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Connecting underlying factors in the associations between perceived neighborhood social environments and type 2 Diabetes: Serial mediation analyses

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ABSTRACT

Aims: This study tested direct and indirect associations between perceived neighborhood social environments and type 2 diabetes (T2D), serially mediated via health-related (physical activity [PA], body mass index [BMI]), psychosocial factors, and inflammation.
Methods: Data came from the Midlife in the United States (MIDUS 3 [2013–2014] and MIDUS 3 Biomarker Project [2017–2022]; n = 518). T2D (yes/no) was based on the American Diabetes Association criteria. Perceived neighborhood social cohesion and safety were assessed separately (higher scores = more favorable neighborhoods). PA, BMI, perceived stress, depression, and c-reactive protein (CRP) were included as mediators in the associations between exposure and the outcome adjusting for covariates.
Results: Higher social cohesion was indirectly related to lower likelihood of T2D, serially mediated through PA, BMI, and CRP (odds ratio [OR] = 1.00; 95 % bias-corrected confidence interval [BC CI] = 0.99, 1.00). Higher social cohesion and safety were indirectly associated with a lower likelihood of T2D, serially mediated via stress, depression, and CRP (Social cohesion: OR = 0.98; 95 % BC CI = 0.96, 1.00; and safety: OR = 0.98; 95 % BC CI = 0.96, 1.00, all $p < 0.05$).
Conclusions: This study may be the first to demonstrate underlying potential mechanisms through which socially cohesive and safe neighborhoods lower the risk of T2D. These pathways present potential targets for interventions to reduce the risk.

1. Introduction

Diabetes, a complex chronic metabolic disease, ranks as the eighth leading cause of death in the United States (US) [1]. In 2021, the Centers for Disease Control and Prevention estimated that 14.7 % of US adults aged ≥ 18 years (equivalent to 38.1 million) had diabetes, with > 90 % classified as type 2 diabetes (T2D) [2]. Additionally, 38 % (97.6 million) of the US adults had prediabetes, placing them at high risk of T2D [2]. By 2060, the number of US adults with T2D is projected to rise to 60.6 million [3]. In 2022, T2D imposed an annual economic burden estimated at $412.9 billion, 74 % of which was attributed to direct medical expenditures and 26 % to lost productivity [4]. Identifying effective intervention programs is urgently needed to mitigate the healthcare burden of T2D in the US.

The determinants of diabetes are multi-factorial, yet much of the research has focused on individual health-related factors, such as physical activity (PA) [5], weight-related factors (e.g., diet [6], obesity [7]), and psychosocial stressors (depression, stress [8]). A socio-ecological perspective [9] highlights how neighborhood environments—both physical (e.g., access to parks and greenspace) and social (e.g., social norms, cohesion, and safety)—interact with psychosocial and biological factors [10] to influence T2D risk, thereby contributing to

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its prevalence and incidence [11–13]. For instance, deprived neighborhoods with fewer socioeconomic resources are consistently linked with higher T2D in most studies [12]. Walkable neighborhoods, characterized by mixed land use, population density, and street connectivity, can promote PA and lower diabetes risk [11].

Perceived neighborhood social environmental (PNSE) factors are particularly relevant, as they reflect social norms, culture, and interpersonal dynamics [14]. Few studies suggest links between PNSE factors and T2D; however, these findings are inconsistent [15,16]. A study among African American adults from the Jackson Heart Study (JHS) in Jackson, Mississippi found that perceived neighborhood social cohesion (e.g., trust and shared values among neighbors) was negatively associated with incident T2D but not for violence (fight, assault, robbery) and problems (noise, heavy traffic). Contrastingly, only neighborhood problems were positively related to the prevalence of T2D in the fully-adjusted model (including demographic and health-related factors), but not for social cohesion and violence [15]. However, a study among racial and/or ethnic participants using the Multi-Ethnic Study of Atherosclerosis (MESA) data in six US cities found no associations of perceived neighborhood social cohesion or safety with T2D [16]. Such mixed findings may arise from differences in age (JHS: 54 vs 61 years for MESA). Furthermore, those neighborhood measures were assessed differently. Perceived neighborhood social environmental factors from the JHS were based on principal component analysis, in particular, four items were used for social cohesion [15]. In contrast, neighborhood measures from the MESA were based on the mean of item responses for social cohesion [16]. In addition, these mixed findings underscore the need to clarify the biological mechanisms linking PNSE factors and diabetes. It has been postulated that PNSE factors contribute to chronic oxidative stress and inflammation, playing a role in the pathogenesis of cardiometabolic diseases [17,18], particularly inflammation has been more pronounced in African American adults [19].

Underlying factors of the PNSE-diabetes nexus, such as PA [5], body mass index (BMI) [20], psychosocial stressors, and inflammatory biomarkers [7] have remained understudied. Previously, many studies have investigated the associations of neighborhood social environments with PA and BMI [21,22]. PA levels are known to relate to BMI [23,24], vice versa [25]. Further, it is well demonstrated that those who are physically active tend to have lower levels of psychosocial stressors [26,27], while those who have higher BMI are likely to have a higher risk of depression. [28,29] Individuals who are depressed tend to have higher perceived stress [30], while those who are stressed also have a higher risk of depression [31]. Those who have higher psychosocial stressors tend to have elevated inflammatory biomarkers [32], which could lead to the development of T2D [8,33–35]. Taken together, it is essential to elucidate these mechanisms by which neighborhood social contexts are linked to T2D, through those underlying factors.

Understanding such pathways is critical to identifying effective interventions focusing on neighborhood social contexts, particularly cohesive and safe neighborhoods promoting physical activity [36], which in turn could ease psychosocial stress and improve inflammatory biomarkers [37]. This study aimed to investigate the direct association between PNSE factors (social cohesion and safety) and T2D and examine serial mediations through health-related, psychosocial, and biological factors in a sample of middle-to-older US adults.

2. Materials and methods

2.1. Data and study participants

This study utilized data from the Midlife in the United States (MIDUS) study, a nationally representative longitudinal cohort examining health and well-being among US adults aged 25–75 years. MIDUS comprises three waves of data collection: MIDUS 1 (1995–1996), MIDUS 2 (2004–2006), and MIDUS 3 (2013–2014). A subset of participants from MIDUS 3 was also enrolled in the MIDUS 3 Biomarker Project (2017–2022), which provided detailed biological assessments. The analytic sample is the cross-sectional data of those who completed both MIDUS 3 (n = 3,294) and the MIDUS 3 Biomarker Project (n = 747). After merging two datasets, 103 participants from the MIDUS 3 Biomarker Project were excluded, yielding 644 participants. Additional exclusions were made for self-reported T1D status (n = 7), mediators (total n = 50, perceived stress n = 2, physical activity n = 39, and BMI n = 9), T2D (fasting glucose level and HbA1c levels n = 8), covariates (total n = 52, race n = 39, age n = 1, and marital status n = 12), and perceived neighborhood social environmental factors (n = 7). The final analytic sample comprised 518 participants (Supplemental Fig. S1). This study was not deemed human subject research by the National Institutes of Health Institutional Review Board (IRB). All protocols for the MIDUS received all ethical approval from the University of Wisconsin-Madison IRB.

2.2. Type 2 diabetes (T2D)

T2D (yes/no) was defined as participants with an HbA1c $\geq$ 6.5 % (48 mmol/mol) or a fasting glucose level (FPG) $\geq$ 126 mg/dL (7.0 mmol/L), which is consistent with the American Diabetes Association criteria [38–40].

2.3. Perceived neighborhood social environments (PNSE)

Participants' perceptions of neighborhood social cohesion were evaluated using responses to two statements: "I can call a neighbor for help if needed." and "People in my neighborhood trust each other." Responses were rated on a scale of 1 ("A Lot") to 4 ("Not at All"), reverse-scored, and averaged, with higher scores indicating greater neighborhood social cohesion [41]. Neighborhood safety was assessed based on agreement with two statements: "I feel safe being out alone in my neighborhood during the daytime." and "I feel safe being out alone in my neighborhood during the night." Responses were recorded on a scale from 1 ("A Lot") to 4 ("Not at All"), reverse-scored, and averaged, with higher scores reflecting greater perceived safety [42]. Perceived neighborhood social cohesion and safety were developed by Keyes [43] and provided moderate reliability of the measures (Cronbach $\alpha = 0.65$) [44].

2.4. Mediators

2.4.1. Physical activity (PA)

Moderate PA was assessed using six items, asking participants to report how frequently they engaged in moderate physical activities (e.g., brisk walking) at home, work, and during leisure time in the summer and winter. Responses were recorded on a scale from 1 (several times a week) to 6 (never) and were reverse-scored. Similar to previous studies, [45,46] a continuous physical activity measure was created. MIDUS 3 classified PA into 3 categories based on the reason for PA (e.g., work, home chores, or leisure), which half of the month this activity occurred (e.g., summer or winter). The highest summer and winter PA from the 3 categories were averaged to create a moderate PA score, with higher scores indicating greater engagement in moderate PA [45,46]. Based on this approach, this score is proximal to suggest that adults engage in at least 150 min of moderate aerobic activity [46].

2.4.2. Body mass index (BMI)

BMI was calculated by dividing the respondent's self-reported weight in kilograms by their height in meters squared. BMI classifications were defined as underweight (<18.5), normal weight (18.5–24.9), overweight (25.0–29.9), and obese (≥30.0).

2.4.3. Depression

Participants' depressive symptoms were assessed using the validated Center for Epidemiologic Studies – Depression (CES-D) scale (range 0–60 based on the 20 items) [47]. The survey items included four

subscales on depressed affect (seven items), positive affect (four items), somatic complaints (seven items), and interpersonal issues (two items). Participants reported how often they feel a certain way over the past week (e.g., "I thought my life had been a failure." and "I felt depressed."). Response options ranged from 0 (rarely or none of the time) to 3 (most or all of the time), which were summed to create a continuous depressive symptoms score. The higher score indicates more severe depressive symptoms, and individuals with a score ≥ 16 are at risk for clinical depression [48]. The CES-D scale indicated high construct validity among older adults [49].

2.4.4. Perceived stress

The Perceived Stress Scale is a 10-item self-reported questionnaire used to measure an individual's stress level over a month [50]. Responses to each item (e.g., "In the past month, how often have you been upset because of something that happened unexpectedly?") range from 1 (never) to 5 (very often) (Cronbach α = 0.86) [51–53]. All responses were summed, with a higher score reflecting greater perceived stress and no predetermined cut points for certain stress levels [54].

2.4.5. Inflammatory marker – C-reactive protein

In the MIDUS III Biomarker Project, blood specimens were used to assess inflammatory biomarkers. Clinical nurse staff collected fasting blood samples from each participant before breakfast on the second day of their hospital stay. C-reactive protein (CRP) was assessed by immunoelectrochemiluminescence using the V-PLEX Plus Human CRP Kit (cat# K151STG, Meso Scale Discovery, Rockville, MD). An elevated CRP level is ≥ 8 μg/mL [55,56].

2.5. Covariates

The analyses included potential demographic covariates that could confound the association between neighborhood social environments and T2D. These covariates included age (in years) [57], sex (male/female) [57], race (Non-Hispanic [NH] White/Non-White adults) [57], marital status (married/not married) [58], and educational attainment (did not complete college/college graduate) [57].

2.6. Statistical analyses

Means and standard deviations or medians and interquartile ranges, as appropriate, were reported for continuous variables, while frequencies and percentages were used for categorical variables. This study sequentially examined direct and indirect associations between each PNSE factor and T2D through mediators (M1, M2, and M3, Fig. 1). Initially, age-adjusted direct associations were assessed. Mediation analyses were subsequently conducted using the SAS PROCESS Macro v4.3 [59] (i.e., cross-sectional mediation) to sequentially evaluate the mediating roles of PA, BMI, perceived stress, depression, and CRP.

This approach provided inferential tests of the indirect effects of primary exposure measures on the outcomes through the specified mediators. Bootstrap resampling (k = 5000) with 95 % bias-corrected confidence intervals (BC CIs) was employed to determine associations [59], with statistically significant mediation defined as BC CIs excluding zero. The PROCESS MACRO estimated the direct effects to investigate the associations between each PNSE variable (i.e., social cohesion and safety, separately) as the primary exposure variable and T2D as an outcome.

3. Results

3.1. Participant characteristics

On average, participants were 61.0 years (SD ± 9.5) (Table 1). The majority were female (53.9 %), predominantly NH White adults (93.8 %), well-educated (60.6 %), and married (70.1 %). Participants had a mean HbA1c of 5.7 % (SD ± 1.0) and fasting blood glucose of 107.2 (SD ± 28.7) mg/dL, with 17.9 % reporting a diagnosis of T2D. Participants' average level of moderate PA was 4.9 (SD ± 1.3), while they had a mean BMI of 28.1 (SD ± 5.5). The average depressive symptoms and perceived stress scores were 7.9 (SD ± 6.9) and 21.0 (SD ± 6.1), respectively. The mean CRP level (ug/mL) was 3.5 (SD ± 5.2). Participants reported moderate levels of perceived neighborhood social cohesion (mean = 3.4 [SD ± 0.6]) and safety (mean = 3.7 [SD ± 0.5]).

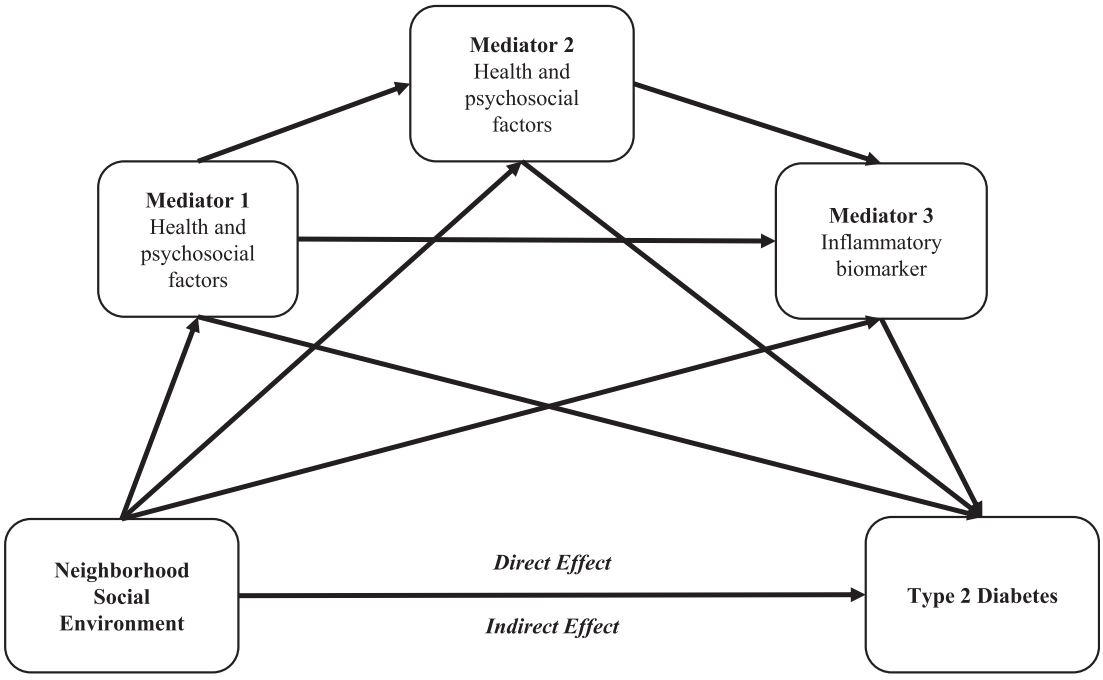

Fig. 1. Conceptual framework of direct and indirect associations of perceived neighborhood social environments (social cohesion and safety) and type 2 diabetes, serially through mediators 1, 2, and 3.

Table 1
Participants' Characteristics (n = 518).

Factors	Mean (SD) or n (%)
Demographics	
Age	60.99 (9.49)
Sex	
Male	239 (46.10)
Female	279 (53.90)
Race	
White adults	486 (93.80)
Non-White adults	32 (6.20)
Education	
Less than college	204 (39.40)
College or more	314 (60.60)
Marital Status	
Married	363 (70.10)
Not married	155 (29.90)
Type 2 diabetes criteria	
HbA1c (%)	5.74 (0.96)
Fasting blood glucose level (mg/dL)	107.20 (28.65)
Type 2 diabetes status	
Yes	92 (17.86)
No	423 (82.14)
Mediators	
Health-related factors	
Moderate physical activity	4.89 (1.34)
Body mass index	28.11 (5.51)
Psychosocial Factors	
Depressive symptoms	7.94 (6.92)
Perceived stress	20.97 (6.07)
Biomarkers	
C-reactive protein (μg/mL)	3.50 (5.22)
Perceived Neighborhood Social Environment	
Social cohesion	3.36 (0.64)
Safety	3.72 (0.49)

Note: Abbreviations; HbA1c: hemoglobin A1c.

3.2. PA as the first mediator on associations between PNSE and T2D

Key significant indirect associations were reported for three mediators and corresponding path associations. Higher neighborhood social cohesion was indirectly associated with a reduced risk of T2D, mediated through PA, BMI, and CRP (OR = 1.00; 95 % BC CI = 0.99, 1.00, $p < 0.05$, Table 2, Fig. 2). Specifically, greater social cohesion was positively associated with higher PA (β = 0.34; 95 % CI = 0.16, 0.52, Table 3), which was inversely associated with BMI (β = -0.63; 95 % CI = −0.99, −0.27). Higher BMI was, in turn, positively linked to CRP levels (β = 0.18; 95 % CI = 0.10, 0.26), and elevated CRP levels were associated with increased T2D risk (OR = 1.05; 95 % CI = 1.00, 1.09, all paths $p < 0.05$).

Neighborhood safety showed no significant indirect association with T2D when mediated through the sequence of serial mediation pathways (i.e., SF → PA → BMI → CRP → T2D, Table 2). However, both neighborhood social cohesion and safety demonstrated indirect associations with T2D risk mediated through other pathways involving PA and BMI (Social cohesion: OR = 0.97; 95 % BC CI = 0.94, 0.99, Supplemental Fig. S2; and safety: OR = 0.98; 95 % BC CI = 0.94, 0.99, Table 2). Further, neighborhood social cohesion was indirectly related to T2D through PA as a single mediator (OR = 0.93; 95 % BC CI = 0.86, 0.99, Supplemental Fig. S3).

3.3. BMI as the first mediator on associations between PNSE and T2D

Neighborhood social cohesion and safety were not associated with T2D when mediated sequentially through three mediators (e.g., BMI, depression, and CRP) (Supplemental Table S1). However, other pathways were observed. Higher neighborhood social cohesion was indirectly associated with a lower risk of T2D through depression and CRP (OR = 0.99; 95 % BC CI = 0.97, 1.00, $p < 0.05$, Supplemental Table S1). Greater social cohesion was associated with lower depression scores (β

Table 2
Direct (D) and indirect (I) associations between perceived neighborhood social environments and type 2 (T2D) diabetes through mediators (n = 518).

Neighborhood Social Cohesion (SC)	OR (95 % CI or BC CI)	Neighborhood Safety (SF)	OR (95 % CI or BC CI)
Mediators: Physical activity (PA), body mass index (BMI), c-reactive protein (CRP)			
D: SC → T2D	0.85 (0.58, 1.25)	D: SF → T2D	0.87 (0.53, 1.43)
I: SC → PA → T2D	0.95 (0.88, 1.02)	I: SF → PA → T2D	0.96 (0.87, 1.01)
I: SC → BMI → T2D	0.95 (0.86, 1.04)	I: SF → BMI → T2D	1.04 (0.93, 1.18)
I: SC → CRP → T2D	0.96 (0.90, 1.00)	I: SF → CRP → T2D	0.96 (0.88, 1.03)
I: SC → PA → BMI → T2D	**0.97 (0.94, 0.99)**	I: SF → PA → BMI → T2D	**0.98 (0.94, 1.00)**
I: SC → PA → CRP → T2D	0.99 (0.98, 1.00)	I: SF → PA → CRP → T2D	0.99 (0.98, 1.00)
I: SC → BMI → CRP → T2D	1.00 (0.99, 1.00)	I: SF → BMI → CRP → T2D	1.00 (0.99, 1.01)
I: SC → PA → BMI → CRP → T2D	**1.00 (0.99, 1.00)**	I: SF → PA → BMI → CRP → T2D	1.00 (0.99, 1.00)
Mediators: PA, stress (STR), CRP			
D: SC → T2D	0.94 (0.64, 1.38)	D: SF → T2D	1.06 (0.64, 1.75)
I: SC → PA → T2D	**0.93 (0.86, 0.99)**	I: SF → PA → T2D	0.94 (0.85, 1.00)
I: SC → STR → T2D	0.91 (0.81, 1.00)	I: SF → STR → T2D	**0.92 (0.82, 0.99)**
I: SC → CRP → T2D	0.95 (0.88, 1.00)	I: SF → CRP → T2D	0.96 (0.88, 1.05)
I: SC → PA → STR → T2D	1.00 (0.99, 1.01)	I: SF → PA → STR → T2D	1.00 (0.99, 1.00)
I: SC → PA → CRP → T2D	**0.99 (0.97, 1.00)**	I: SF → PA → CRP → T2D	0.99 (0.97, 1.00)
I: SC → STR → CRP → T2D	0.99 (0.97, 1.00)	I: SF → STR → CRP → T2D	0.99 (0.97, 1.00)
I: SC → PA → STR → CRP → T2D	1.00 (1.00, 1.00)	I: SF → PA → STR → CRP → T2D	1.00 (1.00, 1.00)
Mediators: PA, depression (DEP), CRP			
D: SC → T2D	0.94 (0.64, 1.39)	D: SF → T2D	1.04 (0.63, 1.71)
I: SC → PA → T2D	**0.94 (0.86, 0.99)**	I: SF → PA → T2D	0.94 (0.86, 1.00)
I: SC → DEP → T2D	0.91 (0.80, 1.03)	I: SF → DEP → T2D	0.94 (0.85, 1.01)
I: SC → CRP → T2D	0.97 (0.9, 1.01)	I: SF → CRP → T2D	0.97 (0.89, 1.06)

(*continued on next page*)

Table 2 (*continued*)

Neighborhood Social Cohesion (SC)	OR (95 % CI or BC CI)	Neighborhood Safety (SF)	OR (95 % CI or BC CI)
I: SC → PA → DEP → T2D	1.00 (0.99, 1.00)	I: SF → PA → DEP → T2D	1.00 (0.99, 1.00)
I: SC → PA → CRP → T2D	**0.99 (0.97, 1.00)**	I: SF → PA → CRP → T2D	0.99 (0.97, 1.00)
I: SC → DEP → CRP → T2D	**0.98 (0.95, 1.00)**	I: SF → DEP → CRP → T2D	**0.99 (0.96, 1.00)**
I: SC → PA → DEP → CRP → T2D	1.00 (1.00, 1.00)	I: SF → PA → DEP → CRP → T2D	1.00 (1.00, 1.00)

Note: **Boldface** indicates statistical significance $p < 0.05$. OR = odds ratio. CI = confidence interval. BC CI = bias-corrected confidence interval.

= -3.37; 95 % CI = −4.27, −2.48), and depression was linked to elevated CRP levels (β = 0.08; 95 % CI = 0.01, 0.15) (Supplemental Table S2). Elevated CRP, in turn, was associated with greater T2D risk (OR = 1.05; 95 % BC CI = 1.00, 1.09, all $p < 0.05$). Neighborhood safety was also indirectly associated with reduced T2D risk via perceived stress, as well as through depression and CRP (all $p < 0.05$) (Supplemental Table S1).

3.4. Depression as the first mediator on associations between PNSE and T2D

Indirect associations between neighborhood social cohesion and T2D were observed through pathways involving depression and CRP (OR = 0.97; 95 % BC CI = 0.93, 0.99, $p < 0.05$) (Supplemental Table S3). Greater neighborhood social cohesion was associated with lower depression (β = -3.44; 95 % CI = −4.34, −2.54), and depression was positively associated with CRP (β = 0.13; 95 % CI = 0.03, 0.23) (Supplemental Table S4). Elevated CRP was subsequently linked to increased T2D risk (OR = 1.07; 95 % CI = 1.03, 1.11, all $p < 0.05$). Similarly, neighborhood safety demonstrated indirect associations with diabetes risk mediated through depression and CRP ($p < 0.05$) (Supplemental Table S3).

3.5. Perceived stress as the first mediator on associations between PNSE and T2D

Both neighborhood social cohesion (OR = 0.98; 95 % BC CI = 0.96, 1.00) and safety (OR = 0.98; 95 % BC CI = 0.96, 1.00, both $p < 0.05$) were indirectly associated with T2D via stress, depression, and CRP (Supplemental Table S5). Higher neighborhood social cohesion and safety were linked to lower perceived stress (β = -2.46; 95 % CI = −3.26, −1.66, and β = -2.01; 95 % CI = −3.10, −0.92, respectively) (Supplemental Table S6). Lower stress was associated with reduced depression scores (β = 0.81; 95 % CI = 0.74, 0.87, and β = 0.84; 95 % BC CI = 0.77, 0.91). Higher depression scores were linked to increased CRP levels (β = 0.13; 95 % CI = 0.03, 0.23, and β = 0.14; 95 % CI = 0.05, 0.24). Elevated CRP levels were subsequently associated with higher T2D risk (OR = 1.07; 95 % CI = 1.03, 1.11; and OR = 1.07; 95 % CI = 1.03, 1.11, all $p < 0.05$, respectively). These indirect effects and pathways were detailed in Supplemental Tables S5-S6.

There were no direct associations between each PNSE and T2D in any combination of mediators. In addition, neighborhood social cohesion and safety were not associated with T2D in age-adjusted models.

4. Discussion

This study examined whether neighborhood social cohesion and safety were associated with T2D, serially mediated through health-related factors (PA and BMI), psychosocial stressors (depression, stress), and an inflammatory biomarker (CRP) among middle-to-older adults. Serial mediation analyses indicated several underlying mechanisms in the association between each PNSE factor and T2D. First, higher neighborhood social cohesion was indirectly related to lower risk of T2D, serially mediated through PA, BMI, and/or CRP. Second, higher social cohesion was indirectly associated with lower risk of T2D, mediated through PA only, PA and CRP, and depression and CRP. Third, higher safety was indirectly associated with T2D, mediated through stress only, PA and BMI, and depression and CRP. Fourth, higher neighborhood social cohesion and safety were indirectly associated with lower risk of T2D, mediated through depression and CRP. Lastly, higher neighborhood social cohesion and safety were indirectly associated with lower risk of T2D, mediated via stress, depression, and CRP.

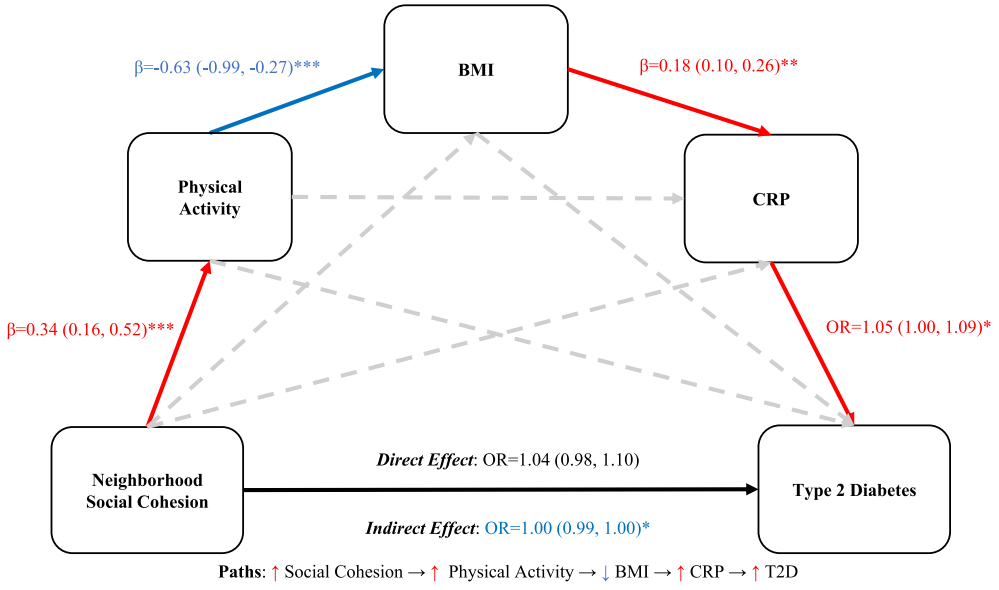

Fig. 2. Direct and indirect associations of perceived neighborhood social cohesion and type 2 diabetes, serially through physical activity, body mass index (BMI), and c-reactive protein (CRP). **Note**: Model (n = 518) adjusted for age, sex, race (NH White, Non-White adults), marital status, and education. Significance: ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$. Solid and dashed lines for each path indicate the tested associations in the analyses. As an example, solid lines for each path were presented. The results for dashed lines were also presented in tables.

Table 3
Paths of serially mediated associations between perceived neighborhood social environments and type 2 diabetes (T2D) through mediators (n = 518).

Neighborhood Social Cohesion (SC)		Neighborhood Safety (SF)	
Mediators: Physical activity (PA), body mass index (BMI), c-reactive protein (CRP)			
Paths	**β (95 % CI)**	**Paths**	**β (95 % CI)**
SC → PA	**0.34 (0.16, 0.52)*****	SF → PA	**0.30 (0.05, 0.54)***
SC → BMI	−0.43 (−1.20, 0.33)	SF → BMI	0.28 (−0.73, 1.29)
PA → BMI	**−0.63 (−0.99, −0.27)*****	PA → BMI	**−0.68 (−1.03, −0.32)*****
SC → CRP	**−0.86 (−1.56, −0.15)***	SF → CRP	−0.84 (−1.77, 0.10)
PA → CRP	**−0.43 (−0.78, −0.10)***	PA → CRP	**−0.47 (−0.80, −0.13)****
BMI → CRP	**0.18 (0.10, 0.26)*****	BMI → CRP	**0.18 (0.10, 0.26)*****
	OR (95 % CI)		**OR (95 % CI)**
PA → T2D	0.87 (0.73, 1.04)	PA → T2D	0.86 (0.72, 1.03)
BMI → T2D	**1.13 (1.09, 1.18)*****	BMI → T2D	**1.13 (1.09, 1.18)*****
CRP → T2D	**1.05 (1.00, 1.09)***	CRP → T2D	**1.05 (1.01, 1.09)***
Mediators: PA, stress (STR), CRP			
Paths	**β (95 % CI)**	**Paths**	**β (95 % CI)**
SC → PA	**0.34 (0.16, 0.52)*****	SF → PA	**0.30 (0.05, 0.54)***
SC → STR	**−2.46 (−3.27, −1.65)*****	SF → STR	**−1.98 (−3.08, −0.88)*****
PA → STR	0.01 (−0.38, 0.39)	PA → STR	−0.11 (−0.50, 0.28)
SC → CRP	**−0.80 (−1.54, −0.06)***	SF → CRP	−0.65 (−1.61, 0.31)
PA → CRP	**−0.55 (−0.89, −0.21)****	PA → CRP	**−0.59 (−0.92, −0.25)*****
STR → CRP	0.05 (−0.02, 0.13)	STR → CRP	0.07 (−0.01, 0.14)
	OR (95 % CI)		**OR (95 % CI)**
PA → T2D	**0.82 (0.69, 0.97)***	PA → T2D	**0.82 (0.69, 0.96)***
STR → T2D	1.04 (1.00, 1.08)	STR → T2D	**1.04 (1.00, 1.09)***
CRP → T2D	**1.06 (1.02, 1.10)****	CRP → T2D	**1.06 (1.02, 1.10)****
Mediators: PA, depression (DEP), CRP			
Paths	**β (95 % CI)**	**Paths**	**β (95 % CI)**
SC → PA	**0.34 (0.16, 0.52)*****	SF → PA	**0.30 (0.05, 0.54)***
SC → DEP	**−3.39 (−4.30, −2.48)*****	SF → DEP	**−2.12 (−3.37, −0.87)*****
PA → DEP	−0.15 (−0.58, 0.28)	PA → DEP	−0.33 (−0.78, 0.11)
SC → CRP	−0.62 (−1.37, 0.13)	SF → CRP	−0.57 (−1.52, 0.39)
PA → CRP	**−0.54 (−0.87, −0.20)****	PA → CRP	**−0.56 (−0.89, −0.22)*****
DEP → CRP	**0.09 (0.02, 0.16)****	DEP → CRP	**0.10 (0.04, 0.17)****
	OR (95 % CI)		**OR (95 % CI)**
PA → T2D	**0.82 (0.7, 0.97)***	PA → T2D	**0.82 (0.69, 0.97)***
DEP → T2D	1.03 (0.99, 1.06)	DEP → T2D	1.03 (1.00, 1.06)
CRP → T2D	**1.06 (1.02, 1.10)****	CRP → T2D	**1.06 (1.02, 1.10)****

Note: ***p < 0.001, **p < 0.01, *p < 0.05. OR = odds ratio. CI = confidence interval.

Despite some inconsistencies with previous studies, particularly regarding the associations of perceived neighborhood social cohesion and safety with PA, these variations may be attributed to differences in study design, populations, methodologies, and geographical contexts [60–62]. For instance, African American adults in New Orleans reported that higher social cohesion and safety were not related to a higher likelihood of engaging in PA [61]. Another study in California found that mothers who reported higher perceived neighborhood safety had higher PA levels, mediated through higher social cohesion. Furthermore, consistent with prior research, higher BMI and elevated CRP levels were associated with increased T2D risk [63,64], highlighting the critical role of inflammatory pathways in the progression of diabetes. The observed mediations through psychosocial stressors, such as stress and depression, underscore the importance of addressing mental health in diabetes prevention. Elevated stress and depressive symptoms were linked to unhealthy behaviors, such as reduced PA levels, dietary habits, and increased BMI, and were associated with higher CRP levels, further exacerbating T2D risk [65,66].

Potential explanations for these pathways were that middle-to-older adults reporting higher perceived neighborhood social cohesion (i.e., helping each other, trustworthy neighbors) tend to report higher perceived safety, leading to higher PA levels [60–62]. In turn, physically active people tend to have lower BMI or maintain a healthy weight [24,67]. Those who are obese or have higher BMI often have higher CRP levels [63,64], leading to a higher risk of T2D. A possible explanation for some inconsistent associations of neighborhood social cohesion and safety with diabetes [61] might be due to differences in study sites and demographic characteristics. Further research should investigate whether such linkages can be observed in various racial and/or ethnic groups with a large sample size.

This study's strengths include using data from the MIDUS 3 and MIDUS 3 Biomarker Project, which allowed for an innovative investigation of serial mediations involving health-related, psychosocial, and biological factors. However, some limitations should be acknowledged. The predominantly White, older, and well-educated sample of adults may limit the generalizability of findings to other populations, particularly socially disadvantaged minority groups that have historically experienced higher levels of neighborhood disadvantage. Additionally, the cross-sectional study design precludes causal inferences of the identified bio-behavioral pathways. Future research should explore these pathways in diverse populations as the MIDUS 3 participants were predominantly White adults and further consider bidirectional relationships among mediators, such as stress and depression, to clarify their roles in T2D risk among a diverse sample of participants. Stratified analyses by sex, racial and/or ethnic, and socio-economic status (SES) groups are warranted to identify differential effects in disadvantaged populations. These findings highlight potential intervention targets, such as enhancing neighborhood social cohesion and safety, promoting PA, addressing psychosocial stressors, and reducing inflammation to mitigate T2D risk among at-risk groups.

5. Conclusions

This study explored the role of serial mediations and provided novel insights into how supportive neighborhood social contexts may influence diabetes risk through behavioral, psychosocial, and biological mechanisms. Given this, continued local and national endeavors to create cohesive, safer communities could promote physical activity participation and better access to healthy food choices [21,68]. In turn, such activity-friendly and safe environments and better access to healthy foods can reduce psychosocial stressors [65], thereby contributing to a reduction in the risk of diabetes at the population level. Further research is needed, particularly from the minority population, to elucidate and understand the differential effects by sex, racial and/or ethnic groups, and SES levels to confirm and refine these findings. The identified pathways offer promising targets for interventions to reduce T2D risk for at-risk populations.

CRediT authorship contribution statement

Kosuke Tamura: Writing – review & editing, Writing – original draft, Conceptualization, Funding acquisition, Investigation, Methodology. **Mohammad Moniruzzaman:** Writing – review & editing, Methodology, Formal analysis. **Breanna J. Rogers:** Writing – review & editing, Formal analysis. **Yangyang Deng:** Writing – review & editing. **Lu Hu:** Writing – review & editing. **Ram Jagannathan:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.diabres.2025.112165.

Data availability

The data that support the findings of this study are available in the National Archive of Computerized Data on Aging at https://www.icpsr.umich.edu/web/NACDA/studies/36346/publications, reference number [ICPSR 36346] and https://www.icpsr.umich.edu/web/NACDA/studies/38837, reference number [ICPSR 38837]. These data were derived from the following resources available in the public domain: Inter-university Consortium for Political and Social Research (ICPSR; https://www.icpsr.umich.edu/web/pages/index.html).

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