highest in this class (0.22). When considering protective factors, these women were often married (0.70), had a positive perception of health (0.90) and low healthcare expenditures (0.83). Class 3 was named 'socioeconomic vulnerability'.

Class 4 (n = 1005; 24%) was characterized by psychosocial health issues. The majority had a moderate to high risk of depression or anxiety disorders prior to pregnancy (0.71). These women were likely to feel lonely (0.57) and nullipara were overrepresented (0.55). Regarding protective factors, the majority had a full-time contract (0.69), an owner-occupied house (0.64) and no high healthcare expenditures (0.95). Class 4 was named 'psychosocial vulnerability'.

Class 5 (n = 2040; 48.9%) was characterized by women with low probabilities of all risk factors to vulnerability before pregnancy. Instead, in general, these women had a positively perceived health (1.00), did not feel lonely (0.86), had a high educational level (0.70) and paid work (0.98). Women in Class 5 had the highest probability to experience high control over life (0.37). Class 5 was named 'healthy and socioeconomically stable'.

The analyses in the two additional study populations (women who gave birth before and all women aged 19-44 years) showed similar results. The five-class model was preferred and classes could be interpreted similarly.

Figure 2 shows associations between classes and adverse outcomes. Class 5 (healthy and socioeconomically stable) was the reference-category. Women classified in Class 1 (multidimensional vulnerability) were more likely to have babies who were born prematurely, SGA or admitted to a NICU. These women were also more likely to have a caesarean section. There were no significant associations found for other maternal health outcomes including hypertension/pre-eclampsia and postpartum haemorrhage. Compared to Class 5 (healthy and socioeconomically stable), all other classes except Class 4 (psychosocial vulnerability) were more likely to not receive postpartum care (at home) and to not receive antenatal care on time. Adverse outcomes were quite similar in Class 2 (socioeconomic vulnerability) and Class 5 (healthy and socioeconomically stable), except from the odds of planned caesarean section. Appendix 4 shows prevalences of outcomes for each class.

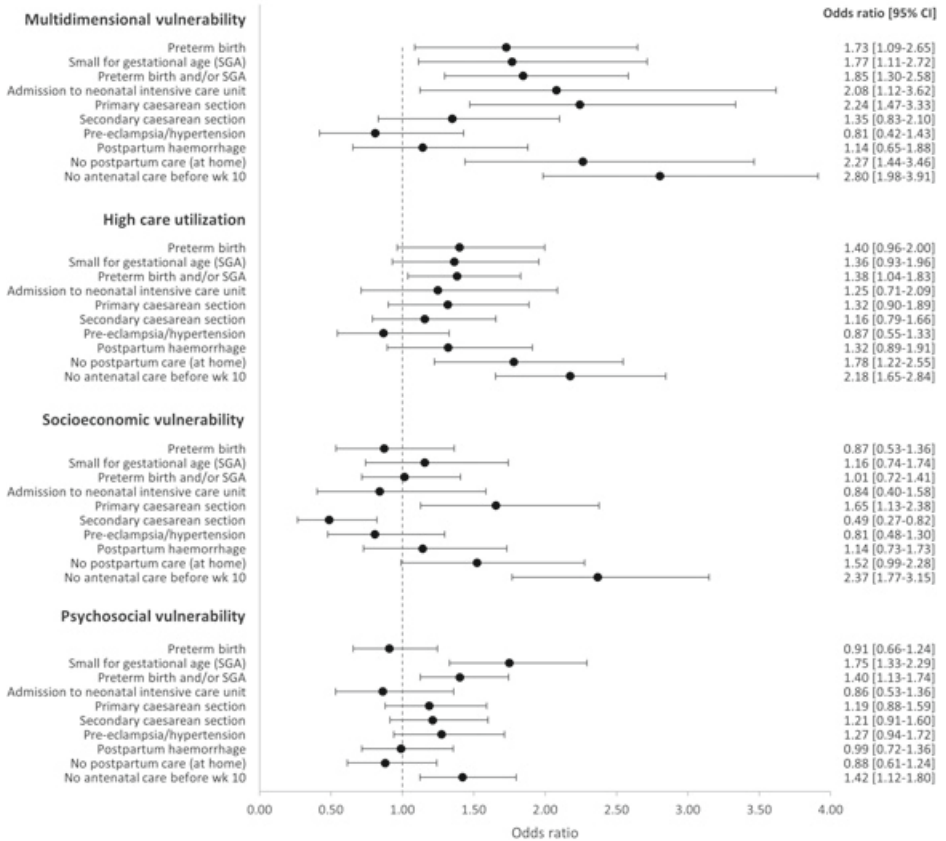


Figure 2. Likelihood of adverse perinatal and maternal health outcomes and healthcare utilization for four classes, compared to the reference-category 'healthy and socioeconomically stable'. The figure shows the OR and 95% CI (graphically and in text)

DISCUSSION

This study aimed to identify classes of vulnerability among pregnant women and to validate these classes by studying the association with adverse perinatal and maternal health outcomes and care utilization. The LCA procedure identified five classes with different combinations of risk and protective factors to vulnerability. Most women were classified into the 'healthy and socioeconomically stable' class with mainly protective factors. Women classified in the classes 'high care utilization', 'socioeconomic vulnerability' or 'psychosocial vulnerability' shared risk factors to vulnerability in one specific domain and protective factors in others. Women classified into the 'multidimensional vulnerability' class shared multiple risk factors in several domains (e.g., psychosocial, medical and socioeconomic) and were more likely to develop poor health outcomes such as premature birth, SGA, caesarean section and NICU admission.

Our study showed that multidimensional vulnerability leads to experiencing worse outcomes compared to vulnerability on a single domain or no vulnerabilities. This indicates the importance of co-existence or clustering of multiple risk factors (such as no income, high healthcare expenditures and feelings of loneliness) in increasing the probability of adverse outcomes for mother and child. Our findings strengthen results from previous studies that aimed to explain differences in adverse outcomes by interrelated individual or contextual risk factors (10, 11, 17). Previous LCA studies also led to classes of pregnant women with different health behaviours, psychosocial or socioeconomic characteristics that show differences in outcomes, although these studies included less factors and domains, and other populations in comparison to our study (17, 32, 33). The findings do not inform us on how risk factors interplay and lead to adverse health outcomes. The syndemic model provides a perspective on this interplay by describing how co-occurring health adversities are fuelled by different social and contextual factors that interact and increase the health burden of both mental and physical illness (34). This suggests the need to combine social and medical care and support, instead of focussing on the separate domains to combat multidimensional vulnerability.

We found that women with socioeconomic vulnerability generally did not experience worse outcomes. This finding is not in congruence with previous research indicating that adverse perinatal health outcomes are more prevalent among women with a low socioeconomic status (SES) (9, 10, 14). Previous studies often focussed on a limited number of risk factors or domains, or used more traditional (regression) techniques to study the relation between SES and outcomes. However, as the impact of risk factors can depend on other factors, it is important to step away from traditional independent 'ceteris paribus' linear effect assumption of social determinants. Therefore, we used LCA as analytical approach that considers the combination of both risk and protective factors, allowing a more comprehensive approach to study vulnerability. Protective factors (e.g. social support) can act as positive exposures or buffering mechanisms that promote resilience and improve health (3, 8, 35, 36). This indicates the importance of acknowledging both strengths and challenges in families to create a supportive environment for early development (37). Additionally, low SES may not necessarily be a risk factor for adverse outcomes unless it coincides with other hardships. The relation between SES and health can be described by processes such as social causation (adverse conditions of poverty impact health through, for example, stress and food insecurity) and health selection (people with worse physical or mental health outcomes fall into poverty through, for example, stigma, health expenditures and lower productivity) (38). This increases the importance for healthcare professionals to understand different domains of vulnerability and tailor the need for support to the individual (39, 40).

Our findings reveal a difference in care utilization patterns. The 'healthy and socioeconomically stable' class was most likely to receive early antenatal care and postpartum care (at home). This corresponds to findings of Grabovschi et al. (6) in their scoping review into vulnerability. People with higher vulnerability levels (i.e. multiple vulnerability aspects) have higher

healthcare needs, but less access to services and lower quality of healthcare. This raises questions about whether current support meets parents' needs.

The main strength of this study is that we linked routinely collected nationwide observational data sources to self-reported data on health, well-being and lifestyle. This offered the opportunity to include data on a wide range of medical and social factors for a large group of pregnant women to better understand vulnerability. While previous studies often had a unidimensional perspective to vulnerability (focussing on single risk factors such as individual SES, or neighbourhood SES on aggregated level), we could unravel the difference between unidimensional and multidimensional types of vulnerability due to our extensive dataset. Another strength is that we included protective factors, while most studies focus primarily on factors that increase the risk of adverse outcomes and less on protective factors that might counteract these effects (18, 19). Unfortunately, data on topics such as nutrition, stress, health literacy, preconception care and adverse childhood experiences were not available, while these factors could provide additional insights into vulnerability. Next, using largest posterior probability to assign women to classes is a limitation, because not all women are fully representative of one class only. Our study was moreover limited by not including the father or woman's partner, despite growing evidence of their importance in promoting healthy pregnancy, childbirth and child-outcomes. Another limitation relates to the representativeness of the study population due to using the PHM-2016. Compared to all other pregnant women in 2017/2018, women in our study less often had a low income (5% vs 8%), low educational level (8% vs 12%) and migration background (18% vs 32%). Since generally people with higher vulnerability less often participate in research, we assume that the size of the multidimensional vulnerability-class is an underestimation. Nevertheless, since we could identify classes of vulnerability and differentiate between single and multidimensional vulnerability, we expect that their characteristics are also applicable beyond the study population. Similar results from our additional analyses strengthen this expectation. Nevertheless, our approach and findings should be validated in other cohorts and countries and until then be interpreted with caution.

Our findings can have several implications for practice and research. We believe that screening instruments for vulnerability before and during pregnancy could benefit from including a balanced set of both risk and protective factors. In refining screening instruments, we have to consider the various criteria for responsible screening, such as the availability of associated care or support strategies (41). Greater consciousness among healthcare providers regarding the complexity of vulnerability in terms of risk and protective factors and personal perceptions could enhance the provision of person-centred care and support (6, 40, 42). Multiple studies argue that future strategies should also pay attention to underlying, root causes of vulnerability in policies, laws and governance (3, 15, 43). Advancing health equity requires both individual-level interventions targeted at vulnerable individuals as well as systemic-level change (3, 15, 43). Factors related to housing, education and social security for example, frequently lie upstream of individual lifestyle and behavioural factors modifiable through individual-level interventions. Findings of our study can be input for longitudinal monitoring of vulnerability at population level. Future

research is needed to identify if vulnerability classes can be identified using solely routinely collected population data, without using self-reported data. Additionally, more research is necessary regarding the role of the father or woman's partner in relation to vulnerability.

In conclusion, there is growing attention for early detection of vulnerability and implementing effective strategies to improve health and well-being of current and next generations. Results of this data-driven study suggest that several vulnerability classes can be distinguished among pregnant women in the Netherlands. The co-existence of risk factors in multiple domains leads to more adverse outcomes for mother and child. Effective strategies, starting preconceptionally, should include both medical and social care and support.

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Conflicts of interests: None declared

Data availability

We are unable to share the individual data used for this study as data linkage and analysis was conducted within the highly safeguarded Remote Access (RA) platform of Statistics Netherlands (23). All data within this platform are pseudonymised to ensure data safety and confidentiality. Access to the data from Perined, Vektis, Statistics Netherlands and the Public Health Monitor 2016 can be requested from the relevant parties.

Acknowledgements

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Key points

- Previous evidence supports the influence of social factors on maternal and perinatal health, but few studies consider the combination of different social risk and protective factors to vulnerability.
- Pre-pregnancy data of 4172 women on a wide range of social risk and protective factors to vulnerability were used to identify latent vulnerability classes.
- Five classes could be distinguished: multidimensional vulnerability, high care utilization, socioeconomic vulnerability, psychosocial vulnerability and a healthy and socioeconomically stable-class.
- Multidimensional vulnerability, characterized by experiencing risk factors in different domains and few protective factors, was associated with adverse outcomes for mother and child, while experiencing risk factors solely in one domain was not necessarily associated with adverse outcomes.
- Public health programmes should start preconceptionally, include both medical and social care and support, and be attentive to systemic causes of vulnerability

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APPENDIX 1.

Description of data sources, variables and outcomes included

Data sources

The Dutch Perinatal Registry Perined collects routine care data on pregnancy after 22 weeks of gestation, birth and the first 28 days after birth, as supplied by midwives, gynaecologists and paediatricians.¹ Perined includes data on type of care used and health outcomes of mother and child. From 2000 onwards, Perined contains data on 96 – 99% of all births.

Healthcare information centre Vektis collects claims data under the Dutch Healthcare Insurance Act and provides data on healthcare utilization and spending.² Data on 99% of the Dutch (insured) population is available. DIAPER contains detailed claims data of Vektis as available from 2015.

Statistics Netherlands collects and publishes data on societal matters and provides access to data through their System of Social Statistical Datasets (SSD).^{3,4} This linkable SSD-data covers nearly 20 themes, including health, welfare, income, education and labour. Data originate from various (governmental) organisations, including municipalities and the National Tax Authority.

We enriched DIAPER with self-reported data on health, well-being and lifestyle of the Public Health Monitor 2016 (PHM-2016). This is a health survey among a varying sample of the Dutch population aged 19 years and older, carried out every four years by the Community Health Services (GGD), Statistics Netherlands and the National Institute for Public Health and the Environment. The PHM-2016 had 457.153 participants and was mainly conducted from September-December 2016.

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Variables in LCA

Variable	Definition	Categories	Data source*
Individual characteristics			
Age	Age of the woman in categories, based on an increased risk for pregnancy complications related to age ^{5,6}	19– 23; 24 – 35; >35	SSD
Ethnicity	Migration status based on birthplace of parents, following categorization of Statistics Netherlands. ⁷ A person with a migration background is a person of whom at least one parent was born abroad	Non-Western; Western; Native Dutch	SSD
Parity	The number of times that a woman has given birth after a gestational period of 24 weeks or more: 0 times (nullipara), 1 time (primipara), 2 or more times (multipara)	Nullipara; primipara, multipara	Perined
Asylum seeker status	Registered as asylum seeker, status holder or refugee and included in the municipal population register	Yes; no	SSD
Socioeconomic characteristics			
Educational level	Highest completed education, according to the International Standard Classification of Education and following categorization of Statistics Netherlands ⁸	Low; moderate; high	PHM-2016 and SSD
Household income	Household income based on percentage groups of standardized disposable income of private households; low is <10 th percentile, moderate is 10 th – 90 th percentile and high is >90 th percentile	Low; moderate; high	SSD
Socioeconomic position	Source of income, if any	No income/ receiving benefits; student; paid work	SSD
Debts and payment arrears	Difficulty paying bills, based on registration of debt restructuring and/or delayed health insurance payments for more than six months	Yes; no	SSD
Insufficient financial resources**	Having insufficient means, based on the question: 'in the past 12 months, have you struggled to make ends meet on your household income?'	Yes; no	PHM-2016
Permanent contract	Having a permanent type of work contract	No; yes	SSD
Full-time contract	Being full-time employed	No; yes	SSD
Lifestyle factors			
Smoking**	Based on the question: 'do you ever smoke?'	Yes; no	PHM-2016
Alcohol use	Alcohol use, categorized as excessive based on the number of glasses of alcohol in a week (>7), following Dutch 'Guidelines for Good Nutrition' ⁹	Yes (excessive); no	PHM-2016

5 Londero, A.P., Rossetti, E., Pittini, C. et al. Maternal age and the risk of adverse pregnancy outcomes: a retrospective cohort study. *BMC Pregnancy Childbirth* 19, 261 (2019).

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9 Gezondheidsraad [Dutch Health Council]. Richtlijnen goede voeding 2006 [Guidelines good nutrition 2006]. Den Haag: Gezondheidsraad, 2006.

Variable	Definition	Categories	Data source*
Physical activity	Compliance with guidelines for physical activity (>150 minutes of moderate to vigorous intensive activities every week, as well as muscle and bone strengthening activities) as measured by the SQUASH-questionnaire ¹⁰	Less than recommended; as recommended or more	PHM-2016
Body Mass Index (BMI)	BMI based on height and weight. According to the International Obesity Task Force, BMI <15 is underweight, BMI 18,5 – 25 is normal weight and BMI ≥25 overweight ¹¹ . Underweight and overweight are categorized into 'unhealthy BMI'. Normal weight is categorized into 'healthy BMI'	Unhealthy BMI; healthy BMI	PHM-2016
Household characteristics			
Type of household	Type of household was categorized based on registrations of persons living at the same home address. Women without a registered partner were classified as a one-person household (without children) or a one-parent household (with children). All other types were categorized into 'other'	One-person/parent household; other	SSD
Marital status	Marital status of the woman	Unmarried; married	SSD
Dissolution of marriage***	Having been divorced [2012-2016]	Yes; no	SSD
Household size	Number of persons registered at the same home address	≥6 persons; <6 persons	SSD
Youth support uptake***	Previously received youth support for children within the family [2015-2016]	Yes; no	SSD
Self-reported health			
Perceived health status	Based on the question: 'how is your health in general?' and categorized into negative (very bad or bad) and positive (very good, good or moderate)	Negative; positive	PHM-2016
Long-term illness	Based on the question: 'do you have one or more long-term (≥ 6 months) illnesses or disorders?'	Yes; no	PHM-2016
Restricted by health	Based on the question 'to what extent have you been limited in activities due to health for the last 6 months or longer?' into yes (severely limited or limited) and no (not limited)	Yes; no	PHM-2016
Healthcare expenditures and utilization			
Overall healthcare expenditures	Total healthcare expenditures in 2016 subdivided into quintiles and divided into high (quintile 5) and low-average (quintile 1 to 4). In case a woman was pregnant in 2016, total healthcare expenditures of the previous year (2015 or 2014) were included	High; low-average	SSD (Vektis)
General practitioners' (GP) expenditures	GP expenditures in 2016 subdivided into quintiles and divided into high (quintile 5) and low-average (quintile 1 to 4)	High; low-average	SSD (Vektis)

10 Gezondheidsraad [Dutch Health Council]. Beweegrichtlijnen 2017 [exercise guidelines 2017]. Den Haag: Gezondheidsraad, 2017.

11 Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ*. 2000;320(7244):1240-3.

Variable	Definition	Categories	Data source*
Hospital expenditures	Hospital expenditures in 2016, categorized using a cut-off value corresponding to the highest 10% of expenditures among all women with hospital expenditures. In case a woman was pregnant in 2016, hospital expenditures of the previous year (2015 or 2014) were included, to avoid including pregnancy related health care costs	High; low or none	SSD (Vektis)
Medication use	Number of registered types of medication used in 2016 categorized into high (≥ 5 different types) and low (< 5) according to the most common definition of polypharmacy ¹²	High; low or none	SSD
Addiction related care uptake ***	The presence or history of a diagnosis-treatment combination for mental healthcare related to addiction [2011-2016]	Yes; no	SSD
Psychosocial characteristics			
Mental healthcare uptake	Expenditures that were made regarding mental healthcare services	Yes; no	SSD (Vektis)
Risk of depression or anxiety disorders**	Based on ten questions of the Kessler Psychological Distress scale ¹³ , categorized into moderate to high risk and no or low risk	Moderate-high risk; no or low risk	PHM-2016
Loneliness**	Based on 11 statements of the De Jong – Gierveld scale ¹⁴ , categorized into feeling lonely (moderate – severe) and not feeling lonely	Feeling lonely; not feeling lonely	PHM-2016
Feelings of control over life**	Based on seven statements ¹⁵ of the Pearlin Mastery scale and categorized into low (insufficient), moderate and high	Low; moderate; high	PHM-2016
Mild intellectual disability	Registered indication for a mild intellectual disability as recorded in data sources of occupational disabilities, sheltered employment and entitlement to the Long-Term care Act	Yes; no	SSD
Life-events			
Crime suspect***	Having been registered as a crime suspect [2009-2016]	Yes; no	SSD
Crime victim***	Having been a victim of a crime that was reported to the police [2011-2016]	Yes; no	SSD
Having been detained***	Having been detained [2004-2016]	Yes; no	SSD
History of frequent moving	A change of registered home address of more than five times in the past five years	Yes; no	SSD
Loss of a family member***	Loss of a parent and/or child [2011-2016]	Yes; no	SSD
Living conditions			
Home ownership	The home ownership of the woman's home address	Rented; owner-occupied	SSD
Motorized vehicle ownership	A registered motorized vehicle at the woman's home address, according to the Dutch vehicle registration authority	No; yes	SSD

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Defining vulnerability subgroups among pregnant women

Variable	Definition	Categories	Data source*
Proximity to GP office	Distance (by road) between registered home address and the nearest GP's office	>3 km; <3 km	SSD
Liveability neighbourhood	According to the Dutch Leefbaarometer ¹⁶ , based on various elements including housing characteristics, residents, distance to services, safety and physical environment	Low-mediocre; high	SSD

* SSD and Perined are nationwide observational data sources, the Public Health Monitor 2016 (PHM-2016) contains self-reported data.

** The data of the PHM-2016 is collected through a combination of the regular Health Survey of Statistics Netherlands (98% of the study population) and the health surveys of the Municipal Health Services (2% of the study population). The variables indicated by the asterisks were not included in the regular Health Survey of Statistics Netherlands.

*** The number of included years was based on data-availability, which varied per item.

Outcomes

Outcome	Definition	Categories	Data source
Preterm birth	Birth occurring from 24 weeks of gestation and before 37 weeks of gestation	Yes; no	Perined
Small for gestational age (SGA)	Birth weight below 10th percentile, corrected for gestational age and fetal sex ¹⁷	Yes; no	Perined
Preterm birth and/or SGA	Baby born prematurely and/or SGA, following definitions above	Yes; no	Perined
Admission to neonatal intensive-care unit (NICU)	Admission to the Neonatal Intensive Care Unit after birth	Yes; no	Perined
Primary caesarean section	Birth by caesarean section, decision taken before the start of birth	Yes; no	Perined
Secondary caesarean section	Birth by caesarean section, decision taken during birth	Yes; no	Perined
Pre-eclampsia/hypertension	Having pre-eclampsia or maternal hypertension (high blood pressure), chronic or pregnancy induced	Yes; no	Perined
Postpartum haemorrhage	Heavy bleeding after birth (>1000 ml blood loss)	Yes; no	Perined
No postpartum care (at home)	Woman does not receive postpartum care at home by a maternity care assistant ¹⁸	No postpartum care; postpartum care	Vektis
No antenatal care before week 10	Not having the first antenatal care appointment (i.e., booking visit) before the 10th week of pregnancy	No antenatal care before week 10; antenatal care before week 10	Perined

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APPENDIX 2.

Details on the multiple imputation process

The missing data (range missing values per variable: 0 to 9.1%) for the latent class analysis were imputed using multiple imputation¹⁹. We created five imputed datasets in R through the package Multiple Imputation using Chained Equations (MICE)²⁰. Model development was done in each set and the outcomes were compared. The outcomes were highly similar: they led to the same conclusions for both fit-statistics and class-specific probabilities. Subsequent analyses and the presentation of results was done for one randomly chosen imputed dataset.

	Multiple Imputation
Software used	R version 3.6.2
Imputation method and key settings	Fully conditional specification (package mice version 3.13.0); maximum iterations: 5
Number of imputed datasets created	5
Analyses variables	Age; Ethnicity; Parity; Asylum seeker status; Educational level; Household income; Socioeconomic position; Debts or payment arrears; Insufficient financial resources*; Permanent contract; Full-time employment; Smoking*; Alcohol use; Physical activity; Body Mass Index (BMI); Type of household; Marital status; Dissolution of marriage; Household size; Youth support; Perceived health status; Long-term illness; Restricted by health; Total healthcare expenditures; General Practitioners' expenditures; Hospital expenditures; Medication use; Addiction related care uptake; Risk of depression or anxiety disorders*; Loneliness*; Feelings of control over life*; Mental healthcare use; Mild intellectual disability; Crime suspect; Crime victim; Having been detained; Frequent moving; Loss of a family member; Home ownership; Motorized vehicle ownership; Proximity to the GP's office; Liveability of the neighbourhood
Auxiliary variables	11 variables for loneliness (statements + sum scores); 9 variables for control over life (statements + sum scores); 11 variables for depression or anxiety disorders (statements + sum scores); 2 variables for alcohol use; language of questionnaire; 7 variables for noise nuisance; 2 variables for socioeconomic status; 3 variables for crime victim; 2 variables for addiction related care uptake; 2 variables for loss of family member; 2 variables for insufficient financial resources; number of movements; number of life-events.
Treatment of continuous data	Predictive mean matching
Treatment of binary data	Logistic regression
Treatment of unordered categorical data	Polytomous logistic regression
Population	For the imputation we used additional data from the Public Health Monitor 2016 and Statistics Netherlands (SSD). There were 3043 complete cases and 1129 women with missing data. These women mostly had missing data on one variable (n = 641).

* The data of the Public Health Monitor 2016 is collected through a combination of the regular Health Survey of Statistics Netherlands (98% of the study population) and the health surveys of the Municipal Health Services (2% of the study population). The variables indicated by the asterisks were not included in the regular Health Survey of Statistics Netherlands and thus contain missing values.

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APPENDIX 3.

Fit results of LCA model with increasing number of classes

Model*	Akaike Information Criterion (AIC)	Relative decrease AIC	Size adjusted Bayesian Information Criterion (aBIC)	Relative decrease aBIC	Bayesian Information Criterion (BIC)	Relative decrease BIC	Entropy
Model 1	144228.5	NA	144380.1	NA	144532.6	NA	NA
Model 2	137476.2	-0.047	137782.5	-0.046	138090.8	-0.045	0.807
Model 3	135647.8	-0.013	136108.9	-0.012	136572.8	-0.011	0.781
Model 4	134443.5	-0.009	135059.5	-0.008	135679.1	-0.007	0.803
Model 5	133396.3	-0.008	134167	-0.007	134942.3	-0.005	0.784
Model 6	132491.5	-0.007	133417	-0.006	134348	-0.004	0.771
Model 7	131736.2	-0.006	132816.5	-0.005	133903.2	-0.003	0.774
Model 8	131271.7	-0.004	132817	-0.002	133749.1	-0.001	0.680
Model 9	130858.8	-0.003	132506.7	-0.002	133646.7	-0.001	0.757
Model 10	130494.3	-0.003	132248.6	-0.002	133592.7	0	0.645
Model 11	130226.1	-0.002	132038.8	-0.002	133635	0	0.625
Model 12	130006.5	-0.002	131925.4	0	133725.8	0.001	0.537
Model 13	129830.9	-0.001	131860.6	0	133860.7	0.001	0.524
Model 14	129699.4	-0.001	131863	0	134039.7	0.001	0.531
Model 15	129599.9	-0.001	131918.3	0	134250.7	0.002	NA

*The model number reflects the number of classes included in each model. For example, model 5 reflects a model with 5 classes.

APPENDIX 4.

Prevalence of outcomes for the five latent classes

	Multi-dimensional vulnerability	High care utilization	Socio-economic vulnerability	Psycho-social vulnerability	Healthy and socio-economically stable
Preterm birth	10.4%	8.6%	5.6%	5.8%	6.3%
Small for gestational age (SGA)	10.5%	8.3%	7.1%	10.4%	6.2%
Preterm birth and/or SGA	19.4%	15.3%	11.7%	15.5%	11.6%
Admission to neonatal intensive care unit	6.0%	3.7%	2.5%	2.6%	3.0%
Primary caesarean section	13.3%	8.2%	10.1%	7.5%	6.4%
Secondary caesarean section	9.2%	8.0%	3.5%	8.4%	7.0%
Pre-eclampsia/hypertension	4.8%	5.1%	4.8%	7.4%	5.9%
Postpartum haemorrhage	6.8%	7.8%	6.8%	6.0%	6.0%
No postpartum care (at home)	11.2%	9.1%	7.8%	4.7%	5.3%
No antenatal care before week 10	25.3%	20.9%	22.3%	14.7%	10.8%