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The association between the community SARS exposure and allostatic load among Chinese older adults

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Abstract

Objectives: Previous studies have found that severe acute respiratory syndrome (SARS) was associated with the physical and psychological stress of those infected. However, research is sparse regarding the long-term health consequence of community SARS exposure for older adults.

Methods: Using data from the 2011 and 2015 China Health and Retirement Longitudinal Study (CHARLS), we estimated multilevel regression models of allostatic load (AL) in the years after the SARS epidemic among 7735 respondents. Interaction terms between SARS epidemic exposure and social participation or community environment were included to examine potential effects.

Results: We found that community SARS exposure was associated with greater AL for those who had no social participation. Among those who were in worse community environment, community SARS exposure was strongly related to elevated load in the cardiovascular system. However, for those had social participation and lived in better community environment, community SARS exposure manifested no association with AL years later. Active social participation and better community environment could offset the negative association between SARS exposure and AL.

Conclusions: Taken together, these findings helped determine the positive direction of future social efforts and policy decisions to guide the global recovery from the devastating COVID-19 pandemic.

KEYWORDS

Allostatic load, China, community environment, severe acute respiratory syndrome, social participation

INTRODUCTION

The coronavirus disease 2019 (COVID-19) has been a worldwide pandemic and caused a significant health burden. Although China has successfully controlled the spread of COVID-19, the trauma and loss of life that have been caused is evident. Many older people are much more vulnerable not only to health problems related to the disease itself but also to toxic stressors associated with experiencing this traumatic life event.[1] However, it is too early to know whether the COVID-19 pandemic will cause any changes in health outcomes for China's aging population years later, since the pandemic has not been under control worldwide and there are few available data sources for researchers to study. So we turned to the similar pandemic, severe acute respiratory syndrome (SARS) between 2002 and 2004, for inspiration.

SARS, caused by SARS-associated coronavirus (SARS-CoV), was found in China's Guangdong province in November 2002 and then in other 30 countries. By the spring of 2003, it had infected more than 8000 people worldwide and killed more than 800 people.[2] SARS and COVID-19 share several similarities.[3] First, the two diseases are caused by two related coronavirus strains, so that they have similar symptoms: they can be spread rapidly through close person-to-person contact or contacting with contaminated materials and are highly contagious and deadly. Second, they required testing and quarantine and created large-scale public health emergencies. Third, during the SARS outbreak and the current COVID-19 pandemic, the older adults were highly prevalent in terms of infection and mortality.

SARS was found to be associated with the physical and psychological stress of those infected.[4,5] The disaster may also affect those who were not directly infected, resulting in bereavement, poverty, stigma, and guilt for survival.[6,7] In addition, it is possible to increase the likelihood of infection through community contact and thus act as a source of psychosocial stress for community residents.[7] Allostatic load (AL), as manifested by multisystem physiological indicators, represents the price paid for the compensation to frequent or severe challenges exacted on the body that enables adaptation to psychosocial stressors to be able to enhance stress reactivity and regain physiological balance.[8,9] It is seen as a useful summary measure of overall health.[10] There are possibilities that the trauma and stress exposure to SARS may have a lasting effect on the physiological health.[11,12]

In addition, people exposed to stressors of the same type and intensity may not exhibit similar results due to other factors.[13] Social participation may make up for trauma and stress exposure to catastrophic events.[14] It can meet the psychological and social needs and increase the resilience of older adults.[13] It contributes to the sense of self-efficacy and mastery of older adults and help them better cope with disasters.[15] Besides, community resources, such as neighborhood environment and community socio-economic status, can provide social capital and help those affected recover more quickly from the negative consequences of the disaster exposure.[16] However, research on the mitigating effects of social participation and community resources on SARS exposure is lacking.

Older adults were at higher risk of infection and mortality due to poorer predisaster health, reduced sensory awareness, and lower socio-economic status.[5] Even if they were not infected or eventually recovered, this may lead to an intensification of the stress response.[17] It is therefore crucial to understand the long-term association between SARS and AL for older adults. Using nationally representative data from the 2011 and 2015 China Health and Retirement Longitudinal Survey (CHARLS), we aim to examine whether community exposure to the SARS epidemic was associated with AL among Chinese older adults, and whether the association can be mitigated by social participation and/or community environment. Specifically, we test the following hypotheses:

Key Points

- SARS exposure is associated with greater allostatic load for those having no social participation or living in worse community environment.
- Social participation and better community environment could mitigate the negative association.

Why Does this Paper Matter?

Our study will help determine the positive direction of policy decisions to guide the global recovery from the devastating coronavirus disease 2019 (COVID-19) pandemic.

Hypothesis 1. Chinese older adults living in communities exposed to SARS were more likely to have higher AL compared to those not living in communities exposed to SARS.

Hypothesis 2. The association between whether living in communities exposed to SARS and the AL was weaker among Chinese older adults who reported having social participation in 2011 or 2015.

Hypothesis 3. The association between whether living in communities exposed to SARS and the AL was weaker for Chinese older adults who reported living in better community environment in 2011 or 2015.

METHODS

Data and sample

We obtained data from the 2011 and 2015 China Health and Retirement Longitudinal Study (CHARLS). CHARLS is a prospective cohort survey using the method of probabilities proportional to size (PPS) sampling in 28 provinces, including 150 counties, 450 communities (villages), and 12,400 households. It targeted Chinese middle-aged and older adults aged 45 years and above, aiming to collect a set of high-quality socioeconomic and health data in China.[18] Venous blood was collected by staff from the China Center for Disease Control in 2011 and 2015. CHARLS 2011 also included a questionnaire regarding the social, economic, history, and environments of the community, based on interviewers' and residents' observations.

Venous blood was collected from 11,847 respondents in the 2011 baseline survey, with a response rate of 67%. In the 2015 follow-up, 13,420 individuals' venous blood were collected, among which 7648 were interviewed in 2011. Therefore, we got 17,619 participants with venous blood collection in either 2011 or 2015. 7021 individuals were excluded due to missing community SARS exposure data in CHARLS 2011. We matched the communities these participants are living in 2011 and 2015 with the corresponding community SARS exposure data, and dropped 261 participants who ever moved during 2003–2015, to ensure that all participants lived in the same community of the corresponding SARS outbreak. The remaining 10,337 participants were converged into 20,674 panel participants, of which we excluded 4935 participants with missing data on AL indicators and 8180 participants with missing data on age or aged younger than 60 years. The remaining 7559 respondents constituted the final analytic sample (Figure S1).

Measures

Allostatic load

We examined 11 biomarkers of physiological health from 4 physiological systems, including 10 blood-based biomarkers and 1 anthropometric measurements.[19] The methods of laboratory assay for the blood-based biomarkers have been described in detail elsewhere.[20,21] We constructed a dichotomous indicator for each biomarker to indicate whether the marker fell into a high-risk category. Cutoff points for high-risk levels were based on commonly used clinical cutoff points, which were recommended by the manufacturer of the assay kit, as shown in Table S1.[20,21] Summary indices for each system were constructed based on their measurers, respectively. Following previous studies, the AL score was calculated as a count of these dichotomous indicators (ranging = 0–11).[19]

SARS exposure

In the community questionnaire of CHARLS 2011, local officials, or two to three older adults most familiar with the community history provided information about the three most severe natural disasters/epidemics occurred in their community since 1945. These disasters/epidemics included floods, droughts, fires, earthquakes, typhoons, snow and ice disasters, hepatitis A, SARS, plagues, measles, mumps, hand, foot and mouth disease, influenza A, AIDS, and swelling. If the SARS epidemic was mentioned as one of the three natural disasters/epidemics within a community, we then regarded the community to be exposed to SARS. Previous study has demonstrated that the measure of community SARS exposure has sufficient structure validity.[22]

It was worth noting that, as the CHARLS questionnaire did not contain such information on whether the participants were infected directly by the virus, we cannot fully certify that the participants in the study were not infected by the SARS-CoV virus. Fortunately, as the total number of people infected by SARS in mainland China was only 5327,[2] it was almost impossible that our nationally representative sample ($N = 7559$) contained participants directly infected by the SARS-CoV virus. Therefore, what we measured was much more about the damage caused by the psychosocial stress or isolation that results from being quarantined, losing a loved one, material deprivation, and experiencing survivor's guilt.[6,7]

Social participation

Social participation was assessed by self-reported participation in social activities a month before the interview, which was a multiple-choice question including 10 activities: (1) interactions with friends; (2) playing Mahjong, chess, cards or going to the community club; (3) helping family, friends, or neighbors who do not live with participants; (4) going to sport, social, or other kind of club; (5) taking part in a community organization; (6) voluntary or charity work; (7) caring for a sick or disabled adult who does not live with the respondents and who did not pay for the help; (8) attending educational or training course; (9) stock investment; and (10) using internet.[23,24] A code of 0 indicated that the respondent did not participate in the above social groups or social activities, and a code of 1 indicated that the respondent did participate in at least one of them.

Community environment

Community environment includes the living environment (the physical characteristics and often includes village infrastructure), the socioeconomic environment (the social and economic characteristics), and the human environment (characteristics of people residing in the community), which was measured by interviewers'

TABLE 1 Characteristics of Chinese older adults by community SARS epidemic exposure, from the 2011 and 2015 China Health and Retirement Longitudinal Study (CHARLS)

	Full sample ($N = 7559$)		Exposed to SARS ($N = 535$)		Not exposed to SARS ($N = 7024$)		
Variables	**Mean/N**	**SD/%**	**Mean/N**	**SD/%**	**Mean/N**	**SD/%**	***t* or χ^2**
Allostatic load	2.148	0.020	2.303	0.079	2.136	0.021	0.036
Load in the cardiovascular system	0.460	0.008	0.515	0.031	0.456	0.008	0.050
Load in the metabolic system	0.971	0.013	1.004	0.050	0.969	0.014	0.492
Load in the inflammation system	0.219	0.005	0.242	0.019	0.217	0.005	0.206
Load in the renal system	0.522	0.008	0.551	0.031	0.520	0.009	0.334
Had social participation	3264	44.79	260	50.29	3004	44.37	0.009
Better community environment	3518	46.71	353	65.98	3165	45.24	<0.001
Age (in years)	68.062	0.076	68.643	0.293	68.018	0.079	0.036
Female	3771	49.89	277	51.78	3494	49.74	0.365
Education							<0.001
Illiterate/no formal education	2883	38.16	160	29.91	2723	38.79	
Elementary school	3370	44.61	206	38.50	3164	45.07	
Middle school and above	1302	17.23	169	31.59	1133	16.14	
Married	6003	79.43	405	75.70	5598	79.71	0.027
Rural residence	5553	73.46	315	58.88	5238	74.57	<0.001
Nonagriculture work/never worked	3778	50.40	351	65.61	3427	49.23	<0.001
Impaired ADLs	2080	27.65	133	24.95	1947	27.85	0.149
Impaired IADLs	2531	33.55	158	29.53	2373	33.85	0.041
CES-D scores	8.924	0.077	8.179	0.255	8.980	0.080	0.007
Smoking							0.026
Never smoking	4128	55.08	321	60.23	3807	54.69	
Former smoking	1241	16.56	86	16.13	1155	16.59	
Current smoking	2125	28.36	126	23.64	1999	28.72	
Alcohol drinking							0.324
Never drinking	5693	77.55	405	80.20	5288	77.36	
Occasionally drinking	654	8.91	41	8.12	613	8.97	
Regularly drinking	994	13.54	59	11.68	935	13.68	

Abbreviations: ADL, activities of daily living; CES-D, Center for Epidemiologic Studies Depression Scale; IADL, instrumental activities of daily living; SARS, severe acute respiratory syndrome; SD, standard deviation.

evaluation of (1) community socioeconomic status (1 = poor to 7 = rich), (2) tidiness of roads (1 = very dirty to 7 = very tidy), (3) construction structure (1 = very disorganized to 7 = very organized), (4) crowdedness (1 = very crowded to 7 = very sparse), (5) handicapped access (1 = no handicapped access to 7 = very convenient), and (6) mandarin fluency (1 = cannot speak to 7 = fluent).[22,25] A mean score was created (range = 1–7; $\alpha = 0.71$) and we further converted it into a binary variable with a code of 0 indicating worse community environment (the score was below 3.5) and 1 indicating better community environment (the score was above 3.5).

Covariates

Covariates included (a) participants' socioeconomic status: age (continuous), sex (male or female), education (Illiterate/no formal education, elementary school, middle school, or high school and above), marital status (married or unmarried), residence (urban or rural), and work status (agriculture work or nonagriculture work/never worked); (b) health status: activities of daily living (ADLs, impaired or unimpaired), instrumental activities of daily living (IADLs, impaired or unimpaired), and the Center for Epidemiologic Studies Depression Scale (CES-D) scores

TABLE 2 Results from multilevel regression models for community SARS epidemic exposure and allostatic load among Chinese older adults, from the 2011 and 2015 China Health and Retirement Longitudinal Study (CHARLS)

	Model 1		Model 2	
Variables	Coef.	95% CI	Coef.	95% CI
Allostatic load				
Fixed effects				
SARS exposure	0.105	−0.094, 0.304	0.337	−0.038, 0.712
× Social participation			−0.307*	−0.607, −0.006
× Better community environment			−0.107	−0.531, 0.318
Social participation	0.088*	0.009, 0.166	0.110**	0.028, 0.191
Better community environment	0.059	−0.048, 0.166	0.066	−0.044, 0.177
Age (in years)	0.022***	0.015, 0.029	0.022***	0.015, 0.029
Female	−0.110	−0.232, 0.013	−0.110	−0.232, 0.013
Education (Ref: illiterate/no formal education)				
Elementary school	−0.011	−0.115, 0.093	−0.011	−0.114, 0.093
Middle school and above	−0.149*	−0.289, −0.008	−0.146*	−0.287, −0.006
Married	−0.003	−0.110, 0.104	−0.001	−0.108, 0.107
Rural residence	−0.199***	−0.320, −0.078	−0.200***	−0.320, −0.079
Nonagriculture work/never worked	0.272***	0.188, 0.355	0.272***	0.188, 0.355
Impaired ADLs	0.209***	0.114, 0.304	0.210***	0.115, 0.305
Impaired IADLs	0.004	−0.084, 0.093	0.003	−0.086, 0.092
CES-D scores	0.001	−0.006, 0.007	0.001	−0.006, 0.007
Smoking (Ref: never smoking)				
Former smoking	0.051	−0.079, 0.182	0.049	−0.082, 0.180
Current smoking	−0.029	−0.150, 0.093	−0.031	−0.153, 0.091
Alcohol drinking (Ref: never drinking)				
Occasionally drinking	−0.287***	−0.424, −0.150	−0.286***	−0.423, −0.149
Regularly drinking	−0.224***	−0.352, −0.096	−0.221***	−0.349, −0.092
Random effects				
Individual variance	1.053***	1.001, 1.107	1.052***	1.000, 1.106
Community variance	0.239***	0.183, 0.312	0.237***	0.181, 0.310

Abbreviations: ADL, activities of daily living; CES-D, Center for Epidemiologic Studies Depression Scale; CI, confidence interval; IADL, instrumental activities of daily living; SARS, severe acute respiratory syndrome.

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

(continuous); (c) Health behaviors: smoking (never, former, or current), and alcohol consumption (never, occasionally, or regularly).

Statistical analysis

We first conducted bivariate analyses of individual and community characteristics by community-level SARS epidemic exposure, with analysis of variance for continuous variables, and the χ^2-test for categorical variables. Next, we estimated mixed effects multilevel regression models for AL. Mixed effects multilevel modeling included extra hierarchical levels of community and individuals to account for the clustering of repeated observations within community and individuals.[26] Interaction terms between SARS epidemic exposure and (a) social participation or (b) community environment were then included to examine potential effects. A *p*-value <0.05 was considered to indicate statistical significance. Multiple imputation methods with chained equations were carried out to address missing values.[27] A total of 10 complete data sets generated and analyzed in Stata/SE version16.0 for Mac (StataCorp LD, College Station, TX, USA).

Sensitivity analyses using different ways to construct AL, as reported in the sister studies to CHARLS, viz. US Health and Retirement Study (HRS) and the English Longitudinal Study of Ageing (ELSA), were conducted to check the robustness of the results. We included different numbers of biomarkers as previous studies have done.[28] Eight biomarkers (systolic and diastolic blood pressure, glycated hemoglobin, high-density lipoprotein, total cholesterol, waist circumference, cystatin C, and C-reactive protein) as in the HRS[29] and 11 biomarkers (systolic and diastolic blood pressure, glycated hemoglobin, high-density lipoprotein, total cholesterol, waist circumference, BMI, triglyceride, glucose, cystatin C and C-reactive protein) as in the ELSA[30] were included in the analysis and found consistent results (Tables S2 and S3).

Ethics approval

Ethical approval for collecting data on human subjects was received from the Biomedical Ethics Review Committee of Peking University (IRB00001052–11015). All participants provided written informed consent.

RESULTS

Characteristics of our sample are presented in Table 1. Results from bivariate analyses showed that Chinese older adults living in communities exposed to the SARS epidemic were more likely to have higher AL (2.303 vs. 2.136, $p = 0.036$), load in the cardiovascular system (0.515 vs. 0.456, $p = 0.050$), social participation (50.29% vs. 44.37%, $p = 0.009$), and in better community environment (65.98% vs. 45.24%, $p < 0.001$) compared to their counterparts living in communities not exposed to SARS. However, they did not differ in load in the metabolic system ($p = 0.492$), the inflammation system ($p = 0.206$), or the renal system ($p = 0.334$).

Table 2 presents results from multilevel regression models concerning SARS epidemic exposure and AL. The results showed that living in communities exposed to SARS was not significantly associated with AL overall (Model 1: 0.105, 95% CI, −0.094 – 0.304). We found a significant interaction between SARS exposure and social participation (Model 2: −0.307, 95% CI, −0.607 – −0.006). In a stratified analysis (Table S4), exposure to the SARS epidemic was significantly related to higher AL for Chinese older adults who reported no social participation last month (0.256, 95% CI, 0.001–0.511); however, the association between SARS exposure and AL was not significant for older adults who had social participation (−0.016, 95% CI, −0.279 – 0.247). Figure 1 illustrates how SARS exposure was related to predicted AL depending on social participation (calculated from results in Model 2).

Table 3 shows results for multilevel regression models concerning SARS epidemic exposure and load in multiple systems. Results indicated that living in communities exposed to the SARS epidemic was not significantly associated with load in multiple systems overall (Model 1). We found a significant interaction between SARS exposure and social participation for load in the inflammation system (Model 2: −0.112, 95% CI, −0.190 – −0.034). In a stratified analysis (Table S4), community exposure to SARS was significantly associated with higher load in the inflammation system among those having no social participation (0.256, 95% CI, 0.001–0.511) but nonsignificant among those who had social participation (−0.016, 95% CI, −0.279 – 0.247).

In Table 3, we also found a significant interaction between SARS exposure and community environment for older adults' load in the cardiovascular system (Model 2: −0.204, 95% CI, −0.374 – −0.035). In a stratified analysis (Table S5), community exposure to SARS was significantly associated with higher load in the cardiovascular system among those living in worse community environment (0.175, 95% CI, 0.021–0.330) but nonsignificant among those living in better community environment (−0.012, 95% CI, −0.098 – 0.073). Figure 2 illustrates community exposure to the SARS epidemic and predicted load in the cardiovascular system by community environment, as well as predicted load in the inflammation system by social participation (calculated from results in Model 2).

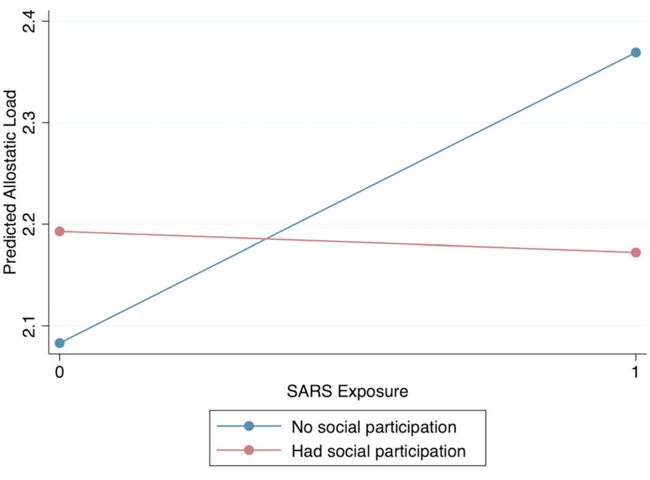

FIGURE 1 Community severe acute respiratory syndrome (SARS) epidemic exposure and social participation for allostatic load among Chinese older adults, from the 2011 and 2015 China Health and Retirement Longitudinal Study (CHARLS). Models adjusted for age, sex, education, marital status, residence, work status, ADLs, IADLs, CES-D scores, smoking, and alcohol drinking

TABLE 3 Results from multilevel regression models for community SARS epidemic exposure and load in multiple systems among Chinese older adults, from the 2011 and 2015 China Health and Retirement Longitudinal Study (CHARLS)

	Model 1		Model 2	
Variables	**Coef.**	**95% CI**	**Coef.**	**95% CI**
Load in the cardiovascular system				
Fixed effects				
SARS exposure	0.040	−0.040, 0.120	0.184*	0.034, 0.334
× Social participation			−0.010	−0.129, 0.109
× Better community environment			−0.204*	−0.374, −0.035
Social participation	−0.012	−0.043, 0.019	−0.011	−0.043, 0.020
Better community environment	−0.030	−0.074, 0.013	−0.017	−0.061, 0.028
Random effects				
Individual variance	0.398***	0.377, 0.421	0.398***	0.376, 0.421
Community variance	0.102***	0.080, 0.130	0.100***	0.078, 0.128
Load in the metabolic system				
Fixed effects				
SARS exposure	−0.0120	−0.144, 0.120	−0.104	−0.350, 0.142
× Social participation			−0.047	−0.242, 0.148
× Better community environment			0.173	−0.108, 0.453
Social participation	0.067**	0.017, 0.118	0.070**	0.018, 0.123
Better community environment	0.049	−0.022, 0.120	0.038	−0.035, 0.111
Random effects				
Individual variance	0.744***	0.715, 0.775	0.744***	0.715, 0.775
Community variance	0.161***	0.125, 0.208	0.160***	0.124, 0.207
Load in the inflammation system				
Fixed effects				
SARS exposure	0.020	−0.022, 0.062	0.085*	0.006, 0.164
× Social participation			−0.112**	−0.190, −0.034
× Better community environment			−0.013	−0.101, 0.075
Social participation	0.004	−0.016, 0.024	0.012	−0.009, 0.032
Better community environment	0.008	−0.014, 0.029	0.009	−0.014, 0.031
Random effects				
Individual variance	0.196**	0.178, 0.216	0.196**	0.178, 0.216
Community variance	0.027**	0.010, 0.068	0.027**	0.011, 0.066
Load in the renal system				
Fixed effects				
SARS exposure	0.044	−0.038, 0.125	0.055	−0.099, 0.208
× Social participation			−0.089	−0.212, 0.033
× Better community environment			0.053	−0.120, 0.227
Social participation	0.009	−0.023, 0.041	0.018	−0.015, 0.051
Better community environment	0.015	−0.030, 0.059	0.012	−0.034, 0.058
Random effects				
Individual variance	0.280***	0.250, 0.313	0.281***	0.252, 0.314
Community variance	0.114***	0.093, 0.139	0.114***	0.093, 0.140

Note: Models adjusted for age, sex, education, marital status, residence, work status, ADLs, IADLs, CES-D scores, smoking, and alcohol drinking.
Abbreviations: ADL, activities of daily living; CES-D, Center for Epidemiologic Studies Depression Scale; CI, confidence interval; IADL, instrumental activities of daily living; SARS, severe acute respiratory syndrome.
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

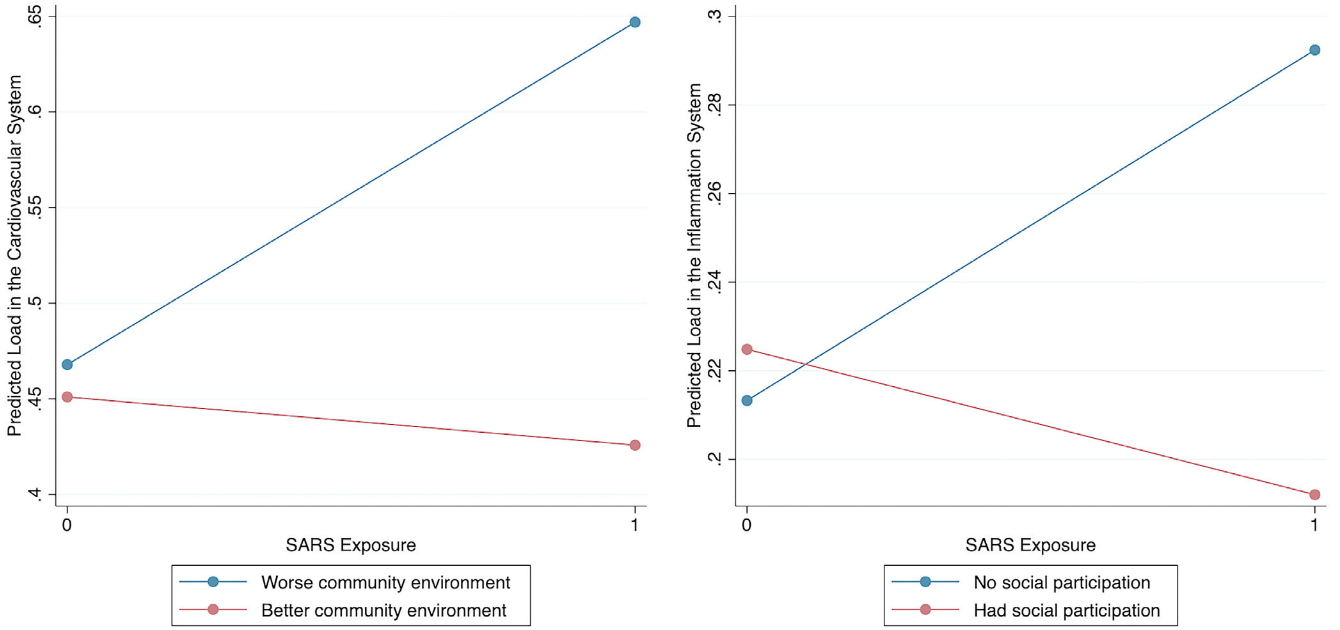

FIGURE 2 Community SARS epidemic exposure, community environment, and social participation for the load in cardiovascular and inflammation system among Chinese older adults, from the 2011 and 2015 China Health and Retirement Longitudinal Study (CHARLS). Models adjusted for age, sex, education, marital status, residence, work status, ADLs, IADLs, CES-D scores, smoking, and alcohol drinking

DISCUSSION

From a life-course perspective, this study is the first to examine the associations between community-level exposure to the 2003 SARS epidemic in adulthood and AL years in older age. Results demonstrated long-lasting association of community SARS exposure with higher AL and load in the inflammation system among Chinese older adults with no social participation, as well as an association between community SARS exposure and higher load in the cardiovascular system for older adults living in worse community environment. Social participation and better community environment emerged as salient protective factors for the allostatic risks of Chinese older adults exposed to the SARS epidemic. This correlational finding is important for drawing insights into future studies on the COVID-19 pandemic and health.

We found that community-level SARS exposure was not related to AL and offered little support for Hypothesis 1. However, the interaction term with social participation was statistically significant. Results from the stratified model revealed a significant association between community-level SARS exposure and AL among those who had no social participation, which supported Hypothesis 2. This may indicate physiological changes were associated with posttraumatic stress disorder following the SARS exposure, at least among those who did not engage in social activities and those who survived to follow-up. Yet for people who often have psychological trauma after exposure to a disaster, they may cope with traumatic experiences and rebuild their psychological resilience by social participation.[31] Conversely, those who did not recover from trauma may be at higher risk of mortality and unavailable to provide data years after an epidemic.

Our findings further revealed that community SARS exposure was related to higher load in the inflammation system (measured by c-reactive protein, CRP) for those had no social participation, which also offers support for Hypothesis 2. This is in some way consistent with a recent finding that community SARS exposure was more strongly related to elevated CRP among Chinese older adults who had low levels of social participation.[22] Elevated CRP reflects some of the underlying physiological responses to a community-level traumatic stressor and a risk factor for cardiovascular disease, functional decline, and mortality.[32,33] One physiological response to social isolation is increased CRP, thus social participation can mitigate the negative effects of SARS on the inflammation system.[34,35] On the other hand, health consequences of infectious disease epidemics for those individuals who had no social participation may be quite long-lasting.

In addition, results revealed a significant association between community-level SARS exposure and load in the cardiovascular system only among those living in worse community environment. That is, better community environment could alleviate load in the cardiovascular system associated with the SARS epidemic, which supported Hypothesis 3. Like other large-scale natural disasters, exposure to the SARS epidemic was a traumatic stressor for older adults. Community environment manifested by community socioeconomic status, tidiness of roads, construction structure, crowdedness, handicapped access, and mandarin fluency reflects a kind of social capital, which can help older adults better cope with the traumatic stressor and lower cardiovascular mortality.[36,37] However, evidence of the precise mechanisms or underlying pathways is needed.[36]

Overall, findings were suggestive of the protective role that social participation and community environment may play in the setting of an infectious disease epidemic. These findings are of particular interest because many of the social partners and relationships these older adults relied on were also likely to be exposed to the SARS epidemic within the same community. This study indicated that, even in circumstances that require social distancing and self-quarantine, efforts to bolster social participation and build supportive community environment may be the key in facilitating allostatic resiliency.[38] Thus, maintaining active social participation throughout life and living in better community environment provide resilient coping strategies for older adults, even when disasters are not predictable.

There are some contributions and potential implications. First, we explored the relationship of AL and the load in each system with SARS exposure comprehensively, which has never been done before. Second, we used longitudinal datasets of CHARLS 2011 and 2015, hoping to provide insight into the longitudinal relationship between exposure to SARS and AL in older age from a life-course perspective. Third, since SARS and COVID-19 share similar epidemiological and clinical characteristics, the results may provide important insights for future pandemic studies on COVID-19 and its associations with AL among aging populations.[3] Policy makers can improve older adults' access to social participation and better community environment, even under circumstances of social distancing and isolation. Such programs may help enhance the resilience of older adults and mitigate the harmful effects of COVID-19 exposure.

The first potential limitation of this study is that the retrospective reports of SARS exposure may be subject to potential recall bias. Second, CHARLS did not provide community identifiers, so objective information could not be used to validate the incidence and severity of SARS exposure. Third, as the CHARLS questionnaire did not contain information on whether the participants were infected directly by the virus, we were unable to isolate the effects of participants' infection with the virus itself. Fourth, potential confounders not included in CHARLS may also explain the implications of the epidemic, such as pre-SARS health status, personality traits, and psychological stressors. In addition, there may be other unmeasured environmental factors that may partially explain the association between epidemic exposure and older adults' health, such as neighborhood cohesion, availability of relatives, and the environment, which eases cross-species jump of pathogens which made SARS possible.

CONCLUSIONS

In conclusion, our findings contribute to the growing literature concerning epidemic and health by highlighting the importance of social participation and better community environment in mitigating the negative association. Results manifested that the association between AL and exposure to the 2003 SARS epidemic is long-lasting for community residents with no social participation and living in worse community environment. This was particularly evident concerning elevated load in the cardiovascular system and the inflammation system. The findings may help indicate the direction of future social efforts and policy interventions to alleviate AL associated with the devastating COVID-19 pandemic.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

Study concept and design: Ping He and Xin Ye. *Acquisition of data*: Xin Ye. *Analysis and interpretation of data*: Xin Ye and Ping He. *Preparation of the manuscript*: Xin Ye and Ping He. *Supervison*: Ping He.

SPONSOR'S ROLE

None.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

Table S1. Descriptive statistics for allostatic load, from the 2011 and 2015 China Health and Retirement Longitudinal Study (CHARLS).
Table S2. Sensitivity analysis from multilevel regression models for eight biomarkers among Chinese older adults, from the 2011 and 2015 China Health and Retirement Longitudinal Study (CHARLS).
Table S3. Sensitivity analysis from multilevel regression models for 11 biomarkers among Chinese older adults, from the 2011 and 2015 China Health and Retirement Longitudinal Study (CHARLS).
Table S4. Results from multilevel regression models for community SARS epidemic exposure, allostatic load, and load in the inflammation system by social participation among Chinese older adults, from the 2011 and 2015 China Health and Retirement Longitudinal Study (CHARLS).
Table S5. Results from multilevel regression models for community SARS epidemic exposure and load in the cardiovascular system by community environment among Chinese older adults, from the 2011 and 2015 China Health and Retirement Longitudinal Study (CHARLS).
Figure S1. Sample flowchart showing data sources and how the study sample was derived.

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