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Disparities in spatiotemporal clustering of maternal mental health conditions before and during the COVID-19 pandemic

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ABSTRACT

Mounting evidence indicates the worsening of maternal mental health conditions during the COVID-19 pandemic. Mental health conditions are the leading cause of preventable death during the perinatal and postpartum periods. Our study sought to detect space-time patterns in the distribution of maternal mental health conditions in pregnant women before (2016–2019) and during (2020–2021) the COVID-19 pandemic in North Carolina, USA. Using the space-time Poisson model in SaTScan, we performed univariate and multivariate cluster analysis of emergency department (ED) visits for perinatal mood and anxiety disorders (PMAD), severe mental illness (SMI), maternal mental disorders of pregnancy (MDP), suicidal thoughts, and suicide attempts during the pre-pandemic and pandemic periods. Clusters were adjusted for age, race, and insurance type. Significant multivariate and univariate PMAD, SMI, and MDP clustering persisted across both periods in North Carolina, while univariate clustering for both suicide outcomes decreased during the pandemic. Local relative risk (RR) for all conditions increased drastically in select locations. The number of zip code tabulation areas (ZCTAs) included in clusters decreased, while the proportion of urban locations included in clusters increased for non-suicide outcomes. Average yearly case counts for all maternal mental health outcomes increased during the pandemic. Results provide contextual and spatial information concerning at-risk maternal populations with a high burden of perinatal mental health disorders before and during the pandemic and emphasize the necessity of urgent and targeted expansion of mental health resources in select communities.

1. Introduction

Mental health conditions are the leading cause of preventable pregnancy-related deaths, affecting up to 20% of pregnant people (CDC, 2023; Trost et al., 2021). Poor mental health during pregnancy increases the likelihood of adverse maternal and obstetric outcomes, including preterm labor, hypertension, postpartum mental health conditions, and long-term health consequences (Cox et al., 2016; Franks et al., 2017; Griffen et al., 2021; Watson et al., 2019). Infants born to birthing people with untreated mental health disorders are at a higher risk for low birth weight and sustained neurodevelopmental and behavioral problems in childhood and adolescence (Cox et al., 2016; Franks et al., 2017; Margiotta et al., 2022; Watson et al., 2019). The onset of the COVID-19 pandemic exacerbated existing challenges within the U.S. healthcare system, including staffing shortages, health outcome disparities, healthcare access, and growing numbers of permanent maternity ward closures (Li et al., 2023). A growing prevalence of mental health conditions during the pandemic (Bourmistrova et al., 2022; Ryan et al., 2023) increased the demand for mental health services in the United States, including among pregnant and postpartum populations (Byrne et al., 2021; Brunier and Drysdale, 2022). The redirection of resources toward COVID-19 response efforts led to reductions in nonemergency medical care, including routine perinatal and postpartum care (Birkmeyer et al., 2020; Covid-19 and the Upcoming Financial Crisis in Health Care | NEJM Catalyst., 2020; Li et al., 2023). Interruptions in maternity care during the pandemic have been linked to adverse birth outcomes and maternal health complications, including mental health challenges (Arzamani et al., 2022). The implementation of social distancing requirements and stay-at-home mandates beginning in March 2020 by federal, state, and local agencies further complicated maternity care in North Carolina (Governor Cooper Announces Statewide Stay at Home Order Until April 29 | NCDHHS., 2020). Statewide restrictions

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were largely lifted by May of 2021, but select municipalities in North Carolina (NC) continued to implement restrictions on gatherings, schools, and businesses (Governor Cooper Lifts North Carolina's COVID-19 State of Emergency | NC Gov. Cooper., 2022). NC hospital systems further restricted visitors for births to just one per labor to protect against the spread of COVID-19 (Novant restricts birth, labor visitor limits amid COVID-19 | Charlotte Observer., 2020). This interruption in social support, while implemented to control the spread of a deadly virus, has been attributed to increased adverse mental health impacts among pregnant and birthing people (Al-Mutawtah et al., 2023; Tania et al., 2023).

Research published in early 2020 anticipated increased negative mental health consequences among pregnant and postpartum populations worldwide (Almeida et al., 2020; Hessami et al., 2022; Davenport et al., 2020; Kotlar et al., 2021; Kinser et al., 2021), while subsequent research provided further insight into the full scope of maternal mental health challenges faced during the pandemic (Ahmad and Vismara, 2021; Chmielewska et al., 2021; Firestein et al., 2022; La Verde et al., 2021; Wall and Dempsey, 2023; Shuman et al., 2022). Emerging studies estimate that depression and anxiety affected as many as one in three pregnant or postpartum people worldwide during the pandemic (Caffieri et al., 2024; Mesquita et al., 2023; Smith et al., 2023; Wilson, 2022). Elevated prenatal stress during the pandemic (Preis et al., 2020) was associated with increased depression, anxiety, post-traumatic stress disorder, and suicidality among pregnant populations (Choi et al., 2020; Thapa et al., 2020). Multiple studies observed higher rates of maternal depression and anxiety during the pandemic (Chen et al., 2022; Davenport et al., 2020; Perzow et al., 2021; Suwalska et al., 2021; Ahmad and Vismara, 2021; Wall and Dempsey, 2023; Chmielewska et al., 2021; Safi-Keykaleh et al., 2022; Almeida et al., 2020; Basu et al., 2021), especially among those infected by the virus during pregnancy or the postpartum period, or who lived in close contact with someone infected (Usmani et al., 2021; Suwalska et al., 2021). Limited research also suggests that residence in rural areas is a risk factor for maternal depression during the pandemic (Bérard et al., 2022).

The pandemic exacerbated existing risk factors and structural barriers that contribute to the development of maternal mental health conditions, including logistical and financial challenges to accessing care (Chen et al., 2022; Griffen et al., 2021; Moore et al., 2021; Shidhaye et al., 2020; Preis et al., 2020); socioeconomic inequality (Griffen et al., 2021; Kendig et al., 2017; Moore et al., 2021; Weil, 2021; Trost et al., 2021); and a lack of social support and feelings of isolation or loneliness (Almeida et al., 2020; Suwalska et al., 2021; Ahmad and Vismara, 2021; Perzow et al., 2021; Chen et al., 2022; Basu et al., 2021). Disruption of daily life and routine, anxiety concerning infection risk, and interruptions in the provision of prenatal and postpartum care have been identified as predominant factors contributing to increased pandemic-related maternal mental health burdens (Preis et al., 2020; Shidhaye et al., 2020; Choi et al., 2020; Brooks, 2019; Byrne et al., 2021), particularly among minority and low-income populations (Masters et al., 2021; Shidhaye et al., 2020). Appointment cancellations, changes to birth plans, and difficulty accessing services are among the most frequently cited prenatal and postpartum care disruptions associated with worsening depression and anxiety symptoms (Hendrix et al., 2022; Brislane et al., 2021; Choi et al., 2020). Other studies showed that racially and ethnically diverse groups and low-income populations were more likely to experience pandemic-related changes to mental health care (Masters et al., 2021; Mi et al., 2022), which contributed to the observation of increased pandemic-related pregnancy stress, anxiety, and depression symptoms among women of color (Preis et al., 2020; Hendrix et al., 2022).

A significant research priority is understanding the geographic distribution of maternal mental health burdens among pregnant populations before and during the COVID-19 pandemic. Limited research has examined geographic differences in perinatal health (Harden et al., 2022), and few have examined perinatal mental health (Ulrich et al., 2023). The objective of this analysis was to examine the space-time clustering of five different maternal mental health conditions (Perinatal Mood and Anxiety Disorders, Suicidal Thoughts, Suicidal Attempts, Severe Maternal Illness, and Maternal Mental Disorders of Pregnancies) before (2016–2019) and during (2020–2021) the COVID-19 pandemic, using emergency department (ED) admissions in North Carolina, USA. Additional analysis examines changes in the rural, suburban, and urban distribution of cluster locations during the pre-pandemic and pandemic periods, and changes in the distribution of cases among age, race, ethnicity, and insurance categories. Cluster locations provide insight into the spatial distribution of heightened maternal mental health burdens at the community level before and during the pandemic. Locations identified within clusters should be prioritized for the expansion of maternal mental health care services and resources.

2. Methods

2.1. Emergency department visits during pregnancy

Maternal mental health conditions examined in this study include perinatal and postpartum mood and anxiety disorders (PMAD); maternal mental disorders of pregnancy (MDP); severe mental illness (SMI); and incidence of suicidal thoughts and suicide attempts among recorded emergency department (ED) visits for pregnant people in North Carolina from 2016 to 2021. Case counts in the data are recorded at the monthly level. All maternal mental health outcomes were defined using the International Classification of Disease (ICD) diagnosis and procedure codes, Tenth Revision, Clinical Modification (ICD-10-CM) (Supplemental Table 1). PMADs are all pre-existing mental health conditions that persist or recur during pregnancy, including anxiety and depression. MDP includes new or incident mental disorders that emerged during pregnancy. SMI encompasses mental, behavioral, or emotional disorders that cause substantial functional impairment and include bipolar and psychotic disorders (Montagnoli et al., 2021; Runkle et al., 2023).

2.2. Cluster analysis

We applied the space-time scan statistic to identify maternal mental health clusters, defined as locations with higher-than-expected incidence of one or more of our five outcomes in this study (Kulldorff 1997; Kulldorff, 1997). Our space-time analysis used the discrete Poisson model to identify geographic clusters of elevated risk for PMAD; MDP; SMI; suicidal thoughts; and suicide attempts before and during the pandemic across North Carolina (Fig. 1). Univariate cluster analysis considered each outcome individually, while multivariate cluster analysis examined the co-occurrence of all five outcomes. All clusters were calculated using a 10% at-risk window to allow for the identification of more localized clusters compared to SaTScan's default 50%. A 25% window was also tested and resulted in similar cluster locations. All clusters were calculated with a maximum cluster duration of 12 months and a minimum duration of one month. The case minimum was set at 10 for PMAD, MDP, SMI, and multivariate clusters, and two for suicidal thought and suicide attempt clusters. A maximum likelihood ratio test statistic was utilized to evaluate the null hypothesis of clusters reflecting an inhomogeneous Poisson process with an intensity proportional to the at-risk population, which is defined in Equation (1):

$$\frac{L(Z)}{L_0} = \frac{\left(\frac{y_Z}{E(Z)}\right)^{n_Z}\left(\frac{Y-y_Z}{Y-E(Z)}\right)^{Y-y_Z}}{\left(\frac{Y}{E(A)}\right)^{Y}} \quad (1)$$

Where L(Z) is the likelihood function for potential space-time cluster Z; L_0 is the likelihood function for the null hypothesis of potential space-

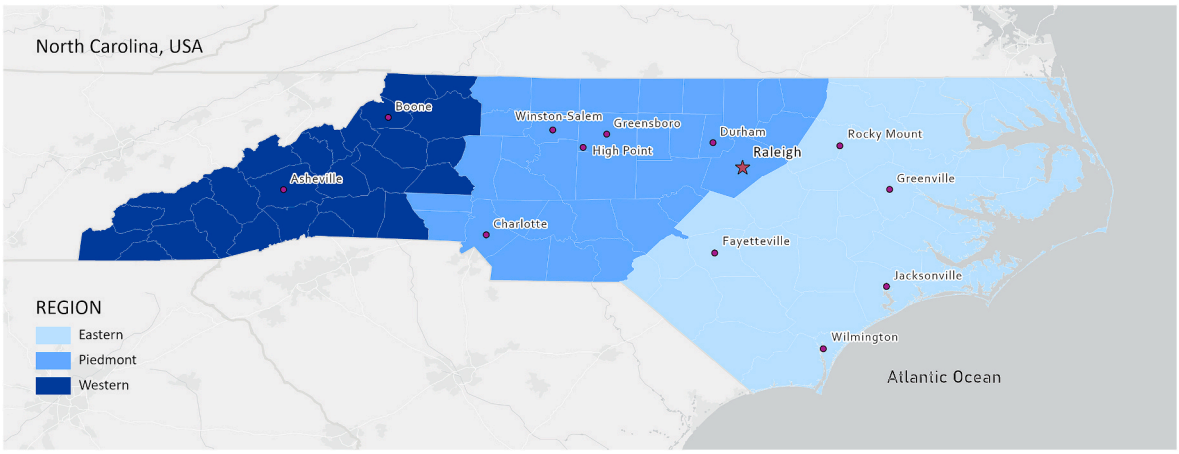

Fig. 1. North Carolina Study Area.

time cluster *Z*; parameter *yZ* is the observed cases in potential space-time cluster *Z*; *E*(Z) is the expected cases in potential space-time cluster *Z*; *Y* is the total number of observed cases in the study area across all time periods; and *E*(A) is the total number of expected cases in the study area across all time periods. The potential space-time clusters with a log-likelihood ratio (LLR) is > 1 are flagged as elevated risk of the mental health outcome under examination.

All clusters were then assessed for statistical significance using Monte Carlo simulations (n = 999) and the null hypothesis was rejected at $p < .05$. All analyses were implemented in SaTScan v10.1 software.

The default reporting in SaTScan produces primary and secondary high-risk clusters. Primary clusters have the highest log likelihood ratio, while secondary clusters are other high-risk cluster locations. Relative risk (RR) with the corresponding log-likelihood ratio test values are automatically calculated for each cluster (Cluster RR) and for each ZCTA (Local RR) in North Carolina. A RR < 1 is considered lower than expected risk, and a RR > 1 is considered greater than expected risk. All SaTScan analyses were adjusted for age, race, and insurance type using quasi-poisson regression-fitted values to derive the expected number of cases per ZCTA, described in Equations (2) and (3):

$$Y_{ij} \sim QuasiPoisson \tag{2}$$

$$\log\left[E\left(Y_{ij}\right)\right] = \beta_0 + \beta_1 Age_i + \beta_2 Race_i + \beta_3 Insurance_i \tag{3}$$

Where Yij is the observed mental health outcome count in ZCTA *i* and month *j*; and E(Yij) is the expected mental health outcome count in ZCTA *i* and month *j*; which was adjusted for age, race, and insurance type as noted in Equation (3).

This method controls for potentially confounding demographic and socioeconomic factors, thus identifying cluster locations that cannot be explained by age, race, or insurance type alone (Fontanella et al., 2018; Fonseca-Rodríguez et al., 2021).

Rural-urban commuting area (RUCA) codes were used to determine if the distribution of purely spatial clusters across rural, urban, or sub-urban areas shifted during the pandemic. We calculated the percent of ZCTAs identified in RUCA codes 1–3 (urban), 4–6 (suburban), and 7–10 (rural) (USDA ERS - Rural-Urban Commuting Area Codes).

The similarity between pre-pandemic (2016–2019) and pandemic (2020–2021) cluster locations was examined using the Rand index. A Rand index of 0 indicates no similarity between clusters, while 1 indicates perfect similarity between cluster locations during the pre-pandemic and pandemic periods. The Rand index was calculated using the 'fossil' package in RStudio version 4.3.1, and described in Equation (4):

$$R = \frac{a+b}{nC_2} \tag{4}$$

Where *a* is the number of times a pair of ZCTAs belong to a significant space-time cluster; *b* is the number of times a pair of ZCTAs belong to different space-time clusters; and nC_2 is the number of unordered pairs in a set of n ZCTAs. The percent change in ZCTA-level local relative risk from the pre-pandemic to the pandemic period was calculated for all outcomes.

3. Results

3.1. Descriptive statistics

Our sample comprised 387,449 North Carolina ED visits for pregnant persons from 2016 to 2019 (pre-pandemic period) and 203,332 from 2020 to 2021 (pandemic period). Case counts for all outcomes in both study periods are shown in Table 1. A large proportion of women who visited the ED for PMAD, MDP, SMI, suicidal thoughts, or suicide attempts were Medicaid beneficiaries and identified as white during both the pre-pandemic and the pandemic periods. Average yearly cases increased for all outcomes between the pre-pandemic and the pandemic periods, but the most substantial increases were observed for PMAD and SMI. The proportion of cases observed among Hispanic women, commercial insurance users, Medicaid beneficiaries, and women ages 30 to 39 increased across all outcomes during the pandemic period. Increases in the proportion of ED visits for all outcomes increased among commercial insurance users and were highest for PMAD (+14.5%) and MDP (+14.4%), while increases in ED visits for Medicaid beneficiaries were highest for suicidal thoughts (+7.7%) and SMI (+6.3%). Decreases in mental health-related ED visits for self-pay declined during the pandemic for all outcomes.

3.2. Multivariate clustering

Multivariate clusters are locations where case counts for all five maternal mental health outcomes (PMAD; MDP; SMI; suicidal thoughts; and suicide attempts) are greater than expected. Multivariate cluster locations are areas where maternal health burdens are the most severe and the risk for multiple maternal health outcomes is elevated. SaTScan detected space-time multivariate clusters for all mental health-related ED visits in the prenatal period during both pre-pandemic and pandemic periods (Tables 2 and 3; Fig. 2). During the pre-pandemic period, SaTScan detected a total of 16 multivariate clusters encompassing a total of 293 ZCTAs. A total of 279 of these ZCTA locations displayed RR > 1. Cluster duration varied, with most clusters persisting

Table 1
Emergency department visits summary of perinatal mood and anxiety disorder (PMAD), severe mental illness (SMI), maternal mental disorder of pregnancy (MDP), suicidal thought, and suicide attempt cases in North Carolina during the pre-pandemic (2016–2019) and post-pandemic (2020–2021) periods.

Strata		PMAD			SMI			MDP			Suicidal thoughts			Suicide attempts		
Period		Pre-Pandemic (2016–2019)	Pandemic (2020–2021)	p-value	Pre-Pandemic (2016–2019)	Pandemic (2020–2021)	p-value	Pre-Pandemic (2016–2019)	Pandemic (2020–2021)	p-value	Pre-Pandemic (2016–2019)	Pandemic (2020–2021)	p-value	Pre-Pandemic (2016–2019)	Pandemic (2020–2021)	p-value
n		23,950	15,271		5801	3260		19,721	13,916		1348	750		1728	920	
Average yearly cases		5988	7635	n.s.	1450	1630	n.s.	4818	6958	n.s.	337	375	n.s.	432	460	n.s.
Age (%)	18–29	15832 (66.1)	9275 (60.7)	***	4111 (70.9)	2110 (64.5)	***	13249 (67.2)	8614 (61.9)	***	1010 (74.9)	543 (72.4)	n.s.	1210 (70.0)	599 (65.1)	*
	30–39	7570 (31.6)	5612 (36.7)		1583 (27.3)	1086 (33.2)		6104 (31.0)	5003 (36.0)		314 (23.3)	200 (26.7)		475 (27.5)	296 (32.2)	
	40+	548 (2.3)	384 (2.5)		107 (1.8)	73 (2.2)		368 (1.9)	299 (2.1)		24 (1.8)	7 (0.9)		43 (2.5)	25 (2.7)	
Race (%)	Asian	105 (0.4)	107 (0.7)	***	17 (0.3)	13 (0.4)	***	83 (0.4)	91 (0.7)	***	18 (1.3)	9 (1.2)	n.s.	18 (1.0)	12 (1.3)	n.s.
	Black	7234 (30.2)	4362 (28.6)		2158 (37.2)	1322 (40.4)		6243 (31.7)	4169 (30.0)		601 (44.6)	309 (41.2)		663 (38.4)	357 (38.8)	
	Indigenous American	201 (0.8)	137 (0.9)		86 (1.5)	68 (2.1)		188 (1.0)	137 (1.0)		19 (1.4)	12 (1.6)		22 (1.3)	16 (1.7)	
	Native Hawiian/PI	10 (0.0)	21 (0.1)		1 (0.0)	11 (0.3)		8 (0.0)	27 (0.2)		0 (0)	2 (0.3)		0 (0)	2 (0.2)	
	Other*	1245 (5.2)	965 (6.3)		241 (4.2)	158 (4.8)		1030 (5.2)	864 (6.2)		95 (7.0)	71 (9.5)		135 (7.8)	81 (8.8)	
	Unknown	326 (1.4)	246 (1.6)		51 (0.9)	24 (0.7)		276 (1.4)	205 (1.5)		22 (1.6)	15 (2.0)		29 (1.7)	17 (1.8)	
	White	14829 (61.9)	9433 (61.8)		3247 (56.0)	1673 (51.2)		11893 (60.3)	8423 (60.5)		593 (44.0)	332 (44.3)		861 (49.8)	435 (47.3)	
Ethnicity (%)	Hispanic	1256 (5.2)	1106 (7.2)	***	213 (3.7)	163 (5.0)	***	997 (5.1)	966 (6.9)	***	76 (5.6)	69 (9.2)	**	127 (7.3)	100 (10.9)	***
	Non-Hispanic	22305 (93.1)	13895 (91.0)		5519 (95.1)	3047 (93.2)		18400 (93.3)	12694 (91.2)		1255 (93.1)	669 (89.2)		1579 (91.4)	797 (86.6)	
	Unknown	389 (1.6)	270 (1.8)		69 (1.2)	59 (1.8)		324 (1.6)	256 (1.8)		17 (1.3)	12 (1.6)		22 (1.3)	23 (2.5)	
Insurance	Commercial	5738 (24.2)	5869 (38.7)	***	713 (12.5)	581 (18.0)	***	4379 (22.4)	5065 (36.6)	***	207 (15.5)	154 (21.0)	***	357 (20.9)	256 (28.2)	***
	Other Gov't	514 (2.2)	387 (2.5)		106 (1.9)	54 (1.7)		363 (1.9)	328 (2.4)		38 (2.8)	20 (2.7)		45 (2.6)	14 (1.5)	
	Medicaid	11514 (48.5)	7392 (48.7)		3507 (61.7)	2178 (67.4)		9520 (48.8)	7070 (51.1)		743 (55.7)	464 (63.4)		880 (51.5)	493 (54.3)	
	Self-Pay	5953 (25.1)	1535 (10.1)		1359 (23.9)	417 (12.9)		5263 (27.0)	1366 (9.9)		347 (26.0)	94 (12.8)		426 (24.9)	145 (16.0)	

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, n.s. = Not significant.

Table 2
Pre-pandemic (2016–2019) spatiotemporal multivariate cluster results for each maternal mental disorder adjusted for age, race, and insurance. Primary clusters (Cluster 1) are the most likely high-risk cluster locations, followed by secondary clusters, which are other high-risk cluster locations.

Pre-Pandemic (2016–2019)											
Cluster	Start Date	End Date	Duration (Months)	ZCTAs	RR > 1	p-value	Outcome	Observed	Expected	Std. Error	Relative Risk
1	8/1/2018	7/31/2019	12	19	18	<0.001	PMAD	674	153.47	0.17	4.49
							MDP	694	124.78	0.21	5.73
							SMI	694	130.46	0.20	5.48
							Suicidal thoughts	14	8.62	0.43	1.63
							Suicide attempts	14	10.98	0.34	1.28
2	10/1/2018	9/30/2019	12	61	59	<0.001	PMAD	886	423.42	0.07	2.14
							MDP	907	345.74	0.09	2.70
							SMI	907	341.63	0.09	2.74
							Suicidal thoughts	32	23.07	0.25	1.40
3	4/1/2018	3/31/2019	12	62	59	<0.001	PMAD	1118	556.85	0.06	2.06
							MDP	1034	479.91	0.07	2.22
							SMI	1034	438.24	0.07	2.44
							Suicidal thoughts	38	31.4	0.20	1.22
							Suicide attempts	50	39.45	0.18	1.28
4	2/1/2018	8/31/2018	7	6	5	<0.001	PMAD	142	52	0.23	2.74
							MDP	141	41.8	0.28	3.39
							SMI	141	44.43	0.27	3.19
5	3/1/2017	2/29/2018	12	44	44	<0.001	PMAD	793	531.67	0.05	1.51
							MDP	624	441.75	0.06	1.43
							SMI	624	447.85	0.06	1.41
							Suicidal thoughts	38	30.6	0.20	1.25
							Suicide attempts	56	38.38	0.19	1.47
6	9/1/2018	8/31/2019	12	22	22	<0.001	PMAD	770	661.51	0.04	1.17
							MDP	727	528.32	0.05	1.39
							SMI	727	504.21	0.05	1.46
							Suicidal thoughts	41	33.52	0.19	1.23
							Suicide attempts	49	45.25	0.15	1.09
7	5/1/2018	3/31/3019	11	5	5	<0.001	PMAD	56	21.83	0.34	2.57
							MDP	53	17.41	0.42	3.05
							SMI	53	16.4	0.44	3.24
							Suicidal thoughts	9	1.08	2.78	8.38
							Suicide attempts	3	1.46	1.19	2.06
8	8/1/2018	12/31/2018	5	4	4	<0.001	PMAD	31	10.66	0.52	2.91
							MDP	37	8.96	0.68	4.13
							SMI	37	8.55	0.71	4.33
							Suicidal thoughts	8	0.61	4.64	13.21
							Suicide attempts	2	0.76	1.86	2.64
9	2/1/2018	1/31/2019	12	4	4	<0.001	PMAD	75	31.4	0.28	2.39
							MDP	61	25.7	0.30	2.38
							SMI	61	22.98	0.34	2.66
							Suicidal thoughts	7	1.61	1.64	4.36
							Suicide attempts	12	2.15	1.61	5.6
10	10/1/2018	9/30/2019	12	4	4	<0.001	PMAD	174	124.65	0.11	1.4
							MDP	174	97.94	0.13	1.78
							SMI	174	82.31	0.16	2.12
							Suicidal thoughts	8	5.62	0.50	1.43
							Suicide attempts	15	8.17	0.47	1.84
11	8/1/2018	7/31/2019	12	24	22	<0.001	PMAD	141	102	0.12	1.38
							MDP	148	84.09	0.14	1.77
							SMI	148	87.45	0.14	1.70
							Suicidal thoughts	7	5.9	0.45	1.19
							Suicide attempts	10	7.4	0.43	1.35
12	4/1/2016	12/31/2016	9	1	1	<0.001	PMAD	13	2.46	1.47	5.29
							MDP	13	1.96	1.84	6.63
							SMI	13	1.65	2.19	7.88
13	6/1/2019	8/31/2019	3	1	1	<0.001	PMAD	17	7.78	0.53	2.19
							MDP	16	6.31	0.63	2.54
							SMI	16	6.29	0.64	2.55
							Suicidal thoughts	10	0.45	7.03	22.34
							Suicide attempts	1	0.55	1.82	1.82
14	11/1/2017	1/31/2018	3	21	21	0.002	PMAD	99	69.8	0.14	1.42
							MDP	91	57.69	0.17	1.58
							SMI	91	57.05	0.17	1.60
							Suicidal thoughts	7	3.94	0.67	1.78
15	7/1/2019	9/30/2019	3	4	2	0.006	PMAD	2	0.59	2.40	3.37
							MDP	6	0.5	4.90	12.07
							SMI	6	0.52	4.71	11.53
							Suicidal thoughts	1	0.046	21.74	21.9
16	6/1/2018	10/31/2018	5	11	8	0.011	PMAD	44	29.78	0.22	1.48
							MDP	48	24.23	0.29	1.98
							SMI	48	25.68	0.27	1.87
							Suicidal thoughts	4	1.73	1.16	2.31

(*continued on next page*)

Table 2 (*continued*)

Pre-Pandemic (2016–2019)											
Cluster	Start Date	End Date	Duration (Months)	ZCTAs	RR > 1	p-value	Outcome	Observed	Expected	Std. Error	Relative Risk
							Suicide attempts	3	2.17	0.80	1.38
Total				293	279						

PMAD= Perinatal mood and anxiety disorders, MDP = Maternal mental disorders during pregnancy, SMI = Severe mental illness.

Table 3
Pandemic (2020–2021) spatiotemporal multivariate cluster results for each maternal mental disorder adjusted for age, race, and insurance. Primary clusters (Cluster 1) are the most likely high-risk cluster locations, followed by secondary clusters, which are other high-risk cluster locations.

Pandemic (2020–2021)											
Cluster	Start Date	End Date	Duration (Months)	ZCTAs	RR > 1	p-value	Outcome	Observed	Expected	Std. Error	Relative Risk
1	1/1/2020	12/31/2020	12	47	42	<0.001	PMAD	827	325.79	0.09	2.63
							MDP	784	297.5	0.09	2.73
							SMI	116	71.84	0.15	1.64
							Suicide attempts	22	19.51	0.24	1.13
2	1/1/2020	12/31/2020	12	28	26	<0.001	PMAD	828	604.06	0.05	1.39
							MDP	837	541.16	0.05	1.58
							SMI	137	111	0.11	1.24
							Suicide attempts	34	32.75	0.18	1.04
3	1/1/2020	12/31/2020	12	23	21	<0.001	PMAD	594	399.58	0.06	1.51
							MDP	539	364.18	0.06	1.5
							SMI	94	82.86	0.12	1.14
							Suicidal thoughts	27	19.06	0.27	1.43
4	1/1/2020	12/31/2020	12	8	8	<0.001	PMAD	147	69.93	0.17	2.11
							MDP	128	63.49	0.18	2.03
							SMI	36	14.71	0.41	2.46
							Suicidal thoughts	12	3.19	1.09	3.81
							Suicide attempts	5	4.21	0.53	1.19
5	1/1/2020	12/31/2020	12	14	14	<0.001	PMAD	123	67.96	0.16	1.82
							MDP	128	60.9	0.19	2.11
							SMI	35	17.91	0.33	1.97
							Suicidal thoughts	11	4.05	0.82	2.74
							Suicide attempts	8	6.18	0.46	1.30
6	1/1/2020	12/31/2020	12	20	19	<0.001	PMAD	676	559.86	0.05	1.22
							MDP	689	503.74	0.05	1.39
							SMI	111	107.21	0.10	1.04
7	1/1/2020	12/31/2020	12	11	10	<0.001	PMAD	136	114.01	0.10	1.19
							MDP	117	105.04	0.10	1.11
							SMI	53	27.14	0.27	1.97
							Suicidal thoughts	20	6.02	0.74	3.39
							Suicide attempts	8	7.09	0.40	1.13
8	1/1/2020	12/31/2020	12	2	2	<0.001	PMAD	20	7.96	0.56	2.51
							MDP	23	7.17	0.67	3.21
							SMI	6	1.31	1.87	4.60
9	1/1/2020	12/31/2020	12	29	26	<0.001	PMAD	237	186.06	0.08	1.28
							MDP	192	169.32	0.08	1.14
							SMI	63	41.45	0.19	1.53
							Suicide attempts	15	11.96	0.32	1.26
Total				182	168						

PMAD= Perinatal mood and anxiety disorders, MDP = Maternal mental disorders during pregnancy, SMI = Severe mental illness.

for 12 months (Table 2). All but two clusters identified during the pre-pandemic period occurred during 2018 and 2019. The primary cluster during this period was detected in the southeastern coastal region around Wilmington, with secondary clustering located geographically throughout the state. During the pandemic period, SaTScan detected nine multivariate clusters affecting 182 ZCTAs, with 168 ZCTAs showing RR > 1 (Table 3; Fig. 2). All significant space-time clusters detected during the pandemic period persisted for 12 months from January to December 2020 (Table 3). During the pandemic period, the primary cluster shifted to western NC (Fig. 2). The distribution of additional clusters was more concentrated in the Piedmont and eastern coastal plains region of the state.

3.3. Univariate clustering

During the pre-pandemic period, cluster analysis identified eight total clusters for PMAD affecting 206 ZCTAs; 13 clusters for SMI affecting 176 ZCTAs; and 11 for MDP affecting 250 ZCTAs (Supplemental Table 2). For the pandemic period, SaTScan identified eight clusters of PMAD affecting 185 ZCTAs; nine clusters of SMI affecting 128 ZCTAs; and eight clusters of MDP affecting 192 ZCTAs (Supplemental Table 3).

Primary PMAD, MDP, and SMI univariate clusters from 2016 to 2019 were located in the southeastern coastal region of NC (Supplemental Figure 1). Significant secondary clustering occurred in the western and Piedmont regions of the state. During the pandemic period (2020–2021), primary clustering persisted in the southeast coastal region for SMI but shifted to the western region of the state for PMAD and MDP.

The total number of ZCTAs included in univariate clusters and within-cluster ZCTAs with RR greater than 1.00 decreased during the pandemic period for PMAD, MDP, and SMI (Supplemental Tables 2-3). Pre-pandemic primary cluster RR was as high as 5.73 for MDP, while relative risks were 4.49 and 4.35 within primary PMAD and SMI

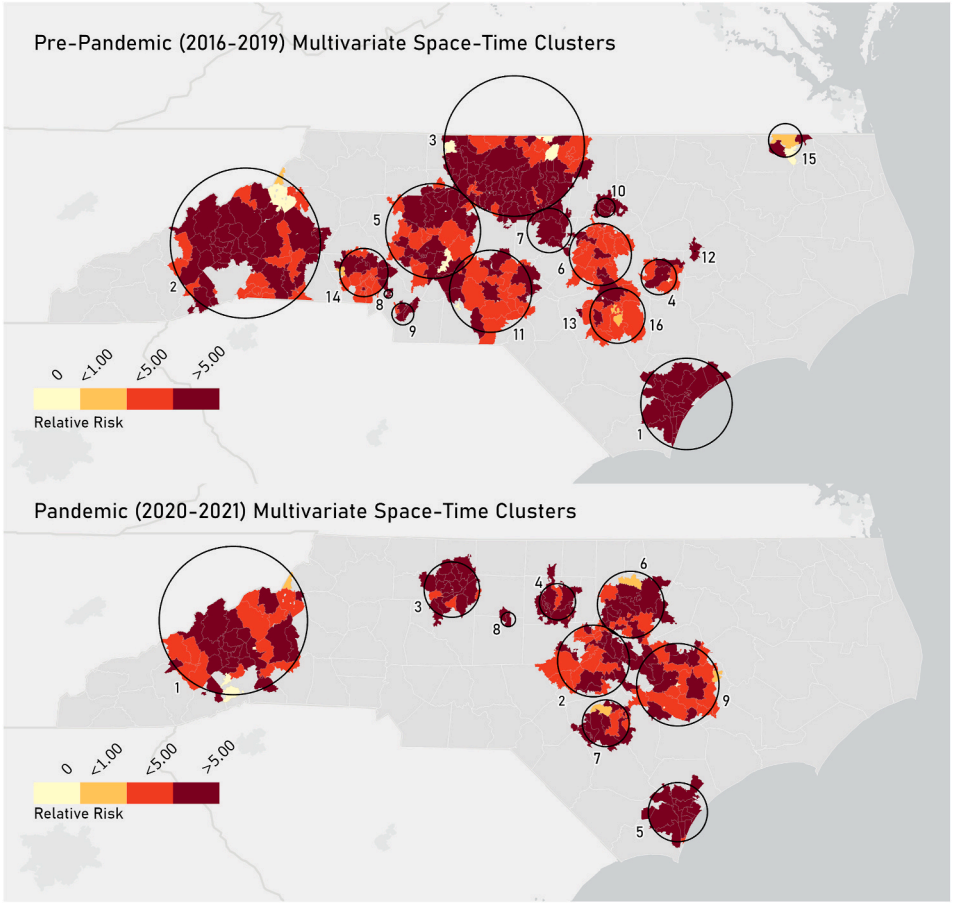

Fig. 2. Multivariate clusters of maternal mental disorder of pregnancy (MDP), perinatal mood and anxiety disorder (PMAD), and severe mental illness (SMI) cases identified during the pre-pandemic and pandemic periods. Relative risk is displayed at the ZCTA level for locations present within clusters, and is calculated as the sum of RRs for each condition.

clusters, respectively (Supplemental Table 2). Primary cluster RR increased to 5.04 for SMI during the pandemic and decreased to 2.66 and 2.68 for PMAD and MDP, respectively (Supplemental Table 3).

Space-time analysis also identified univariate clusters of suicidal thoughts and suicide attempts during the pre-pandemic period, and suicidal thought clustering during the pandemic period (Supplemental Figure 2; Supplemental Table 4). Pre-pandemic clusters of suicidal thoughts were distributed geographically throughout North Carolina, while pandemic clusters were more localized in the central region. The primary cluster RR for suicidal thoughts decreased from 3.39 in the pre-pandemic period to 2.27 during the pandemic (Supplemental Table 4). The number of ZCTAs included in suicidal thought clusters increased during the pandemic, as well as the number of ZCTAs within cl usters with RR > 1 (Supplemental Table 4).

3.4. RUCA

An analysis of the rural, suburban, and urban distribution of cluster locations identified increases in the proportion of urban ZCTAs identified in multivariate (+2.3%), PMAD (+5.1%), SMI (+1.8%) and MDP (8.5%) clusters (Supplemental Table 5). We also observed decreases in the proportion of suburban ZCTAs comprising SMI (−9.9%), MDP (−9.2%), PMAD (−3.2%), and multivariate clusters (−1.1%) (Supplemental Table 5).

The proportion of rural ZCTAs identified in SMI clusters increased significantly during the pandemic (+8.1%) compared to other outcomes. A smaller proportion of urban ZCTAs (−7.5%) and a greater proportion of suburban ZCTAs (+6.4%) were identified in suicidal thought clusters during the pandemic (Supplemental Table 5).

3.5. Rand index

Univariate suicidal thought cluster locations were the most similar between the pre-pandemic and pandemic periods (Rand: 0.85) (Supplemental Table 6). Multivariate cluster locations exhibited the least similarity between periods (Rand: 0.60), followed by SMI (Rand 0.67).

3.6. Local relative risk

Decreases in local RR were observed in the eastern region of North Carolina for PMAD, MDP, and multivariate clustering while SMI, suicidal thoughts, and suicide attempts displayed a more heterogeneous distribution of increases and decreases (Supplemental Figure 3). Although SaTScan did not detect univariate clustering for suicide attempts during the pandemic period, local RR for suicide attempts increased over 1.5 times for select ZCTAs throughout the state.

4. Discussion

The objective of this study was to explore shifts in the space-time clustering of maternal mental health burdens from the pre-pandemic to pandemic periods in North Carolina, USA, using cluster analysis in SaTScan. The clusters identified in our analysis were adjusted for three major risk factors (age, race, and insurance status) to mitigate the influence of unequal population distributions in shaping our results (Root et al., 2009). Despite prior research indicating that the use of emergency

mental health services decreased during the pandemic (Hoyer et al., 2021; Gonçalves-Pinho et al., 2021), we observed an increase in average yearly case counts for PMAD, SMI, MDP, suicidal thoughts, and suicide attempts during the pandemic period (2020–2021). This result aligns with prior findings that perinatal populations experienced greater susceptibility to psychological distress and mood disorders during the pandemic (Kajdy et al., 2020; Spinola et al., 2020; López-Morales et al., 2021).

Poor mental health during pregnancy is a critical precursor to maternal and infant morbidity (Easter et al., 2019; Runkle et al., 2023) that carries substantial adverse impacts on maternal and infant health if left untreated. Our analysis focused on a single state in the U.S. South, however emerging research shows that perinatal mental health burdens increased nationally and internationally during the pandemic (Caffieri et al., 2024; Mesquita et al., 2023; Smith et al., 2023; Wilson, 2022). The pandemic exacerbated an already sensitive physiological period in birthing people's lives, and increased psychological distress because of the dual stressors of a global pandemic and pregnancy.

We observed a significantly higher proportion of Hispanic women coming to the ED for all maternal mental health outcomes during the pandemic period and a higher proportion of Black women coming to the ED for severe mental illness. This result aligns with prior research documenting an increased maternal mental health burden among these groups (Preis et al., 2020; Hendrix et al., 2022; Masters et al., 2021). The proportion of women ages 30 to 39 visiting the ED for maternal mental health conditions also increased during the pandemic period. Older maternal age has been associated with higher rates of depression, and women ages 30 to 39 may be more susceptible to the exacerbation of mental health conditions during the COVID-19 pandemic (McMahon et al., 2015; Muraca and Joseph, 2014).

Fewer communities were identified in multivariate and univariate clusters during the pandemic. Multivariate clusters and univariate clusters of PMAD, MDP, and SMI were more concentrated in urban areas during the pandemic. Results suggest that urban communities continued to carry high maternal mental health burdens for pre-existing conditions persisting during pregnancy (PMAD), severe mental illness (SMI), and new maternal mental disorders of pregnancy (MDP) during the pandemic, while this burden distribution was generally less intense in suburban areas. The burden distribution for SMI displayed the greatest magnitude of changes during the pandemic period. Rural areas displayed a heightened risk for severe mental illness clustering during the pandemic, although results should be interpreted with caution due to the small sample size.

Specific locations across North Carolina continued to show a sustained maternal mental health burden during the pandemic. The risk of clustering for new prenatal mental health conditions (MDP) and the persistence of existing conditions (PMAD) remained present in western NC during the pandemic, corroborating previous research that has also identified western NC as an area with a high mental health burden (Sugg et al., 2023). However, unlike this earlier work that focused on adolescents (under age 24), our work highlights the high mental health burden among maternal populations both before and after the pandemic. The persistence of multivariate clusters and univariate clusters of PMAD, SMI, and MDP in the Piedmont and southeastern coastal regions of the state during the pandemic also indicates an extreme mental health burden among the prenatal population in these areas and are priority locations for increased prenatal mental health resources. The persistence of clustering in western and southeastern coastal NC reflects substantial rural health disparities documented in North Carolina, including poor social determinants of health and limited access to maternal and mental health care (Baxley, 2023; MAHEC., 2022).

Statewide, we observed increased ED visits for suicidal thoughts and suicide attempts among pregnant women during the pandemic. Spatiotemporal clusters for suicidal thoughts persisted and emerged during the pandemic period, encompassing more suburban areas and fewer urban areas, whereas no significant clusters were observed for suicide attempts. We observed increases in local relative risk among ZCTA locations throughout the state for both suicide outcomes. We hypothesize that these outcomes generally increased across the entire state rather than in localized populations, resulting in reduced cluster formation relative to other maternal mental health outcomes.

Pandemic-imposed disruptions in access to standard mental health care services likely contribute in part to our observation of increased ED visits for mental health care (Byrne et al., 2021; Brunier and Drysdale, 2022). Disruptions to perinatal care and mental health care during the pandemic were compounded by increased feelings of stress, isolation, and uncertainty reported by pregnant populations and may have resulted in increased use of the ED for access to necessary mental health support (Pilav et al., 2022; Khoury et al., 2022). We observed a significant increase in the proportion of pregnant women with commercial insurance coming to the ED for all maternal mental health outcomes, especially for pre-existing conditions that persisted during pregnancy (PMAD) and new mental disorders (MDP). The proportion of ED visits for all conditions also increased among women who were beneficiaries of Medicaid, most notably for severe mental illness and suicidal thoughts. ED visits decreased among women without any form of insurance for all conditions. These results reflect a sustained mental health burden among pregnant women with Medicaid during the pandemic and an increased mental health burden among commercially insured pregnant women.

Our findings explore the spatial patterning of five different maternal mental health outcomes before and during the COVID-19 pandemic. The conditions included in our analysis made for a comprehensive, but not exhaustive, examination of mental health disorders during pregnancy. There are several key future research directions to consider following this analysis. Future research should consider instances of substance abuse prior to, during, and following the COVID-19 pandemic among pregnant persons. Limited prior research suggests that maternal substance use increased during the COVID-19 pandemic and that psychological well-being may increase the risk of maternal substance use during the pandemic (Kar et al., 2021; Lien et al., 2023; Smith et al., 2022). Future research should also examine sub-conditions of the broader categories included in this analysis, including specific conditions of anxiety, depression, and PTSD.

4.1. Implications

Our results are the first to explore the spatial distribution of geographic areas of heightened susceptibility to maternal mental health conditions before and during the COVID-19 pandemic. These areas should be considered as priority locations for the expansion of effective maternal mental health screening, treatment, and preventative strategies following the onset of the pandemic. The financial burden of untreated maternal mental health conditions is substantial; in 2017, this cost was measured at $14.2 billion in the U.S., and the average cost per mother-child dyad was measured at over $30,000 (Margiotta et al., 2022; Luca et al., 2020; Griffen et al., 2021).

Our observed increased visits to the ED for maternal mental health conditions may be due in part to the expansion of Medicaid coverage under the Families First Coronavirus Response Act, which averted insurance disruptions for millions of U.S. residents during the COVID-19 pandemic and resulted in a historic low of nationwide uninsured Americans (Murphy et al., 2022). Medicaid expansion has been associated with reduced hospitalizations and increased use of outpatient care for low-income maternal populations (Steenland and Wherry, 2023; Gordon et al., 2020). Prior research showed that the 2014 Medicaid expansion improved equitable access to prenatal care for women of reproductive age, particularly among those from racially and ethnically diverse backgrounds, during the pandemic and that prenatal care use declined during the pandemic for women residing in non-expansion states (Lee and Singh, 2023). The continuity of insurance coverage is an effective intervention that may reduce pregnancy-related

preventable deaths caused by mental health conditions (Postpartum Medicaid Coverage Extended During COVID-19: Resources for Your Practice., 2023)

The co-location of maternal and pediatric services (Pawar et al., 2019; Meltzer-Brody and Kimmel, 2020; Moore et al., 2021; Griffen et al., 2021) and the expansion of telehealth service and related insurance coverage (Meltzer-Brody and Kimmel, 2020; Moore et al., 2021; Griffen et al., 2021; Hendrix et al., 2022) have surfaced as additional policies that can improve access to mental health care for pregnant women following pandemic-related disruptions. A local state program, NC Maternal Mental Health Matters, is already working to enhance the screening, assessment, and treatment of maternal mental health conditions during pregnancy and the postpartum periods (Kimmel 2020).

4.2. Strengths and limitations

Some notable strengths of this study include the use of the ZCTA level of analysis, which is more sensitive to clustering compared to larger geographic units (e.g., county). Additionally, this scale provides a more accurate depiction of clusters while illustrating geographic patterns at a smaller spatial scale (Jones and Kulldorff, 2012). However, the small population size of certain ZCTAs may result in inflated relative risk values in rural and more remote locations. Our analysis focused on one state in the U.S. South. Future research should explore the spatial patterning of perinatal mental health conditions across additional states and regions. The hospital administrative data used for service billing does not include detailed data on maternal income, marital status, family structure, or personal experience during the pandemic. Data on maternal mental health disorders may be subject to bias from coding and diagnostic errors, but prior research shows higher reliability for well-defined disorders such as psychiatric disorders during pregnancy (Davis et al., 2016; Runkle et al., 2023). Hospital administrative data used in this study also excludes the months of October through December of 2021, as the last quarter of data will not be available until the next year of data is released.

Our analysis provides insight into the spatial patterns of maternal mental health conditions related to the pandemic. However, the ED data used in our analysis did not include COVID-19, a significant risk factor for adverse maternal mental health outcomes. Future studies of perinatal mental health should include COVID-19 as a covariate. Our ED data does not contain information on prior obstetric history or current health status, which can provide additional context for maternal mental health cases. The spatial patterns identified in our results can also be affected by access to emergency departments, particularly in northeastern North Carolina and in other areas where the most accessible emergency department is outside of the state. Future research should consider geographic access to emergency departments as a significant factor shaping the clustering of perinatal mental health outcomes.

The register-based format of ED data allows for a large sample size, and therefore the identification of robust clusters that are adjusted for confounding factors (e.g. age, race, and socioeconomic status) at the population level. Register-based is also not subject to nonresponder bias, selection bias, or attrition bias (Olsen, 2011; Thygesen and Ersbøll, 2014). However, register-based data is subject to left truncation, and can lead to unimportant differences becoming statistically significant (Thygesen and Ersbøll, 2014).

5. Conclusion

Our study highlights locations characterized by a high burden of mental health conditions among pregnant populations before and during the COVID-19 pandemic in a Southern state. The pandemic period exacerbated many of the pre-existing mental and physical challenges associated with pregnancy, as well as structural barriers to receiving care. Pandemic-related disruptions in receiving appropriate and timely maternal health care may have contributed to the increased observation of adverse mental health outcomes among pregnant populations, particularly among Black, Hispanic, and low-income women (Pilav et al., 2022; Choi et al., 2020). Rising maternal mortality rates disproportionately impact marginalized and under-resourced communities, making maternal mental health interventions an immediate priority. Future research should consider the contextual neighborhood and individual sociodemographic factors that drive the formation of maternal mental health clusters.

Conflict of interest

The authors declare they have no conflict of interest.

CRediT authorship contribution statement

Sarah E. Ulrich: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Investigation, Formal analysis. **Margaret M. Sugg:** Writing – review & editing, Writing – original draft, Supervision, Resources, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Michael R. Desjardins:** Writing – review & editing, Visualization, Supervision, Methodology, Formal analysis. **Jennifer D. Runkle:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.healthplace.2024.103307.

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