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Determinants of social health trajectories during the COVID-19 pandemic in older adults: the Rotterdam Study

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ABSTRACT

Objectives: The coronavirus disease-2019 (COVID-19) pandemic and accompanying lockdown restrictions impacted social life significantly. We studied associations of sociodemographic factors, mental and social health markers, and brain structure with social health trajectories during the COVID-19 pandemic.

Design: Prospective longitudinal population-based cohort study.

Setting: Community-dwelling inhabitants of Rotterdam, the Netherlands.

Participants: Repeated questionnaires including questions on social health were sent to Rotterdam Study participants from April 2020 onwards. Social health data at study baseline were available for 5017 participants (mean age: 68.7 ± 11.3; 56.9% women).

Measurements: Determinants were assessed in routine Rotterdam Study follow-up (1990–2020), including global brain volumes in a subset of participants (N = 1720). We applied linear mixed models and generalized estimating equations to quantify associations between determinants and trajectories of loneliness, perceived social isolation and social connectedness over three time points from April 22nd to July 31st 2020.

Results: Loneliness prevalence was 27.9% in April 2020 versus 12.6% prepandemic. Social isolation (baseline mean 4.7 ± 2.4) and loneliness scores (baseline mean 4.9 ± 1.5) decreased over time, whereas social connectedness trajectories remained stable. Depressive symptoms, female sex, prepandemic loneliness, living alone, and not owning a pet were independently associated with lower social connectedness and higher social isolation and loneliness at COVID-19 baseline, but recovery of social health was similar for all determinants. Larger intracranial volume was associated with higher social connectedness.

Conclusions: Despite baseline differences for specific determinants, older adults showed similar recovery of loneliness and social isolation alongside stable social connectedness over time during the pandemic. Social health is multidimensional, especially during a global health crisis.

Key words: social health, loneliness, longitudinal analyses, epidemiology, mental wellbeing, COVID-19, imaging

Introduction

The coronavirus disease-2019 (COVID-19) pandemic has greatly impacted social lives globally. Social and physical distancing measures were widely imposed to reduce the spread of the virus, changing daily social interactions significantly. Numerous

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studies have since reported on risk of loneliness in various populations, with conflicting findings for loneliness in older age (Rumas *et al.*, 2021; van Tilburg, 2021; van Tilburg *et al.*, 2021). Additionally, persons who live alone, have small networks or limited access to technology often reported to be lonely during the pandemic (Hansen *et al.*, 2021). Furthermore, women, people with mental health conditions, and persons with low incomes were more likely to experience loneliness during a strict lockdown (Bu *et al.*, 2020). These studies indicate that sociodemographic factors may determine how people respond to pandemic-related changes in social life.

Thus far, many studies have reported on the impact on social health in the early days of the pandemic, but usually applying only a single time-point measurement (El-Zoghby *et al.*, 2020; Geirdal *et al.*, 2021; Rumas *et al.*, 2021; Taylor *et al.*, 2021). Longitudinal studies on how social health evolved over time are emerging now that the pandemic remains ongoing (Hansen *et al.*, 2021; Kotwal *et al.*, 2021), but are still scarce and have focused only on a single, usually negative aspect of social health (i.e. loneliness and isolation; Bu *et al.*, 2020; Peng and Roth, 2021; van der Velden *et al.*, 2021). Social health is the relational domain of health and encompasses the interactional competencies of the individual and their immediate social environment (Vernooij-Dassen and Jeon, 2016; Vernooij-Dassen *et al.*, 2020). As such, social health can range from having a satisfying social life to loneliness, and includes concepts that relate to social network structure and the experience of social relationships (Vernooij-Dassen *et al.*, 2019). It is important to identify how both positive and negative dimensions of social health evolved over time, including after easing of physical distancing restrictions, to identify the ability to maintain social health and to bounce back after a crisis (Dahlberg, 2021).

Many external and internal factors may affect social health, of which mainly sociodemographic factors have been studied in relation to the pandemic so far (Taylor *et al.*, 2021; Teater *et al.*, 2021). In recent years, research has increasingly focused on the neurobiology of social functioning (Duzel *et al.*, 2019; Spreng *et al.*, 2020; van der Velpen *et al.*, 2021). Differences in brain health might explain differences in the individual experience of social health, where brain health can be defined both in the structural (i.e. imaging markers) and functional sense (i.e. cognitive function and mental health). Additionally, the perception of social health prior to the pandemic may play an important role in the experience of social health during the pandemic (Hansen *et al.*, 2021).

Studying determinants of social health trajectories during the COVID-19 pandemic may help to identify risk factors for an adverse response to change in the social environment, even outside of the context of the pandemic (Hwang *et al.*, 2020). Moreover, knowledge on social health trajectories during enforced social isolation may aid recommendations for physical distancing in the future. In this study, we describe trajectories of social health during the COVID-19 pandemic in community-dwelling middle-aged and older adults in the Netherlands during a time when pandemic-related restrictions were gradually eased. In addition, we investigate whether sociodemographic factors, prior social health, mental health, cognitive function, and pre-pandemic brain structure are determinants of social health trajectories.

Methods

Study sample and design

Rotterdam Study

The Rotterdam Study is a population-based longitudinal cohort study in Rotterdam, The Netherlands that started in 1990 and is ongoing (Ikram *et al.*, 2020). Inhabitants of the neighborhood Ommoord were invited to participate from the age of 40 years and older. Participants are invited for regular follow-up measurements, including social health assessment, every 3–6 years. All participants provided written informed consent to participate in the study and to have their information obtained from treating physicians. The Rotterdam Study has been approved by the Medical Ethics Committee of the Erasmus MC (registration number MEC 02.1015) and by the Dutch Ministry of Health, Welfare and Sport (Population Screening Act WBO, license number 1071272-159521-PG). The Rotterdam Study Personal Registration Data collection is filed with the Erasmus MC Data Protection Officer under registration number EMC1712001. The Rotterdam Study has been entered into the Netherlands National Trial Register (www.trialregister.nl) and into the WHO International Clinical Trials Registry Platform (https://apps.who.int/trialsearch/) under shared catalog number NL6645/NTR6831.

COVID-19 data collection and sample size

Shortly after the start of the COVID-19 pandemic in the Netherlands in March 2020, a tailored questionnaire was drafted to start data collection on different aspects of the pandemic in the Rotterdam Study (COVID-19 questionnaire; Licher *et al.*, 2021). The questionnaire included questions on the following categories: COVID-19-related symptoms and risk factors, mental and social health, and health care utilization during the pandemic. The questionnaire

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was sent out repeatedly from April 20th 2020 onwards. The first questionnaire was sent to all Rotterdam Study participants who were alive by April 2020 (N = 8732), excluding those living in nursing homes. The length of the intervals between the consequent questionnaires was based on the actual infection curve in the Netherlands. The first two questionnaires were sent on paper to all participants. From the third questionnaire onwards, questionnaires were sent both digitally and on paper, only to participants who actively agreed to participate (n = 5618). The response rate was 71.5% for the first questionnaire (n = 6241 returned questionnaires), 64.6% for the second (n = 5640), and 88.2% (n = 4956) for the third questionnaire.

For this project, we used data from the first three questionnaires, which were sent out with 2-week intervals between April 20th and May 22nd 2020 (Licher *et al.*, 2021). Participants were able to provide their responses without time limitation. We included questionnaire responses filled out and returned between April 22nd 2020 and July 31st 2020. A flow chart of the study sample can be found in Supplemental Figure 1. All participants with complete responses on the questions concerning loneliness, social isolation, and social connectedness in the questionnaire were included in the baseline sample (N = 5017). A subset of participants in this group had magnetic resonance imaging (MRI) of the brain performed prior to the COVID-19 pandemic (between December 2010 and February 2017). Of the baseline sample, 1771 participants had structural brain imaging data available. After exclusion of scans with cortical brain infarcts (N = 39) and participants with prevalent dementia at the time of the MRI (N = 12), 1720 participants were available for imaging analyses.

COVID-19 restrictions during data collection

Regulations to restrict the spread of SARS-CoV-2 were implemented in The Netherlands from March 12th 2020 onwards. A lockdown strategy was in place from March 23th 2020, with first restrictions lifted from May 11th 2020. An overview of the exact regulations can be found in Supplementary Table 1. The main regulations at the time of study baseline consisted of: keeping 1.5-m distance from others; working from home; and staying home with symptoms of SARS-CoV-2 infection. People were allowed to go outside for walks, but not in a group; people were advised to only go outside for groceries or to care of others, and to only travel for work if they were not able to work from home; social gatherings were not allowed and social activities and groups of people were to be avoided. Older adults and persons with frail health were advised to adhere to the regulations more strictly. Schools, daycares, cafés and restaurants, sports, and fitness clubs were closed. The maximum number of visitors per household was three persons. No visitors were allowed in nursing homes and assisted-living facilities. There was no general face mask policy in the Netherlands prior to October 2020, except for public transport from June 1st 2020 onwards. Restrictions were eased significantly on May 11th, June 1st and July 1st 2020 (Supplementary Table 1).

Determinants of social health trajectories

Sociodemographic factors and pet ownership

Age and sex were self-reported in the COVID-19 questionnaire and verified with existing Rotterdam Study data. Educational attainment was assessed during Rotterdam Study baseline interview and was categorized according to UNESCO classification. Current employment status was assessed in the COVID-19 questionnaire, with the following options: currently employed, retired, sick leave, unemployed, and other. Inspection of the *other* category showed these were mostly incapacitated for work, homemakers, and persons doing volunteer work. Pet ownership of any pet was assessed in the second COVID-19 questionnaire.

Social health markers of prior loneliness and network structure

Loneliness prior to the pandemic was assessed during routine Rotterdam Study assessments with a single item question from the Center for Epidemiologic Studies – Depression scale (CES-D; Beekman *et al.*, 1997; Radloff, 1977). Participants were asked whether they felt lonely during the past week and responses were dichotomized into lonely (experienced loneliness $\geq$ 1 day during the past week) and not lonely (experienced loneliness <1 day during the past week). Marital status and household size were considered as structural aspects of the social health concept for the purpose of this study. Marital status was assessed during the home interview of the last Rotterdam Study assessment prior to the pandemic. Being married and having a partner were grouped, as well as being widowed and being divorced as both denote being previously married. A third category consisted of never married. Marital status was assumed to remain stable over time. Household size was assessed in the first COVID-19 questionnaire and was dichotomized into living alone and living with housemates.

Depressive symptoms and cognitive function

Depressive symptoms were assessed in the COVID-19 questionnaire with the shortened version of the CES-D, which consists of 10 items and

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has a final score ranging from 0 to 30 (Andresen *et al.*, 1994). Responses with less than 9 completed items were excluded. For responses with one missing item, a weighted score was calculated. A higher score indicates more severe depressive symptoms. The cutoff for the presence of clinically relevant depressive symptoms is a score of ≥ 10 (Andresen *et al.*, 1994). Cognitive function was assessed prepandemic during routine Rotterdam Study follow-up. During the visit to the research center, all participants were screened for dementia with the Mini-Mental State Examination (MMSE). Participants with a MMSE < 26 underwent further examination for dementia assessment.

Brain volumetric measures

Imaging of the brain was performed with 1.5 tesla MRI unit (Signa Excite II, General Electric Healthcare, Milwaukee, USA) with an eight-channel head coil. The complete scan protocol including quality control and postprocessing is described in detail elsewhere (Ikram *et al.*, 2015). In brief, the scan protocol for structural imaging included a T1-weighted sequence and fluid-attenuated inversion recovery sequence. Volumetric measures were quantified through automated brain tissue segmentation. Trained raters visually inspected all scans for image quality, presence of artifacts, and segmentation. Segmentations were manually corrected when quality was insufficient. Volumetric markers in our study were intracranial volume, total brain volume, gray matter volume, and white matter volume. Total brain volume was defined as the sum of supratentorial gray matter and white matter volume. White matter volume consisted of normal-appearing white matter volume and white matter hyperintensity volume.

Social health measurements for trajectories during the COVID-19 pandemic

Loneliness was measured with two different items in separate sections of the COVID-19 questionnaires. First, loneliness was assessed using the 3-item UCLA Loneliness Scale, translated to Dutch (Hughes *et al.*, 2004). Responses are summed to a total score ranging from 3 to 9, where higher scores indicate higher degrees of loneliness. Responses with any missing items were excluded. Second, a single-item direct question on loneliness was included in the 10-item CES-D section of the COVID-19 questionnaire (Andresen *et al.*, 1994). Responses were dichotomized into lonely (experienced loneliness ≥ 1 day during the past week) and not lonely (experienced loneliness <1 day during the past week). Perceived social isolation was assessed in the COVID-19 questionnaire on a scale from 1 to 10 (1 = not socially isolated, 10 = extremely isolated). Participants were asked the question: "*How socially isolated on a scale of 1 to 10 have you felt in the past 14 days?*".

Social connectedness during the COVID-19 pandemic was assessed in the questionnaires with five items, to which participants could respond on a 5-Likert scale (strongly disagree – strongly agree). The following statements were included: (1) "*I feel connected to all Dutch people*"; (2) "*I feel connected to my neighbors, family and/or friends*"; (3) "*I receive the help and support that I need from my neighbors, family and/or friends*"; (4) "*I do everything I can to help others who are infected with the coronavirus*"; (5) "*I expect others to do everything they can to help me if I become infected with the coronavirus.*" Cronbach's α for all items combined was 0.65. Next, responses were transformed into continuous scores (1–5 with higher scores corresponding to higher degrees of social connectedness) and standardized. To summarize these items into fewer dimensions, we performed a principal components analysis with Varimax rotation. This yielded two components with an eigenvalue>1 (62.3% of cumulative variance). Items 1, 2, and 3 loaded on the first component, which we therefore labeled "*Feeling connected*". Items 3, 4, and 5 loaded on the second component, which we labeled "*Giving/receiving help during COVID-19 infection.*" Higher values on each component indicate higher degrees of social connectedness.

Other measurements

We selected the following covariates that may be potential confounders of the association between brain structure and social health during COVID-19: intracranial volume, smoking habits, alcohol consumption, body mass index, multimorbidity, clinically relevant depressive symptoms at time of MRI, and ethnicity. These covariates were only applied in analyses involving brain structure. All covariates were collected at the same time as the MRI-scan, prior to the COVID-19 pandemic. A detailed assessment of each covariate is described in Appendix A.

Statistical Analyses

Missingness was <6.0% for all determinants and covariates, except for pet ownership (missingness 13.5%). All missing determinant and covariate data were imputed with fivefold multiple imputation. Participants registered the date on which they completed the questionnaire, which was used to compute the time variable in our analyses. Time was modeled as calendar time in weeks and ranged from April 22nd 2020 to July 31st 2020. The following determinants were included for analyses in the overall study sample: age, sex, education level, employment status, pet ownership, household size, marital

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status, prior loneliness, depressive symptoms during COVID-19 baseline, and MMSE score. Determinants were studied separately in a basic model adjusted only for age and sex, and next in mutually adjusted models with all determinants combined. Age was mean-centered. We studied brain structure as a determinant of social health in a subset of the study sample with available brain imaging data (N = 1720). Brain volumetric measures were standardized. Time difference between the MRI scan and COVID-19 questionnaires was added as separate covariate (time in years). We further adjusted these models for intracranial volume, ethnicity, smoking, alcohol consumption, BMI, multimorbidity score, and CES-D score (all measured at the time of the MRI scan).

Social health trajectories were modeled using linear mixed models (LMM) for continuous outcomes (UCLA Loneliness Scale, perceived social isolation, *Feeling connected to others*, *Giving/receiving help during coronavirus infection*) and generalized estimating equations (GEE) with a logit link function for dichotomous outcomes (CES-D Loneliness). We explored for each outcome whether nonlinear time improved model fit over linear time variables. Since nonlinearity of the time variable did not meaningfully improve model fit, we applied a linear variable for time in all models. The fixed effects structure for the overall basic and mutually adjusted models consisted of an interaction term for the product of calendar time and each determinant. This interaction term indicates the rate of change over time in the outcome for each determinant. For the brain structure models, we only applied an interaction term for the product of time and each brain structure variable, but not with the other covariates in the mutually adjusted models described above. The random-effects structure is described in Appendix A.

Since we included 14 determinants and 5 outcomes (potentially 70 independent tests), but these variables are theoretically correlated, we performed permutation testing to determine the number of independent tests. Linear regressions for each variable were run with a random variable and repeated 10,000 times. For each permutation, the minimum *p*-value was extracted. *P*-values were sorted to determine the significance threshold based on the 5% quantile. We then divided 0.05 by this threshold to obtain the number of independent tests (n = 15.9). We calculated the new significance threshold using Šidák correction, resulting in a multiple-testing adjusted *p*-value threshold of 0.0032 (Sidak, 1967).

As a sensitivity analysis, we created age-adjusted percentiles of brain volumes to account for the variable time difference between MRI scan and COVID-19 questionnaire (ranging from 3 to 10 years). With this approach, we assume that the expected decrease in brain volume at the time of COVID-19 questionnaire in each participant corresponds to the expected decrease based on their percentile curve. Although brain volumes are expected to decrease over time, the percentile is hypothesized to remain stable over time. To this end, we used percentile curves fitted on the entire Rotterdam Study sample which were previously published (Cole and Green, 1992). These percentile curves were applied to participants in this study sample and used as determinants in the LMM and GEE models previously described (i.e. age-adjusted brain volumes in relation to social health trajectories).

Results

Sample characteristics from the COVID-19 study baseline are presented in Table 1. Social health data were complete for 5017 participants (mean age: 68.7 (SD 11.3); 56.9% women). Mean score on the UCLA Loneliness Scale was 4.9 (SD 1.6). Loneliness prevalence (CES-D) was 27.9% in April 2020, compared to 12.6% during the last prepandemic Rotterdam Study assessment. Social connectedness to loved ones was high (89.7%), whereas 65.5% reported feeling connected to all Dutch people. A minority of participants felt they did everything they could to help others who were infected with the coronavirus (34.1%), while 57.6% of participants expected others to provide help if they became infected themselves. In the total sample, 3771 participants (75.2%) responded to all three questionnaires (911 participants responded to two questionnaires, 335 responded to one questionnaire). For the imaging subsample, 1364 out of 1721 participants (79.3%) responded to all three questionnaires. Median time difference between the MRI scan and baseline COVID-19 questionnaire was 6.5 years (min 3.2, max 9.4 years). Participants in the imaging subset were older than the overall sample, but did not differ on other characteristics.

Trajectories of social health during COVID-19

Figure 1 displays trajectories of loneliness and perceived social isolation for the entire study sample and several subgroups. Dates on which physical distancing restrictions were lifted are shown in the figures. Social isolation, loneliness scores, and loneliness prevalence all improved from May 2020 onwards. Figure 2 shows trajectories of social connectedness. *Feeling connected* slightly decreased from April to August, while *Giving/receiving help* increased slightly over time.

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Table 1. Baseline characteristics

	Overall (N = 5017)
Sociodemographic	
Age, Mean (SD)	68.7 (11.3)
Sex (female), (N, %)	2853 (56.9%)
Education level (N, %)	
Primary education	288 (5.7%)
Lower-intermediate	1748 (34.8%)
Intermediate-higher	1519 (30.3%)
Higher-university	1411 (28.1%)
Employment status (N, %)	
Currently employed (fulltime, part-time, self-employed)	1485 (29.6%)
On sick leave	57 (1.1%)
Unemployed	149 (3.0%)
Retired	2985 (59.5%)
Other	246 (4.9%)
Pet ownership (yes), (N, %)	1350 (26.9%)
Social health prior to the pandemic	
Marital status (N, %)	
Married/has partner	3868 (77.1%)
Never married	268 (5.3%)
Widowed/divorced	858 (17.1%)
Lives with housemates (N, %)	3621 (72.2%)
Number of housemates, Median [Min, Max]	1 [0, 6]
Number of children in the household, Median [Min, Max]	0 [0, 4]
Loneliness prior to pandemic (N lonely), (N, %)	632 (12.6%)
Social health at pandemic baseline	
Loneliness during COVID-19 baseline (N lonely), (N, %)	1401 (27.9%)
UCLA Loneliness scale, Mean (SD)	4.9 (1.5)
Perceived social isolation, Mean (SD)	4.7 (2.4)
I feel connected to all Dutch people (N agree), (N, %)	3284 (65.5%)
I feel connected to my neighbors, family and/or friends (N agree), (N, %)	4499 (89.7)
I receive the help and support that I need from my neighbors, family and/or friends (N agree), (N, %)	3570 (71.2)
I do everything I can to help others who are infected with the coronavirus (N agree), (N, %)	1713 (34.1)
I expect others to do everything they can to help me if I become infected with the coronavirus (N agree), (N, %)	2891 (57.6)
Feeling connected to others, Median [Min, Max]	0.3 [−4.5, 1.7]
Giving/receiving help during COVID-19 infection, Median [Min, Max]	0 [−3.1, 2.7]
Mental and cognitive health	
MMSE, Median [IQR]	29.0 [28.0, 30.0]
Clinically relevant depressive symptoms (CES-D ≥ 10) at COVID-19 baseline, (N, %)	830 (16.5%)
CES-D score (weighted) at COVID-19 baseline, Median [IQR]	4.0 [2.0, 8.0]
Brain health and covariates (subset)	(N = 1720)
Intracranial volume (mL), Mean (SD)	1140 (116)
Total brain volume (mL), Mean (SD)	938 (97.0)
Gray matter volume (mL), Mean (SD)	533 (54.8)
White matter volume (mL), Mean (SD)	404 (57.9)
European ancestry, (N, %)	1486 (86.3%)
BMI, Mean (SD)	27.1 (3.9)
Clinically relevant depressive symptoms (CES-D ≥ 16) at scan date, (N, %)	74 (4.3%)
Smoking habits, (N, %)	
Never	626 (36.4%)
Former	909 (52.8%)
Current	186 (10.8%)
Alcohol consumption, (N, %)	
None	199 (11.6%)
Moderate	1199 (69.7%)
Heavy	323 (18.8%)

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Table 1. Continued

	Overall (N = 5017)
Multimorbidity score, (N, %)	
Low	1483 (86.2%)
Moderate	227 (13.2%)
High	11 (0.6%)

CES-D = Center for Epidemiological Studies Depression Scale; IQR = interquartile range; MMSE = Mini Mental State Examination; SD = standard deviation.

Determinants of loneliness and social isolation trajectories

Determinants of social health baseline levels (assessed with the first questionnaire during COVID pandemic) are presented in Tables 2 and 3. In mutually adjusted models after multiple testing correction, clinically relevant depressive symptoms, female sex, living alone, and experiencing loneliness prior to the pandemic were independently associated with higher social isolation, higher loneliness scores (UCLA) and loneliness prevalence (CES-D) at baseline (Table 2). Owning a pet was associated with lower social isolation and lower loneliness scores. Mean differences (95% confidence interval) in baseline UCLA loneliness scores were 1.29 (1.17; 1.41) for clinically relevant depressive symptoms, 0.61 (0.48; 0.74) for prior loneliness, 0.30 (0.22; 0.39) for female sex, − 0.32 (− 0.45; − 0.19) for living with housemates, and − 0.19 (− 0.28; − 0.09) for owning a pet.

Except for pet ownership, change over time in loneliness and perceived isolation trajectories was not significantly different for any of the determinants after multiple testing correction, indicating that the other determinants did not explain symptom resolution. Loneliness and social isolation trajectories are shown separately for clinically relevant depressive symptoms, prior loneliness, and living with housemates in Figure 1.

Determinants of social connectedness trajectories

Age, sex, clinically relevant depressive symptoms and prior loneliness were independent determinants of *Feeling connected to others* at baseline in mutually adjusted models after multiple testing correction, but did not relate to change over time (Table 3). For *Giving/receiving help during coronavirus infection*, only clinically relevant depressive symptoms was an independent determinant of lower baseline levels after multiple testing correction (Table 3). Intracranial volume was associated with change in *Giving/receiving help during coronavirus infection* over time, but not with baseline differences. Persons with larger intracranial volumes showed an increase over time in *Giving/receiving help during coronavirus infection*, while persons with smaller intracranial volume showed a decrease in *Giving/receiving help during coronavirus infection* (Figure 2).

The sensitivity analyses using percentiles of brain structure did not change the interpretation of the results.

Discussion

We aimed to describe trajectories of social health during the COVID-19 pandemic in Dutch older adults and to identify determinants of these trajectories. We found that loneliness prevalence initially doubled at COVID-19 baseline compared to previous years and that loneliness and social isolation scores improved during three months of follow-up. Social connectedness remained high throughout the first months of the pandemic. Determinants of higher levels of loneliness and social isolation at our COVID-19 study baseline were clinically relevant depressive symptoms during COVID-19 baseline, female sex and reporting loneliness prior to the pandemic. Living with housemates and pet ownership were associated with less loneliness and social isolation at our COVID-19 study baseline. The rate with which social health trajectories recovered was similar for all determinants. Larger intracranial volume was associated with an increase in social connectedness over time, but not with a baseline difference.

Overall, we found an initial increase in loneliness in our population, which decreased over time. Several studies have previously reported on the change in loneliness over time, both before and during the pandemic, with differing results. Emotional loneliness among Dutch older adults increased during the first months of the pandemic (van Tilburg, 2021; van Tilburg *et al.*, 2021). A Norwegian study reported that loneliness was stable in June 2020 compared to prior to the pandemic, but increased in the fall of 2020 (Hansen *et al.*, 2021). Older participants in a US study reported an increase in loneliness in the acute phase of the pandemic, which then leveled off in April 2020, while perceived social support

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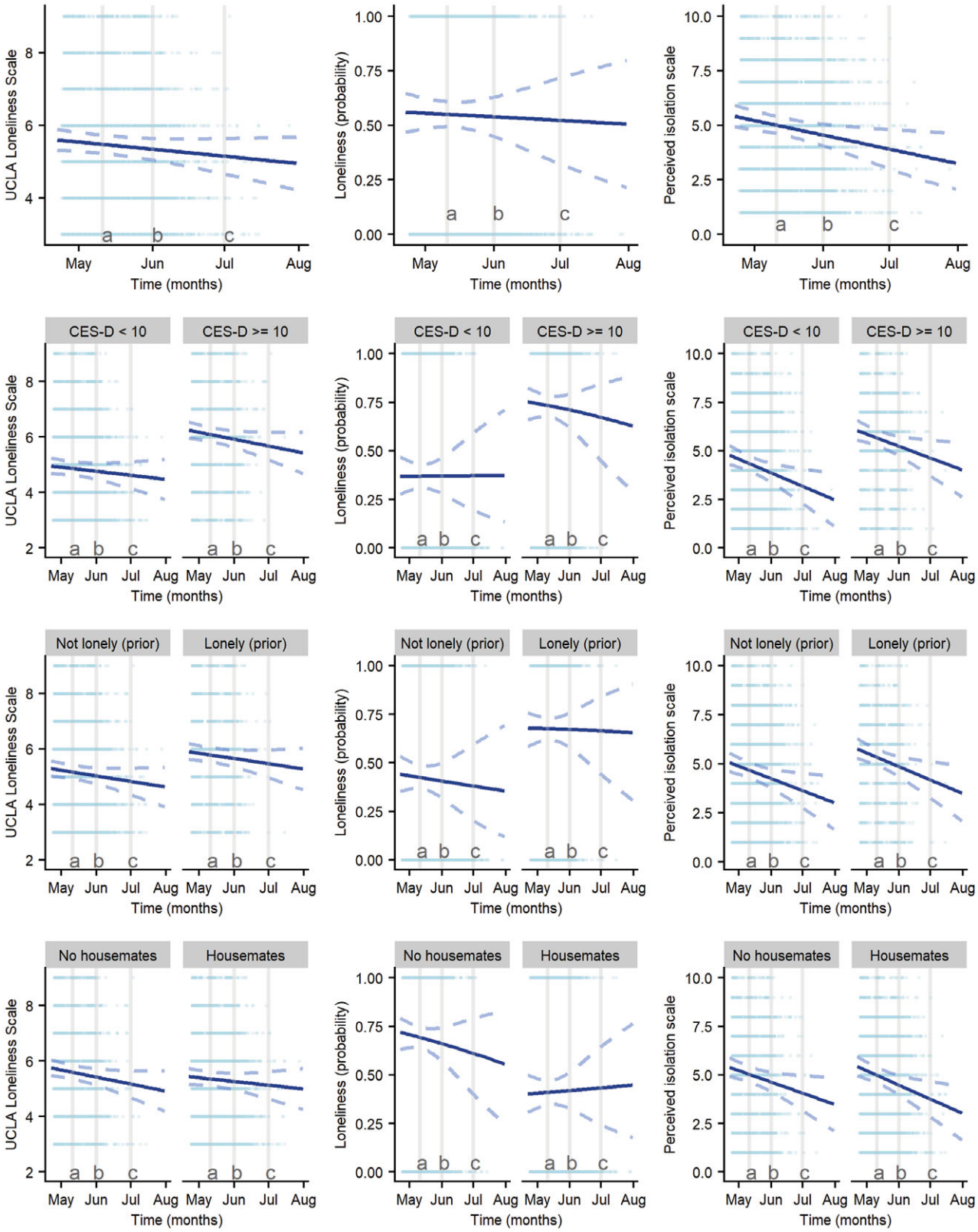

Figure 1. Trajectories of loneliness and perceived isolation during the COVID-19 pandemic in 2020. Change in loneliness and perceived isolation scores and loneliness probability from April 22nd 2020 to July 31st 2020. Solid blue lines represent the marginal (group) change in social health over time, dashed lines represent 95% confidence intervals. Individual data points over follow-up time are presented as dots. Dates during which physical distancing restrictions in the Netherlands were lifted are denoted with a (May 11th 2020), b (June 1st 2020) and c (July 1st 2020). Top row: marginal effect with 95% confidence interval for total study sample. Separate trajectories are shown for persons with or without clinically relevant depressive symptoms during COVID-19 baseline (CESD $\geq$ 10) (second row), with or without loneliness prior to the pandemic (third row), and with or without housemates during the pandemic (fourth row). CES-D = Center for Epidemiological Studies Depression Scale.

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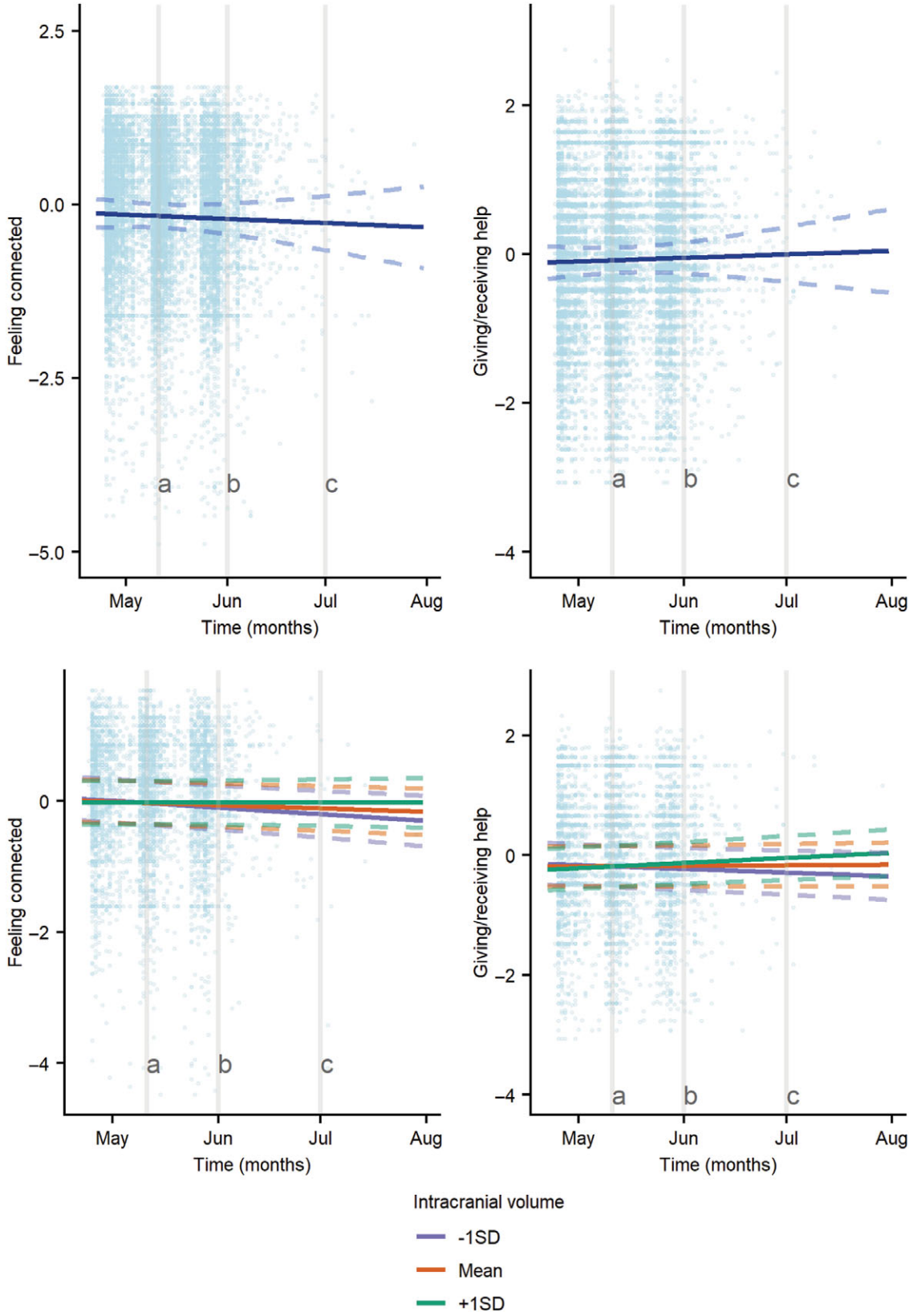

Figure 2. Trajectories of social connectedness during the COVID-19 pandemic in 2020. Change in social connectedness from April 22nd 2020 to July 31st 2020. Solid blue lines represent the marginal (group) change in social health over time, dashed lines represent 95% confidence intervals. Individual data points over follow-up time are presented as dots. Dates during which physical distancing restrictions in the Netherlands were lifted are denoted with a (May 11th 2020), b (June 1st 2020) and c (July 1st 2020). Top row: marginal effect with 95% confidence interval for total study sample. Separate trajectories are shown for mean (in orange), larger (+1SD in green), and smaller (−1SD in purple) intracranial volume prior to the pandemic.

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Table 2. Associations of determinants with perceived social isolation and loneliness at baseline of social health trajectories

	Perceived social isolation		UCLA Loneliness Scale		Loneliness (CES-D)	
	Basic model,	Mutually adjusted,	Basic model,	Mutually adjusted,	Basic model,	Mutually adjusted,
	Mean diff. (95% CI)	Mean diff. (95% CI)	Mean diff. (95% CI)	Mean diff. (95% CI)	OR (95% CI)	OR (95% CI)
Time (weeks)	**−0.17 (−0.20; −0.15)**	−0.11 (−0.42; 0.21)	**−0.03 (−0.04; −0.02)**	−0.12 (−0.28; 0.04)	1.02 (0.99; 1.06)	1.24 (0.82; 1.87)
Sociodemographic						
Age (mean-centered)	0.01 (0.00; 0.01)[b]	0.00 (−0.02; 0.01)	**0.01 (0.01; 0.02)**	0.00 (−0.01; 0.01)[b]	**1.02 (1.01; 1.03)**	1.00 (0.99; 1.01)
Sex (female)	**0.62 (0.47; 0.77)**	**0.39 (0.23; 0.55)**	**0.55 (0.46; 0.64)**	**0.30 (0.22; 0.39)**	**2.45 (2.10; 2.86)**	**1.55 (1.29; 1.85)**
Employment (reference: employed)						
On sick leave	0.50 (−0.21; 1.20)	−0.04 (−0.74; 0.65)	**0.77 (0.36; 1.18)**	0.25 (−0.14; 0.64)	**3.61 (1.92; 6.78)**	1.89 (0.93; 3.86)
Unemployed	**0.74 (0.28; 1.20)**	0.37 (−0.08; 0.82)	**0.61 (0.34; 0.87)**	0.27 (0.02; 0.52)	**1.93 (1.26; 2.96)**	1.11 (0.67; 1.83)
Retired	0.06 (−0.16; 0.29)[b]	0.11 (−0.15; 0.36)	0.15 (0.01; 0.29)	0.20 (0.06; 0.34)	0.93 (0.76; 1.13)	0.98 (0.73; 1.33)
Other	0.16 (−0.22; 0.54)[a]	−0.12 (−0.49; 0.26)[b]	**0.40 (0.17; 0.62)**	0.13 (−0.09; 0.34)	**1.70 (1.20; 2.42)**	1.02 (0.68; 1.54)
Education (reference: primary education)						
Lower-intermediate	−0.33 (−0.68; 0.02)	−0.24 (−0.59; 0.10)	−0.20 (−0.40; 0.01)	−0.08 (−0.27; 0.12)	0.99 (0.71; 1.38)	1.28 (0.85; 1.94)
Intermediate-higher	−0.40 (−0.76; −0.05)	−0.33 (−0.68; 0.02)	−0.29 (−0.49; −0.08)	−0.14 (−0.34; 0.05)	0.91 (0.65; 1.28)	1.12 (0.73; 1.71)
Higher-university	−0.71 (−1.07; −0.36)	**−0.63 (−0.99; −0.28)**[b]	−0.34 (−0.55; −0.15)	−0.17 (−0.36; 0.03)	0.87 (0.62; 1.23)	1.12 (0.73; 1.73)
Pets (owns a pet)	−0.22 (−0.38; −0.05)[b]	**−0.32 (−0.48; −0.15)**[a]	−0.14 (−0.24; −0.04)	**−0.19 (−0.28; −0.09)**	0.95 (0.81; 1.12)	0.88 (0.72; 1.07)
Social health						
Prior loneliness	**1.02 (0.79; 1.24)**	**0.71 (0.47; 0.94)**	**1.02 (0.89; 1.15)**	**0.61 (0.48; 0.74)**	**6.64 (5.37; 8.20)**	**3.96 (3.08; 5.10)**
Housemates (yes)	−0.14 (−0.32; 0.03)[b]	0.05 (−0.18; 0.27)	**−0.46 (−0.57; −0.36)**	**−0.32 (−0.45; −0.19)**[b]	**0.18 (0.15; 0.21)**[b]	**0.16 (0.13; 0.21)**[b]
Marital status (reference: Partner/married)						
Never married	−0.08 (−0.42; 0.26)	−0.22 (−0.58; 0.15)	0.16 (−0.04; 0.36)	−0.21 (−0.42; −0.01)	**2.66 (1.96; 3.61)**	0.71 (0.48; 1.04)
Widowed/divorced	0.23 (0.02; 0.44)	0.04 (−0.22; 0.30)	**0.34 (0.22; 0.46)**	−0.11 (−0.26; 0.03)	**3.11 (2.57; 3.75)**	0.74 (0.56; 0.99)
Mental and cognitive health						
CES-D ≥ 10 (COVID)	**1.40 (1.20; 1.60)**	**1.26 (1.05; 1.47)**	**1.46 (1.35; 1.58)**[b]	**1.29 (1.17; 1.41)**	**8.90 (7.31; 10.84)**	**8.34 (6.69; 10.38)**[b]
MMSE score	−0.07 (−0.11; −0.02)	−0.02 (−0.07; 0.03)	**−0.08 (−0.10; −0.05)**	−0.03 (−0.06; −0.01)	0.94 (0.90; 0.98)	1.00 (0.95; 1.06)
Brain health*						
Total brain volume		0.13 (−0.17; 0.44)		0.09 (−0.10; 0.28)		1.22 (0.85; 1.73)
Intracranial volume		−0.04 (−0.19; 0.10)		−0.02 (−0.10; 0.06)		1.09 (0.93; 1.28)
Gray matter volume		−0.06 (−0.25; 0.13)		−0.03 (−0.15; 0.08)		0.92 (0.74; 1.14)
White matter volume		0.09 (−0.08; 0.27)		0.07 (−0.04; 0.18)		1.28 (1.04; 1.58)

Mean diff. denotes mean difference in social health marker at baseline of social health trajectories. OR denotes odds ratio for loneliness at baseline of social health trajectories. Basic models are age- and sex-adjusted. Mutually adjusted models are mutually adjusted for all determinants presented. Interaction terms of determinant*time (rate of change over time) were included in all models and are presented in supplementary material.

*Brain health analyses were performed in a subset of 1720 participants. Models were adjusted for age, sex, ethnicity, time difference between scan and COVID-19 baseline, education level, employment status, household size, marital status, prior loneliness, clinically relevant depressive symptoms at scan, smoking at scan, alcohol consumption at scan, BMI at scan, multimorbidity at scan. Total brain volume, gray matter and white matter volume were additionally adjusted for intracranial volume. Brain health models were not mutually adjusted.

Statistically significant associations after multiple testing correction in bold ($p < 0.0032$).

[a]Rate of change over time (interaction of determinant*time) statistically significant after multiple testing correction ($p < 0.0032$).

[b]Rate of change over time (interaction of determinant*time) statistically significant at $p < 0.05$ level.

Table 3. Associations of determinants with social connectedness at baseline of social health trajectories

	Feeling connected to others		Giving/receiving help during COVID-19 infection	
	Basic model, Mean diff. (95% CI)	Mutually adjusted Mean diff. (95% CI)	Basic model, Mean diff. (95% CI)	Mutually adjusted Mean diff. (95% CI)
Time (weeks)	**−0.03 (−0.04; −0.02)**	0.00 (−0.13; 0.13)	0.01 (0.00; 0.02)	0.13 (0.01; 0.26)
Sociodemographic				
Age (mean-centered)	**0.01 (0.01; 0.02)**	**0.01 (0.01; 0.02)**	**−0.01 (−0.01; −0.01)**	0.00 (−0.01; 0.00)
Sex (female)	**0.13 (0.07; 0.19)**	**0.18 (0.11; 0.24)**	**−0.12 (−0.18; −0.06)**	−0.06 (−0.13; 0.00)
Employment (reference: employed)				
On sick leave	0.00 (−0.28; 0.28)	0.09 (−0.19; 0.37)	0.04 (−0.25; 0.32)	0.14 (−0.14; 0.43)
Unemployed	−0.23 (−0.41; −0.05)[b]	−0.18 (−0.37; 0.00)	−0.24 (−0.42; −0.05)	−0.17 (−0.36; 0.01)
Retired	0.04 (−0.05; 0.13)	0.02 (−0.09; 0.12)	−0.11 (−0.21; −0.02)	−0.13 (−0.23; −0.02)
Other	**−0.25 (−0.40; −0.10)[b]**	−0.21 (−0.36; −0.06)[b]	**−0.24 (−0.39; −0.09)**	−0.18 (−0.33; −0.02)
Education (reference: primary education)				
Lower-intermediate	0.15 (0.02; 0.29)	0.13 (−0.01; 0.27)	0.08 (−0.06; 0.23)	0.04 (−0.10; 0.18)
Intermediate-higher	0.14 (0.00; 0.28)	0.11 (−0.03; 0.25)[b]	0.09 (−0.05; 0.24)	0.03 (−0.11; 0.18)
Higher-university	0.12 (−0.02; 0.26)	0.09 (−0.06; 0.23)[b]	0.14 (−0.01; 0.28)	0.06 (−0.09; 0.20)
Pets (owns a pet)	−0.03 (−0.10; 0.04)	−0.02 (−0.08; 0.05)	−0.02 (−0.08; 0.05)	−0.01 (−0.08; 0.06)
Social health				
Prior loneliness	**−0.23 (−0.32; −0.14)**	**−0.16 (−0.25; −0.06)**	**−0.19 (−0.28; −0.10)**	−0.09 (−0.19; 0.00)
Housemates (yes)	0.06 (−0.01; 0.13)	0.01 (−0.08; 0.10)	0.08 (0.01; 0.15)	0.01 (−0.08; 0.11)
Marital status (reference: Partner/married)				
Never married	−0.15 (−0.28; −0.01)	−0.10 (−0.24; 0.05)	0.01 (−0.13; 0.15)	0.05 (−0.10; 0.20)
Widowed/divorced	−0.04 (−0.12; 0.04)	0.03 (−0.07; 0.13)	−0.12 (−0.20; −0.04)	−0.06 (−0.17; 0.04)
Mental and cognitive health				
CES-D ≥ 10 (COVID)	**−0.28 (−0.36; −0.20)**	**−0.23 (−0.31; −0.15)**	**−0.25 (−0.33; −0.17)**	**−0.21 (−0.29; −0.12)**
MMSE score	0.01 (−0.01; 0.03)	0.00 (−0.01; 0.02)	**0.03 (0.02; 0.05)[b]**	0.03 (0.01; 0.05)[b]
Brain health*				
Total brain volume		0.14 (0.01; 0.26)[b]		0.02 (−0.12; 0.15)[b]
Intracranial volume		−0.03 (−0.09; 0.03)[b]		−0.05 (−0.11; 0.01)[a]
Gray matter volume		0.03 (−0.05; 0.10)[b]		−0.03 (−0.12; 0.05)
White matter volume		0.00 (−0.07; 0.07)		−0.02 (−0.09; 0.06)[b]

Mean diff. denotes mean difference in social health marker at baseline of social health trajectories. Basic models are age- and sex-adjusted. Mutually adjusted models are mutually adjusted for all determinants presented. Interaction terms of determinant*time (rate of change over time) were included in all models and are presented in supplementary material.

*Brain health analyses were performed in a subset of 1720 participants. Models were adjusted for age, sex, ethnicity, time difference between scan and COVID-19 baseline, education level, employment status, household size, marital status, prior loneliness, clinically relevant depressive symptoms at scan, smoking at scan, alcohol consumption at scan, BMI at scan, multimorbidity at scan. Total brain volume, gray matter and white matter volume were additionally adjusted for intracranial volume. Brain health models were not mutually adjusted.

Statistically significant associations after multiple testing correction in bold ($p < 0.0032$).

[a]Rate of change over time (interaction of determinant*time) statistically significant after multiple testing correction ($p < 0.0032$).

[b]Rate of change over time (interaction of determinant*time) statistically significant at $p < 0.05$ level.

increased over time in all age groups (Luchetti *et al.*, 2020). Another US-based study reported that the daily impact of the pandemic was associated with increased perceived social support in middle-aged adults in March and April 2020 (Tull *et al.*, 2020). Combined, these studies indicate two important methodological considerations: the time points of data collection and the measurement instrument. Most studies collected data in times when physical distancing restrictions were still in place, which may have limited the ability to observe a recovery in loneliness. Conversely, studying loneliness after restrictions had been lifted (i.e. June 2020 in the US and many Western-European countries), may have also prevented researchers to observe a change in loneliness compared to before the pandemic, as loneliness levels may have already returned to normal. In our study, we saw that UCLA Loneliness Scale scores improved after restrictions were eased, although we are unable to make a causal statement about this observation. With regard to the instrument used to measure loneliness: we observed a large increase in loneliness prevalence measured on a direct question on loneliness (CES-D), compared to prepandemic data. Since UCLA Loneliness Scale measures were not available in our study sample prior to COVID-19, we are not able to compare differences on a metric that uses an indirect question. The increase we found may reflect the actual experience of loneliness, but may also reflect people more readily labeling themselves as lonely in response to the pandemic. During COVID-19, the stigma on loneliness may have been reduced, or loneliness was even expected, thus potentially lowering the threshold for reporting loneliness on a direct question. Instruments such as the UCLA Loneliness Scale and the de Jong-Gierveld Loneliness Scale circumvent this issue, which were used in most other studies. Still, our results indicate that loneliness and social isolation were higher than usual during the first COVID-19 lockdown and decreased over time, while social connectedness to loved ones and the community remained high throughout the study period.

Clinically relevant depressive symptoms during COVID-19, loneliness prior to the pandemic and female sex were the most important determinants of baseline levels of social health trajectories during the pandemic. Depressive symptoms accounted for a mean difference of more than one point on the UCLA Loneliness and social isolation scales. Prior loneliness contributed to over half a point higher scores on these outcomes. These mean differences can be considered moderately large and indicate clinical relevance of these determinants. Living with housemates and pet ownership had a positive impact on UCLA Loneliness scores and social isolation at baseline. Although the effect sizes were smaller than for depressive symptoms and prior loneliness, they denote relevant mean differences in loneliness and social isolation at the baseline of our study, comparable to the effect of sex. These determinants may contribute less to clinically relevant differences than depressive symptoms and prior loneliness, but play a role in the experience of social health nonetheless. Previous studies have reported on determinants of social and mental well-being during the pandemic, with conflicting results for age (Bu *et al.*, 2020; Hansen *et al.*, 2021; Luchetti *et al.*, 2020; Peng and Roth, 2021; Rumas *et al.*, 2021; van Tilburg, 2021), but consistent findings for female sex and living with others (Bu *et al.*, 2020; El-Zoghby *et al.*, 2020; Hansen *et al.*, 2021; Taylor *et al.*, 2021). Two previous studies found that having a partner was associated with better social health, which was not replicated in our study (Okabe-Miyamoto *et al.*, 2021; van Tilburg, 2021). However, it is reasonable to assume that in our population, marital status and living situation both reflect living with a partner. Two previous studies reported that persons with a mental health condition suffered from more loneliness during the pandemic (Bu *et al.*, 2020; Rumas *et al.*, 2021). Beneficial effects of pet ownership on mental well-being during the pandemic have been reported (Bowen *et al.*, 2020; Carr *et al.*, 2021; Grajfoner *et al.*, 2021), while acknowledging that pet ownership was accompanied by specific pandemic-related worries (Applebaum *et al.*, 2020; Phillipou *et al.*, 2021; Ratschen *et al.*, 2020). To our knowledge, associations between prior loneliness as a determinant of social health during the pandemic have not been reported before. Combined with our findings on the relevance of depressive symptoms, these findings may aid in the identification of individuals at risk for a worse response to changing social circumstances, such as sudden physical isolation in older age (e.g. due to physical illness).

Brain structure was not evidently associated with social health trajectories during the pandemic, although we did see subtle associations of global brain volumes and intracranial volume with social connectedness over time. While these results mostly lost statistical significance after multiple testing correction, they warrant further studies with a larger sample size into the role of brain health as a potential determinant of resilience during social adversity. Our finding that larger intracranial volume was associated with higher degrees of social connectedness even with a large time difference between measurements, suggests that brain reserve may play a role in how individuals cope with a social challenge.

While our study is strengthened by the collection of repeated measurements during a critical time

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period in a well-defined study population, there are several limitations to take into account. First, potential selection bias is present in any study concerning social health. Persons with the worst social health may be less likely to participate in research and may thus not be part of the Rotterdam Study in the first place, which is reflected in the low prevalence of loneliness during prepandemic Rotterdam Study follow-up (12.6%; Shiovitz-Ezra and Ayalon, 2012). Nonparticipators might have had a worse response to the COVID-19 pandemic, which could have attenuated our findings. While the response rate for the COVID-19 questionnaires was high, 30% of participants did not return the first questionnaire. Nonresponders may have had a different social health trajectory compared to participants who did return the questionnaire. This may have affected our results, painting a more beneficial picture for social health in case of missing worse-off participants. A second limitation concerns potential misclassification of marital status, which was assessed prior to the pandemic with a time difference of max. 10 years. It is plausible that relationship status changed during this time. Household size assessed at COVID-19 baseline may have more reliably estimated current marital status in our study. Third, the time difference between the MRI scan and the COVID-19 baseline was substantial, which may have limited the interpretation of MRI findings. We applied several methods in our analyses to address the fact that brain volumes decrease with age, but misclassification of brain volumetric measures still may have occurred. Finally, an important limitation concerns the generalizability of our findings. The Rotterdam Study sample is predominantly white and Dutch native. Due to international travel restrictions, first-, second-, and third-generation immigrant families may have been disproportionally socially isolated from family members compared to persons with family within the same country, which we have not been able to take into account in our study.

In conclusion, loneliness and perceived isolation were present alongside social connectedness during the first months of the COVID-19 pandemic in Dutch community-dwelling older adults. Social connectedness remained high over time, whereas loneliness and social isolation showed recovery as physical distancing restrictions were eased. These findings highlight the multidimensionality of social health and provide information on which determinants contribute to social health in the face of a challenge. Women, persons with clinically relevant depressive symptoms, persons with prior loneliness, and persons living alone may be at risk of experiencing worse social health when faced with sudden changes in their social life. Since loneliness, social isolation, and sudden changes in social life are not exclusive to a pandemic, at-risk individuals may benefit from tailored support to maintain their social health after this pandemic subsides.

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Conflict of interest

None.

Description of authors' roles

I.F. van der Velpen contributed to formulating the research question(s), designed the study, collected the data, was responsible for the statistical design of the study and for carrying out the statistical analysis, and wrote the paper. R.J.F. Melis contributed to formulating the research question(s), was responsible for the statistical design of the study, contributed to interpretation of the findings, and assisted with writing the article. R.F. Hussainali collected the data and assisted with writing the article. M. Perry contributed to formulating the research question(s), interpretation of the findings, and assisted with critically revising the article. M.J.F. Vernooij-Dassen contributed to formulating the research question(s), interpretation of the findings, and assisted with critically revising the article. M.A. Ikram designed the study, supervised the data collection, contributed to interpretation of the findings, and assisted with critically revising the article. A.I. Luik designed the study, supervised the data collection, contributed to interpretation of the findings, and assisted with critically revising the article. M.W. Vernooij formulating the research question(s), designed the study, supervised

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the data collection, contributed to interpretation of the findings and assisted with writing the article.

Supplementary material

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