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Preventive Medicine 164 (2022) 107329

Contents lists available at ScienceDirect

Preventive Medicine

journal homepage: www.elsevier.com/locate/ypmed

Pre-pandemic social isolation as a predictor of the adverse impact of the pandemic on self-rated health: A longitudinal COVID-19 study in Japan

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ARTICLE INFO

Keywords:
COVID-19
Fixed-effects model
Self-rate health
Social isolation
State of emergency

ABSTRACT

Many studies have found adverse effects of the coronavirus disease pandemic on health. Irrespective of being infected by the coronavirus, lockdowns and other measures to restrict mobility have worsened an individual's subjective health assessment. Unlike previous studies, this study examined how pre-pandemic social isolation (in the form of no interaction with others and having no social support) affected the impact of the pandemic on self-rated health in Japan. To this end, we estimated fixed-effects models using 4172 observations of 2086 individuals obtained from a three-wave Internet nationwide survey conducted in January/February 2019 and February 2020 (before the pandemic), in March 2021 (when the pandemic-related state of emergency was effective in four prefectures and just after it was lifted in six prefectures), and in October/November (a full month after the state of emergency was lifted in all prefectures). The state of emergency raised the probability of reporting poor health by 17.8 (95% confidence interval [CI]:1.9–33.8) percentage points among the participants who had not interacted with others before the pandemic, compared with only 0.7 (95% CI: −3.1–4.5) percentage points among other participants. Similar results were obtained in the absence of social support prior to the pandemic. In conclusion, pre-pandemic social isolation was detrimental to health, suggesting that policy measures are needed to avoid social isolation to increase the resilience of public health to external shocks.

1. Introduction

Many studies have observed the negative impact of the coronavirus disease 2019 (COVID-19) pandemic on mental health, health behaviors, and general health outcomes including self-rated health (SRH) (Breslau et al., 2021; Niedzwiedz et al., 2021; Peters et al., 2020; Tušl et al., 2021; Yarrington et al., 2021). In addition to increasing uncertainties about income and employment conditions and pressures on daily activities, including care for family members (Beach et al., 2021; McNamara et al., 2021; Molarius and Persson, 2022), heightened risks of social isolation are considered to increase the risk of deterioration of health outcomes. Specifically, lockdowns, as well as less stringent policy measures to restrict mobility, had adverse psychological impacts (Prati and Mancini, 2021; Yamamoto et al., 2020). Studies have observed that individuals, especially older adults, feel more isolated and lonelier during the pandemic resulting in increased risks of stress, anxiety, and psychological distress, as well as deterioration in general health outcomes (Kim and Jung, 2021; Kotwal et al., 2021; Macdonald and Hülür, 2021; Müller et al., 2021; Murayama et al., 2021; Sepúlveda-Loyola et al., 2020; Yamada et al., 2021). These findings are generally in line with the well-established view that social isolation has a negative impact on health (Cacioppo et al., 2010; Erzen and Çikrikci, 2018; Holt-Lunstad et al., 2015; Leigh-Hunt et al., 2017), while some studies are skeptical about the direct impact of increased social isolation during the pandemic on mental health (Stolz et al., 2021; van Tilburg et al., 2021).

Unlike previous studies that focused on the impact of the pandemic on social isolation and its association with health, this study examined how pre-pandemic social isolation affected the impact of the pandemic on health in Japan. We focused on SRH as a health outcome that represents overall health conditions (Idler and Benyamini, 1997; Jylhä, 2009). Based on previous observations about the health impact of social isolation, it is reasonable to hypothesize that individuals who had been

Abbreviations: SRH, Self-rated health.

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https://doi.org/10.1016/j.ypmed.2022.107329
Received 30 March 2022; Received in revised form 14 September 2022; Accepted 30 October 2022
Available online 2 November 2022

socially isolated before the pandemic would be more vulnerable to pandemic exposure than others. If this hypothesis is validated, policy measures to prevent people from becoming socially isolated should be recommended to strengthen the resilience of public health against external shocks.

We examined the validity of this hypothesis by utilizing data obtained from a three-wave Internet survey in Japan, which was conducted before the pandemic, during the state of emergency that was effective in some prefectures, and after the state of emergency was completely lifted. The dataset had two key benefits for the statistical analysis of the health impact of the pandemic, potentially distinguishing this study from most previous studies. First, we could determine whether each participant was living in a prefecture that was under the pandemic-related state of emergency when it was effective. Mobility restrictions were more stringent in prefectures that declared the state than in others, although the restrictions were request-based and not legally binding in Japan (Yamamoto et al., 2020). Prefecture-level variations in mobility restrictions allowed us to evaluate their impact on individual health more accurately than previous studies that focused solely on the differences between before and during the pandemic at the national level. Second, we controlled for time-invariant attributes at both individual and prefecture levels by estimating regression models that absorbed fixed effects at both levels (Guimarães and Portugal, 2010). Cross-sectional analysis is likely to overestimate the association between social isolation and health, especially if these variables are subjectively assessed, because these variables are affected by an individual's unobserved and unobservable attributes, such as personality traits. The same is true, albeit to a lesser extent, for the prefecture-level fixed attributes. Fixed-effect regression models can mitigate these potential biases.

2. Methods

2.1. Study sample

This study used data obtained from population-based, nationwide Internet surveys conducted in January/February 2019, February 2020 (Wave 1), March 2021 (Wave 2), and October/November 2021 (Wave 3). We distributed questionnaires to the registrants of an Internet survey company. To construct the pre-pandemic benchmark sample in Wave 1, we planned to collect data from approximately 5000 participants: around two-thirds of them from the survey between January 25 and February 7, 2019, and the remaining one-third from the survey between February 7 and 20, 2020. The target samples were divided into two groups. First, approximately 3800 registrants were distributed equally between each of the 47 prefectures, between men and women, and among the five age groups (15–24, 25–34, 35–44, 45–59, and 60+ years of age). Thus, each prefecture sex-age group included 24 individuals. Next, we allocated approximately 1400 registrants to each gender-age group in each prefecture in proportion to each prefecture's actual population size. When the survey was closed, data from 4177 participants were obtained.

We conducted a Wave 2 survey between March 3 and 11, 2021, when Japan faced the third wave of COVID-19 infections. During the survey, four prefectures in the Tokyo metropolitan area (Tokyo, Chiba, Saitama, and Kanagawa) were still in a state of emergency, and just after six prefectures (Aichi, Gifu, Osaka, Hyogo, Kyoto, and Fukuoka) lifted the emergency on February 28, 2021. We sent the questionnaire to those who participated in the survey in Wave 1 and collected data from 2311 individuals. Finally, we conducted a Wave 3 survey between October 28 and November 8, 2021, a month after all prefectures had lifted the state of emergency on September 30, reflecting the number of new cases. We sent the questionnaire to those who participated in the survey in Waves 1 and 2 and collected data from 2260 individuals who participated in all three waves. The data were used in the statistical analysis. The aims and procedures of this study were reviewed and approved by the Research Ethics Committee of Hitotsubashi University (Reference No. 2021C010). Informed consent was obtained from all the participants.

For statistical analysis, we excluded the respondents whose satisfaction with health or personal relationships was very low in Wave 1 as a measure to control for the potential confounding effects of pre-existing health problems or personal relationships. The participants scored their satisfaction with their health and personal relationships on a scale of 0 (lowest) to 10 (highest). We excluded 174 participants who scored their satisfaction with their health or personal relationships as 0 or 1 at Wave 1, accounting for 7.7% of the total sample. As a result, we used 4172 observations of 2086 participants at Waves 2 and 3 for statistical analysis.

2.2. Measures

2.2.1. Social isolation

We utilized two survey measures to measure the degree of social isolation: no interaction with others and receiving no social support. Regarding no interaction with others, the survey asked, “How often are you interacting (e.g., meeting and communicating) with others on average?” We constructed a binary variable of no interaction with others by allocating one to those who answered that they did not interact with anyone and zero to others. Second, we constructed a binary variable of receiving no social support by allocating one to those who answered *none* to the question, “Do you have any family members or friends who support you if you are in trouble?” and zero to others. The results of these two measures of social isolation were further compared with those of participating in no social activity and living alone, both of which are likely related to social isolation. We constructed a binary variable of participating in no social activity by allocating one to those who answered *never* to the question, “How often are you participating in volunteer or other social activities?” We also constructed a binary variable of living alone based on the answer to the question asking with whom the participant was residing. All these variables (no interaction with others, receiving no social support, participating in no social activity, and living alone) were evaluated in Wave 1, that is, before the pandemic.

2.2.2. Self-rated health

Regarding SRH, the survey asked participants to answer the question, “How do you feel about your health condition?” by selecting *good*, *somewhat good*, *average*, *somewhat poor*, or *poor*, respectively. Considering that the score is generally skewed toward better health, we constructed a binary variable for poor SRH by allocating 1 to those who answered *poor*, *somewhat poor*, and zero to others.

2.2.3. State of emergency at the prefecture-level

To understand the impact of the pandemic, we focused on the pandemic-related state of emergency at the prefectural level. Two binary variables were constructed. First, we constructed a binary variable, Group 1, by allocating one to living in Tokyo, Chiba, Saitama, or Kanagawa in Wave 2, because these prefectures were in a state of emergency during the Wave 2 survey period. Second, we constructed a binary variable, Group 2, by adding living in Aichi, Gifu, Osaka, Hyogo, Kyoto, and Fukuoka in Wave 2 to Group 1, as these six prefectures had been in a state of emergency until just a few days before the Wave 2 survey period. The Wave 3 survey was conducted a month later than the state of emergency was lifted in all prefectures.

2.2.4. Covariates at the individual level

For covariates at the individual level, we considered educational attainment, sex, age, marital status (married or unmarried), educational attainment, occupational attainment, and household income. Regarding age, five binary variables for those in their 20s or below, 30s, 40s, 50s, and 60s or above were considered. Regarding educational attainment, we constructed four binary variables: junior high school, high school, junior college, and college or higher. Regarding occupational status, we

constructed six binary variables of regularly employed, non-regular (i.e., part-time, temporary) employed, self-employed, out of labor force, unemployed, and students. For household income, binary variables were constructed for each quartile.

2.3. Analytic strategy

We started with a benchmark, linear probability model (Battey et al., 2019; Wooldridge, 2013), which linearly explains the probability of reporting poor SRH by assessing the state of emergency and its interaction with pre-pandemic social isolation, as well as covariates for individual i ($i = 1$ to 2086) living in prefecture p ($p = 1$ to 47) in wave w ($w = 2, 3$):

$$Poor\ SRH_{ipw} = \alpha + \beta SE_{pw} + \gamma SE_{pw} \times SI_i + (covariates) + u_i + v_p + \varepsilon_{ipw}. \quad (1)$$

Here, *poor SRH*, *SE*, and *SI* indicate the binary variables of poor SRH, state of emergency, and pre-pandemic social isolation, respectively; u and v are fixed effects at the individual and prefecture levels, respectively; and ε is an error term. The *SI* alone was not included as an explanatory variable because it was determined in Wave 1 and fixed in Waves 2 and 3. The estimated coefficient β indicates the impact of the pandemic on those who had not been socially isolated before the pandemic, while the value of $\beta + \gamma$, which was calculated after regression, indicates the impact on socially isolated participants. We used outcomes of both Waves 2 and 3 as controls for time-invariant individual attributes in the fixed-effects regression.

As for pre-pandemic social isolation (*SI*), we compared two types: no interaction with others and receiving no social support, as well as two alternatives: no engagement in social activity and living alone. Two variables for the state of emergency (*SE*) were Group 1 (under the state of emergency in Wave 2) and Group 2 (under the state of emergency until immediately before Wave 2).

We applied inverse probability weighting to mitigate the attrition bias (Wooldridge, 2010). Specifically, we first used the probit model to predict the probability of staying in the survey until Wave 3 for each participant using their attributes observed in Wave 1. We then used the inverse of the predicted probability as a weight in our main regression analysis, using Eq. (1).

We also examined how the pandemic has affected social isolation. To this end, we replaced poor SRH with social isolation (no interaction with others or receiving no social support) during the pandemic in Eq. (1). The Stata software package (Release 17) was used for all the statistical analyses.

3. Results

Table 1 summarizes the key features of the participants observed at the pre-pandemic baseline in Wave 1. Compared to female participants, male participants had a somewhat higher educational attainment, more stable occupational status, and higher household income. Out of the entire sample, the proportions of those participants who did not interact with others, did not receive any social support, and lived alone in Wave 1 were 11.7%, 9.3%, and 15.6%, respectively; whereas the proportion of those who did not participate in social activity was much higher (61.4%). We also found that 17.4% of the participants rated their health as poor. Although not reported in the table, 308 out of the 2142 participants lived in four prefectures under the state of emergency in Wave 2, and 339 participants lived in six prefectures that lifted the state of emergency just before Wave 2; that is, Groups 1 and 2 consisted of 308 and 647 (308 + 339) participants, respectively.

Fig. 1 compares the (unadjusted) proportion of participants reporting poor health during the state of emergency and the pre-pandemic status of social isolation as defined by Group 1. As seen in this figure, the proportion of poor SRH was much higher among those who had been socially isolated before the pandemic than among others. More importantly, the proportion of poor SRH rose substantially under the state of emergency among those who had been socially isolated before the pandemic, while it while it even fell slightly among others. This result suggests that the impact of the pandemic fell exclusively on those who were socially isolated before the pandemic.

Table 1
Key features of participants at the pre-pandemic baseline.

		All	Men	Women
Married		56.7	55.4	57.8
Educational attainment				
Junior high school		2.2	2.3	2.1
High school		41.8	38.1	44.9
Junior college		12.9	4.2	20.4
College or above		43.1	55.4	32.6
Occupational status				
Regularly employed		43.4	61.6	27.7
Non-regularly employed		23.1	12.4	32.2
Self-rated		7.3	9.1	5.7
Out of labor force		3.3	1.9	4.5
Unemployed		17.9	9.4	25.2
Students		5.1	5.6	4.7
No interaction with others		11.7	15.3	8.6
No social support		9.3	12.5	6.5
No social activity		61.4	59.5	62.9
Living alone		15.6	16.6	14.7
Poor SRH		17.4	18.1	16.9
Age	*M*	44.1	43.5	44.6
(years)	*SD*	(15.4)	(15.4)	(15.5)
Household income	*M*	615.1	692.4	548.4
(annual, million JPY)	*SD*	(708.3)	(879.8)	(507.6)
N		2086	966	1120

Table 2 summarizes the estimation results of the regression models to examine the impact of no interaction with others before the pandemic on the probability of reporting poor SRH. The table compares the results between Groups 1 and 2 as participants were exposed to the state of emergency in Wave 2. At the bottom of the table, we compare the impact on those with interaction with others before the pandemic (β) and those with no interaction with others ($\beta + \gamma$) before the pandemic.

From this table, we observe that the emergency state did not affect those who had interaction with others before the pandemic, judging by the estimated value of β, which was 0.7 (95% confidence interval [CI]: −3.1–4.5) and 0.4 (95% CI: −2.4–3.1) percentage points for Groups 1 and 2, respectively. In sharp contrast, the pandemic increased the probability of reporting poor SRH, which was expressed by the estimated values of $\beta + \gamma$, by 17.8 (95% CI: 1.9–33.8) and 13.8 (95% CI: 4.4–23.2) percentage points for Groups 1 and 2, respectively. These results indicate that the adverse impact of the pandemic on SRH was concentrated in those with no interaction with others before the pandemic, a result consistent with that in Fig. 1. We also found that the impact of the pandemic was somewhat higher for Group 1 than for Group 2, a reasonable result given that the prefectures in Group 1 were actually in a state of emergency in Wave 2.

Table 3 summarizes and compares the estimation results of no interaction with others, receiving no social support, participating in no social activity, and living along, focusing on the estimated values of β, γ, and $\beta + \gamma$. From this table, we observe that, as with the case of no interaction with others, the SRH of those who received no social support before the pandemic worsened during the pandemic while those who received it experienced no impact from it. We also found that participation in no social activity had mixed effects; those who had participated in no social activity before the pandemic experienced a deterioration in SRH during the pandemic in Group 2 but not in Group 1. We further found that living alone before the pandemic did not affect the impact of the pandemic.

Finally, Table 4 summarizes the estimation results of the regression models to explain how the probability of social isolation during the pandemic was affected by pre-pandemic social isolation. When we used Group 2, the probability of no interaction with others decreased by 5.3% among those who had been interacting with others before the pandemic.

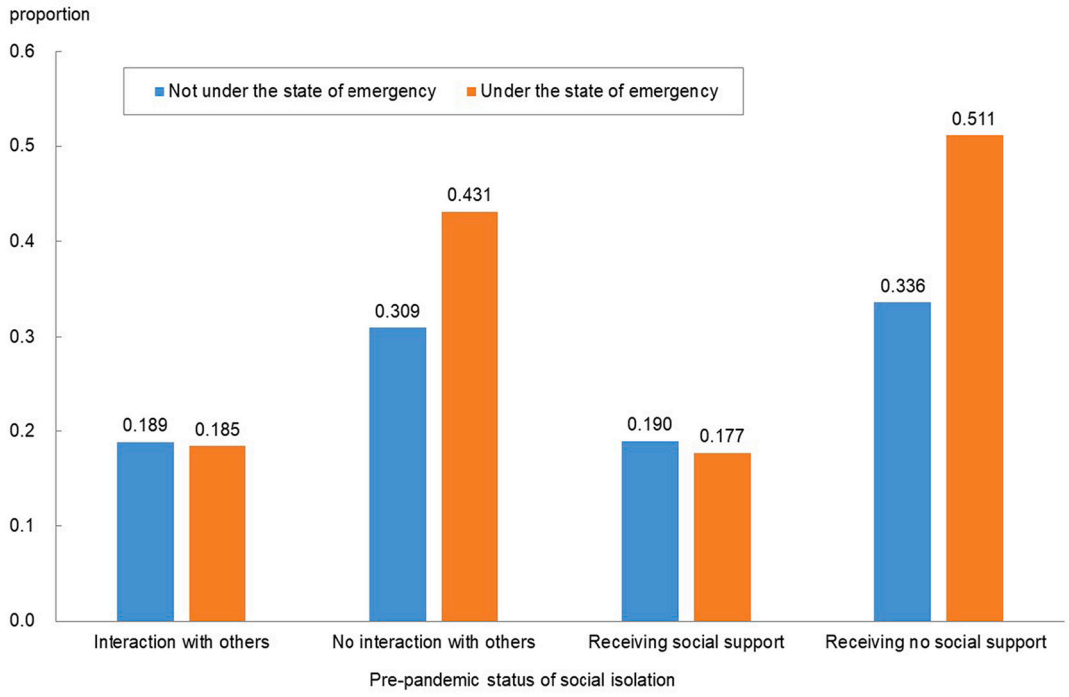

Fig. 1. Proportion of participants reporting poor health.

Table 2
Impact of the state of emergency on the probability of reporting poor health depending on pre-pandemic interaction with others.[a]

	Group 1[b]			Group 2[c]		
	Coef.	95% CI[d]		Coef.	95% CI	
Emergency state (β)	0.007	(−0.031,	0.045)	0.004	(−0.024,	0.031)
Emergency state × No interaction with others (γ)	0.171	(0.007,	0.335)	0.134	(0.037,	0.232)
Married	−0.071	(−0.165,	0.024)	−0.073	(−0.167,	0.022)
Educational status (ref. = college or above)						
Junior high school	0.095	(−0.086,	0.276)	0.096	(−0.085,	0.277)
High school	0.066	(−0.103,	0.235)	0.069	(−0.100,	0.238)
Junior college	0.041	(−0.140,	0.223)	0.038	(−0.143,	0.219)
Occupational status (ref. = regularly employed)						
Non-regularly employed	0.019	(−0.073,	0.112)	0.021	(−0.072,	0.114)
Self-rated	−0.006	(−0.108,	0.095)	−0.005	(−0.106,	0.097)
Out of labor force	0.009	(−0.138,	0.156)	0.019	(−0.128,	0.167)
Unemployed	0.032	(−0.096,	0.159)	0.037	(−0.090,	0.164)
Students	−0.005	(−0.160,	0.151)	−0.003	(−0.158,	0.152)
Household income (ref. = 4th quartile)						
1st quartile	−0.027	(−0.134,	0.080)	−0.031	(−0.138,	0.076)
2nd quartile	−0.088	(−0.169,	−0.006)	−0.093	(−0.175,	−0.011)
3rd quartile	−0.007	(−0.073,	0.060)	−0.009	(−0.075,	0.058)
Age (ref. = 20s or below)						
30s	−0.051	(−0.228,	0.126)	−0.051	(−0.228,	0.126)
40s	−0.074	(−0.294,	0.146)	−0.070	(−0.290,	0.150)
50s	−0.023	(−0.292,	0.246)	−0.021	(−0.289,	0.246)
60s or above	0.007	(−0.266,	0.281)	0.009	(−0.263,	0.281)
Impact on those with interaction with others (β)	0.007	(−0.031,	0.045)	0.004	(−0.024,	0.031)
Impact on those with no interaction with others ($\beta + \gamma$)	0.178	(0.019,	0.338)	0.138	(0.044,	0.232)

$N = 4172$ (of 2086 participants).
Note. [a] Controlled for fixed effects at the individual and prefecture levels.
[b] Tokyo, Chiba, Saitama, and Kanagawa were under emergency conditions during the Wave 2 survey period.
[c] Group 1 + Aichi, Gifu, Osaka, Hyogo, Kyoto, and Fukuoka, which had been in an emergency until a few days before the Wave 2 survey period.
[d] Confidence interval.

Excluding this exception, we observed no impact of the pandemic on social isolation, regardless of the pre-pandemic social isolation, and there was no significant difference between socially isolated individuals and others.

4. Discussion

This study examined how the impact of the COVID-19 pandemic on an individual's SRH depended on pre-pandemic social isolation using a three-wave nationwide Internet survey conducted in Japan. After

Table 3
Impact of the pandemic on the probability of reporting poor health.[a]

	Group 1[b]			Group 2[c]		
	Coef.	95% CI[d]		Coef.	95% CI	
Interaction with others (β)	0.007	(−0.031,	0.045)	0.004	(−0.024,	0.031)
No interaction with others ($\beta + \gamma$)	0.178	(0.019,	0.338)	0.138	(0.044,	0.232)
Difference (γ)	0.171	(0.007,	0.335)	0.134	(0.037,	0.232)
Receiving social support (β)	0.037	(−0.005,	0.078)	0.023	(−0.006,	0.051)
Receiving no social support ($\beta + \gamma$)	0.156	(0.025,	0.286)	0.121	(0.034,	0.207)
Difference (γ)	0.119	(−0.017,	0.256)	0.098	(0.008,	0.188)
Participating in social activity (β)	0.020	(−0.020,	0.060)	−0.015	(−0.052,	0.023)
Participating in no social activity ($\beta + \gamma$)	0.036	(−0.020,	0.091)	0.044	(0.007,	0.082)
Difference (γ)	0.016	(−0.052,	0.084)	0.059	(0.006,	0.112)
Living with family members (β)	0.038	(−0.004,	0.080)	0.036	(0.005,	0.066)
Living alone ($\beta + \gamma$)	−0.001	(−0.103,	0.102)	0.033	(−0.029,	0.095)
Difference($-\gamma$)	−0.039	(−0.148,	0.071)	−0.003	(−0.071,	0.066)

$N = 4172$ (of 2086 participants).
Note. [a] Controlled for fixed effects at the individual and prefecture levels as well as covariates.
[b] Tokyo, Chiba, Saitama, and Kanagawa were under emergency conditions during the Wave 2 survey period.
[c] Group 1 + Aichi, Gifu, Osaka, Hyogo, Kyoto, and Fukuoka, which had been in an emergency until a few days before the Wave 2 survey period.
[d] Confidence interval.

Table 4
Impact of the pandemic on the probability of social isolation.

	Group 1[b]			Group 2[c]		
	Coef.	95%CI		Coef.	95%CI	
Dependent variable = No interaction with others under the pandemic						
Interaction with others (β)	−0.048	(−0.097,	0.001)	−0.053	(−0.086,	−0.020)
No interaction with others ($\beta + \gamma$)	0.056	(−0.126,	0.238)	−0.009	(−0.126,	0.108)
Difference (γ)	0.104	(−0.085,	0.292)	0.044	(−0.077,	0.165)
Dependent variable = Receiving no social support under the pandemic						
Receiving social support (β)	−0.017	(−0.051,	0.017)	−0.010	(−0.032,	0.013)
Receiving no social support ($\beta + \gamma$)	0.006	(−0.183,	0.194)	−0.006	(−0.137,	0.125)
Difference (γ)	0.023	(−0.169,	0.214)	0.004	(−0.130,	0.137)

$N = 4172$ (of 2086 participants).
Note. [a] Controlled for fixed effects at the individual and prefecture levels as well as covariates.
[b] Tokyo, Chiba, Saitama, and Kanagawa were under emergency conditions during the Wave 2 survey period.
[c] Group 1 + Aichi, Gifu, Osaka, Hyogo, Kyoto, and Fukuoka, which had been in an emergency until a few days before the Wave 2 survey period.
[d] Confidence interval.

controlling for individual- and prefecture-level fixed effects, our regression models showed that the adverse impact of the pandemic-related state of emergency fell exclusively on individuals who had been socially isolated before the pandemic, specifically those who had no interaction with others or received no social support.

Unlike most preceding studies that focused on the impact of the pandemic on social isolation and its effect on health, this study highlighted that pre-pandemic social isolation made the exposure to the pandemic—or, more specifically, mobility constraints under the pandemic-related state of emergency and/or their psychological pressure—detrimental to general health conditions during the pandemic. Predictably, the pandemic will increase the feelings of social isolation and worsen subjective health assessments. Previous studies did observe that the pandemic makes individuals feel more socially isolated (Kim and Jung, 2021). However, the results of this study suggest that this impact is not uniform. Individuals who had not been socially isolated may not feel unhealthier during the pandemic. Probably they did not feel socially isolated during the pandemic, as they kept communicating with others or felt linked to others. In contrast, individuals who had been socially isolated before the pandemic felt unhealthy during the pandemic, presumably because they expected the chances of personal interactions to be further reduced and thus increasing the feelings of isolation.

These asymmetric responses do not represent the actual changes in social isolation conditions. We found that the state of emergency during the pandemic did not reduce the frequency of social interaction or the availability of social support, regardless of pre-pandemic social isolation, but socially isolated people feel more isolated and unhealthier during the pandemic, while others do not. This finding suggests that social isolation before the pandemic may make people more vulnerable to the pandemic, probably via its adverse impact on psychological, behavioral, and health problems (Cacioppo et al., 2010, and others), even before the shock.

Another noticeable finding was that unlike no interaction with others and receiving no social support, participating in no social activity or living alone did not affect the impact of the pandemic. This study's definition of social activity centered on volunteer activities, where more than 60% of the participants answered that they were not engaged in any social activity. This probably made participation in social activities far from the conventional concept of social isolation. The observation that living alone or not did not affect the impact of the pandemic is reasonable because individuals living alone can interact with others and receive social support (Oshio and Kan, 2019).

4.1. Study limitations and strengths

This study has several limitations. First, non-random sampling in the Internet survey, in addition to the limited sample size and reduced generalizability of the study findings. Second, all measures of social isolation and health outcomes were evaluated subjectively by each

participant; therefore, their reliability or validity was not evaluated, requiring caution in interpreting the estimation results. Third, our regression analysis implicitly assumed that the declaration and lifting of the state of emergency had a symmetric impact on SRH and ignored the evolution of social isolation or SRH over time. Fourth, and most fundamentally, we did not elucidate the mechanism to explain why and how pre-pandemic social isolation affects the impact of the pandemic on health.

Despite these limitations, the results suggest that social isolation can be considered a reliable indicator of vulnerability to external shock. The validity of the finding was confirmed by the structure of our dataset, which allowed us to identify the residents in the prefectures where the state of emergency was effective. In addition, fixed-effects regression models, which absorbed time-invariant effects at the individual and prefecture levels, helped us capture the precise relationship between social isolation, pandemics, and health.

5. Conclusions

The observations obtained from the three-wave survey, which could identify individuals in the pandemic-related state of emergency, showed that the pre-pandemic socially isolated individuals were more sensitive to the pandemic than others. Therefore, policy measures are required to prevent social isolation and increase public health resilience.

Funding

This study was supported by the Japan Society for the Promotion of Science (Grant No. 20K01722).

CRediT authorship contribution statement

Takashi Oshio: Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing – original draft, Funding acquisition. **Hiromi Kimura:** Validation, Resources, Data curation, Writing – review & editing, Visualization. **Toshimi Nishizaki:** Validation, Resources, Writing – review & editing, Project administration. **Susumu Kuwahara:** Validation, Writing – review & editing, Supervision, Project administration.

Conflicts of interest

None.

Data availability

Data will be made available on request.

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