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Analysis

First, participants were assigned to one of the four groups based on the classi cation of social isolation and loneliness. en, a multinomial logistic regression model was performed to determine the factors related to the discrepancy between social isolation and loneliness; Only S (do not feel lonely even in social isolation) and Only L (feel lonely in the absence of social isolation) compared with SL (social isolation and loneliness). Subsequently, we examined the di erences between Only S and Only L in the model with Only L set as the reference.

As a supplementary analysis, we applied a multinomial logistic regression model utilizing a top-10%tile cut-o threshold for social isolation and loneliness, meaning a greater focus on severe social isolation and loneliness.

Missing data in the multinomial logistic regression model were imputed by multiple imputations with the fully conditional speci cation method. We created ve imputed datasets and integrated each result of the analysis.

e level of signi cance was set at 0.05. Statistical tests were performed using SAS version 9.4, and forest plots based on model statistics were created using the forestplot package [33] in R (version 4.3.1).

Results

Table 1 shows the participants' demographic characteristics by the social isolation and loneliness categories. e groups facing social isolation (Only S and SL) comprise older participants compared to those with no isolation. e groups with social isolation, loneliness, or both had higher proportions of females than the No SL group. e SL group had the highest prevalence of depressive symptoms (37.65%) and IADL dependence (25.34%).

Figure 1 describes the results of multinomial logistic regression analysis for the combinations of social isolation and loneliness, with the SL group set as the reference. Depressive symptoms and personality traits were closely associated with all three groups, No SL, Only S, and Only L. Participants with a less depressive tendency and higher extraversion were more likely to be in No SL,

Table 1 Descriptive statistics of independent variables by social isolation and loneliness categories

		Only loneliness (Only L) *n* = 1141		Only social isolation (Only S) *n* = 1088		Socially isolation and loneliness (SL) *n* = 585		No social isolation and no loneliness (No SL) *n* = 4787	
Continuous variables		**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Age (Year)		66.82	9.85	71.95	10.88	68.77	11.09	68.29	9.84
Household income ($1000/unit)		81.60	145.92	48.17	78.38	38.15	52.84	93.32	145.80
Personality traits (Scores)	Neuroticism	2.27	0.60	1.82	0.56	2.27	0.64	1.84	0.55
	Extraversion	3.05	0.58	3.20	0.53	2.96	0.60	3.30	0.52
Categorical variables		**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Sex	Male	389	34.09	368	33.82	203	34.70	2061	43.05
	Female	752	65.91	720	66.18	382	65.30	2726	56.95
Educational attainment	High school or less	767	67.22	807	74.17	439	75.04	2957	61.77
	College and above	374	32.78	281	25.83	146	24.96	1830	38.23
Race	White	816	71.52	757	69.58	391	66.84	3684	76.96
	Black	215	18.84	264	24.26	140	23.93	708	14.79
	Others	110	9.64	67	6.16	54	9.23	395	8.25
Ethnicity	Hispanic	127	11.13	109	10.02	56	9.57	608	12.70
	Non-Hispanic	1014	88.87	979	89.98	529	90.43	4179	87.30
Subjective health	Healthy	746	65.55	777	71.48	321	54.87	3862	80.73
	Unhealthy	392	34.45	310	28.52	264	45.13	922	19.27
Number of diseases	No disease	129	11.32	78	7.21	60	10.29	700	14.67
	1	237	20.79	223	20.61	92	15.78	1179	24.71
	≥2	774	67.89	781	72.18	431	73.93	2892	60.62
IADL	Independent	939	82.44	938	86.45	436	74.66	4406	92.06
	Dependent	200	17.56	147	13.55	148	25.34	380	7.94
Depressive symptoms	Having	305	26.97	111	10.33	218	37.65	244	5.13
	Not having	826	73.03	964	89.67	361	62.35	4516	94.87

isolation and feeling of loneliness. Our nding suggests that in the gap between social isolation and loneliness, higher extraversion and low neuroticism were associated with not feeling loneliness with social isolation (Only S). Only higher extraversion was associated with loneliness without social isolation (Only L).

Neuroticism and extraversion are personality traits that may be closely associated with stress reactivity and resilience in daily life. A prior study suggested that people with higher neuroticism experience greater stress reactivity to daily stressors than those with lower neuroticism [37]. Additionally, people with lower extraversion and higher extraversion were associated with resilience [38]. Another study reported that higher neuroticism and lower extraversion were related to worse adaptation to the COVID-19 lockdown [39], which is a situation similar to social isolation. In addition, the big ve personality traits including lower neuroticism and higher extraversion may a ect the individual's greater perception regarding how they feel about their availability of

emphasized social contact, and most of them have intervened in a single way (e.g., increase social contact, social skill training). Social involvement intervention may help improve individuals' social isolation and situational loneliness; however, this study suggests that intervention in a single way could not su ciently address the discrepancy of a state of feeling lonely even without social isolation in which individuals' characteristics such as depression, personality traits, and socioeconomic status may be connected in a complex manner. us, this study implies that incorporating social, mental, and psychotherapeutic aspects in social interventions, such as a combination of social involvement and cognitive-behavioral interventions, may be essential for future intervention strategies. Although not clari ed in this analysis, it is also possible that the mechanisms underlying the cognitive aspect of loneliness, and e ective intervention methods, di er depending on the type of combination of social isolation and loneliness. Further studies are needed to understand the mechanisms and di erences of e ective intervention among discrepancy types between social isolation and loneliness in depth.

e limitations of this study should be noted. First, our results could not address the causal relationship between variables and longitudinal changes. e factors related to the discrepancy between social isolation and loneliness in this study, such as depressive symptoms, can be bidirectionally linked to social isolation and loneliness. Second, the results were based on self-administered questionnaires. Self-reported bias, such as feelings of loneliness being in uenced by the emotions at the time of completing the questionnaire, cannot be ruled out. Di erences in evaluation between the clinical evaluation and self-reported indicators are possible in terms of mental and psychological factors, including depressive symptoms, loneliness, and personality traits. ird, there is a limitation in the validity of the cut-o of social isolation and loneliness as there is no clear gold standard when it comes to de ning these concepts. Although we con rmed the robustness of the results and obtained consistent associations between mental status and personality traits with the outcomes across di erent cut-o s in the supplemental analysis, careful consideration is needed along with discussing the standard de nition of social isolation and loneliness. Fourth, as we aim to capture the overall association, this study could not su ciently con-

Data availability
The data sets generated and/or analyzed during the current study are available in the HRS repository at https://hrs.isr.umich.edu/about.

Declarations

Ethics approval and consent to participate
Ethical approval for the HRS Study was obtained from the University of Michigan Institutional Review Board. Further ethical approval and informed consent for the secondary data analysis of HRS data was waived according to the Ethical Guidelines for Medical and Health Research Involving Human Subjects in Japan. All procedures were conducted in accordance with the ethical principles for medical research involving human subjects detailed in the Declaration of Helsinki.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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