Caregiver worry about COVID-19 as a predictor of social mitigation behaviours and SARS-CoV-2 infection in a 12-city U.S. surveillance study of households with children

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ABSTRACT

Objective: Understanding compliance with COVID-19 mitigation recommendations is critical for informing efforts to contain future infectious disease outbreaks. This study tested the hypothesis that higher levels of worry about COVID-19 illness among household caregivers would predict lower (a) levels of overall and discretionary social exposure activities and (b) rates of household SARS-CoV-2 infections.

Methods: Data were drawn from a surveillance study of households with children ($N = 1913$) recruited from 12 U. S. cities during the initial year of the pandemic and followed for 28 weeks (data collection: 1-May-2020 through 22-Feb-2021). Caregivers rated how much they worried about family members getting COVID-19 and subsequently reported household levels of outside-the-home social activities that could increase risk for SARS-CoV-2 transmission at 14 follow-ups. Caregivers collected household nasal swabs on a fortnightly basis and peripheral blood samples at study conclusion to monitor for SARS-CoV-2 infections by polymerase chain reaction and serology. Primary analyses used generalized linear and generalized mixed-effects modelling.

Results: Caregivers with high enrollment levels of worry about COVID-19 illness were more likely to reduce direct social contact outside the household, particularly during the U.S.'s most deadly pandemic wave. Households of caregivers with lower COVID-19 worry had higher odds of (a) reporting discretionary outside-the-home social interaction and (b) SARS-CoV-2 infection.

Conclusions: This was, to our knowledge, the first study showing that caregiver COVID-19 illness worry was predictive of both COVID-19 mitigation compliance and laboratory-determined household infection. Findings should inform studies weighing the adaptive value of worrying about infectious disease outbreaks against established detrimental health effects.

1. Introduction

The COVID-19 pandemic underscored challenges of public health mitigation efforts. Prior to vaccine dissemination, the world relied exclusively on behavioural containment strategies (like physical distancing) (Hutchins et al., 2020). Compliance with public health recommendations was highly variable (Schnell et al., 2022). Understanding determinants of mitigation adherence is critical for informing responses to future public health crises (Jørgensen et al., 2021).

Scholars have applied health behaviour theories to explain mitigation compliance variability (Demirtaş-Madran, 2021). Prominent theories posit that worry about a health threat, in combination with factors like self-efficacy, can motivate protective behaviours (Demirtaş-Madran, 2021). Both healthcare authorities and media used threat appeals to promote compliance with COVID-19 containment guidelines (Stolow et al., 2020). Most evidence suggests that worrying about COVID-19 illness (COVID-19 worry) is associated with, and predictive of, greater compliance with containment strategies (Karakulak et al., 2023; Pengpid et al., 2022). However, many factors may modify this association (Jørgensen et al., 2021). For example, individuals with economic resources were generally better positioned to implement COVID-19 prevention strategies (Clouston et al., 2021). To the extent that COVID-19 worry promoted preventive behaviours, the effects may have been greater among affluent households as those with fewer financial resources may have been compelled to risk exposure despite fear of COVID-19.

Despite the established association between COVID-19 worry and mitigation compliance, we know of no evidence that COVID-19 worry reduced the likelihood of subsequent SARS-CoV-2 infection. Additionally, most existing studies evaluating COVID-19 worry as a predictor of behavioural mitigation strategies have used cross-sectional data (Karakulak et al., 2023) or longitudinal designs with few data points (Jørgensen et al., 2021). Monitoring change in mitigation behaviours over time with frequent assessments may facilitate identification of factors with lasting impact on preventive behaviours and improve understanding of processes like pandemic fatigue (Franzen and Wöhner, 2021).

This study aimed to estimate the prospective association between caregiver worry that family members would become ill with COVID-19 with (a) engagement in outside-the-home social activities, and (b) the odds of SARS-CoV-2 infections in the household. Data were drawn from a surveillance study of families with children from 12 U.S. sites. Participants completed 28 weeks of follow-up during the first pandemic year (May 2020–February 2021). We hypothesized that higher caregiver COVID-19 worry would predict greater compliance with guidelines calling for limited outside-the-home social interaction and reduced odds of subsequent household SARS-CoV-2 infection. Additionally, we hypothesized that these associations would be weaker among caregivers reporting high pandemic-related financial concern.

With frequent prospective outcome measurements, including biospecimens to determine SARS-CoV-2 infection, this study addresses limitations of prior investigations. Findings could inform public health messaging aimed at containing infectious disease outbreaks.

2. Methods

2.1. Study design

Data were drawn from the Human Epidemiology and Response to SARS-CoV-2 (HEROS) study (Fulkerson et al., 2022) (ClinicalTrials.gov: NCT04375761). This prospective cohort study aimed to identify risk factors for SARS-CoV-2 transmission in households with children. The Vanderbilt University Institutional Review Board (IRB) deemed the study satisfied criteria for the public health surveillance exception [45CFR46.102(I)(2)], and IRBs of all participating institutions agreed.

The study enrolled 5598 participants from 1913 households from May–June 2020 (Table 1). All families had participated in one of twenty-seven cohort studies in 12 U.S. cities (Boston, MA; Chicago, IL; Cincinnati, OH; Dallas, TX; Denver, CO; Detroit, MI; Madison, WI; Marshfield, WI; Nashville, TN; New York, NY; St. Louis, MO; Washington, DC). The study enrolled at minimum a child and a caregiver per household. Families could enroll a second child and adult from the household.

2.2. Procedures

Detailed methods are available elsewhere (Fulkerson et al., 2022). All instruments are available at https://www.vumc.org/heros/survey-instruments.

2.2.1. Exposure variable

COVID-19 worry was measured at enrollment with the item: "How often do you worry about you or someone in your family getting sick with coronavirus (SARS-CoV-2, COVID-19)?" Caregivers responded: 0 = Never; 1 = Almost never; 2 = Sometimes; 3 = Frequently (multiple times per day); 4 = Always or almost always (every day for much of the day). To avoid sparse cells, the lowest two levels were combined ("Never/Almost never").

2.2.2. Outcomes

Caregivers estimated the household's levels of outside-the-home social interaction at 14 fortnightly assessments, reporting whether family members engaged in 13 social exposure activities in the prior week (supplement section 1). Caregivers then rated the overall frequency with which they engaged in social contact with individuals outside the household relative to normal: 0 = a lot less; 1 = somewhat less; 2 = about the same; 3 = more. This 4-level variable (overall outside-the-home social interaction) was the planned primary outcome.

The primary outcome did not distinguish between social interaction that was essential (necessary to obtain/deliver critical resources) or discretionary. Many frontline workers had to engage in regular social interaction regardless of COVID-19 worry (Lancet, 2020). As we could not adjust for occupation (unmeasured), we conducted additional analyses using a binary outcome indicating whether household members engaged in either of two discretionary activities: "going to gatherings (e.g., church or concerts)" or "going out to eat". These activities were discouraged by healthcare authorities (Hutchins et al., 2020) and/or prohibited early in the pandemic (US Department of Health and Human Services, 2020). There was less risk of occupation confounding associations with discretionary activities as employers were unlikely to require them.

Additionally, we evaluated whether caregiver COVID-19 illness

Table 1

Characteristics of Caregivers and their Households and Communities from 12 U.S. Cities at Enrollment (May through July 2020) by COVID-19 Illness Worry Level (Exposure Variable).

COVID-19 Worry Level at Baseline	Never/almost never (N = 350)	Sometimes (N = 945)	Frequently (N = 414)	Almost always or always (N = 204)	Statistical Test
Household Crowding (People/Room Ratio)					$F_{31909} = 5.88$, p < 0.001[a]
Mean (SD)	1.36 (0.84)	1.35 (0.54)	1.39 (0.56)	1.54 (0.73)	
Median [1st Quart, 3rd Quart]	1.25 [1.00, 1.50]	1.25 [1.00, 1.50]	1.33 [1.00, 1.67]	1.33 [1.00, 1.67]	
Neighborhood Social Disadvantage (Kind and Buckingham, 2018) (U.S. Percentile)					$F_{31790} = 1.36$, p = 0.254[a]
Mean (SD)	49.6 (26.3)	46.9 (27.2)	48.0 (27.9)	51.1 (31.0)	
Median [1st Quart, 3rd Quart]	47.0 [28.0, 70.0]	44.0 [24.2, 67.0]	46.0 [23.0, 46.0]	47.5 [22.0, 81.0]	
Missing	37 (10.6 %)	46 (4.9 %)	26 (6.3 %)	10 (4.9 %)	
Baseline County Confirmed COVID-19 Deaths per 100K (Reinhart et al., 2021; Dong et al., 2020)					$F_{31791} = 23.7$, p < 0.001[a]
Mean (SD)	33.9 (46.0)	43.2 (52.4)	55.8 (60.8)	82.3 (79.4)	
Median [1st Quart, 3rd Quart]	12.8 [4.3, 45.2]	16.0 [5.5, 76.9]	31.1 [6.8, 89.3]	73.4 [11.6, 122.0]	
Missing	37 (10.6 %)	45 (4.8 %)	26 (6.3 %)	10 (4.9 %)	
County Political Leaning (McGovern et al., 2020) (% Voted Trump - % Voted Clinton)					$F_{31791} = 23.1$, p < 0.001[a]
Mean (SD)	−0.07 (0.38)	−0.13 (0.37)	−0.19 (0.36)	−0.32 (0.36)	
Median [1st Quart, 3rd Quart]	−0.16 [−0.32, 0.24]	−0.16 [−0.38, 0.19]	−0.21 [−0.45, 0.11]	−0.38 [−0.63, −0.16]	
Missing	37 (10.6 %)	45 (4.8 %)	26 (6.3 %)	10 (4.9 %)	
Caregiver Race (self -reported)					$\chi^2_{18} = 122$, p < 0.001[b]
American Indian or Alaska Native	3 (0.9 %)	4 (0.4 %)	3 (0.7 %)	5 (2.5 %)	
Asian	4 (1.1 %)	23 (2.4 %)	3 (0.7 %)	3 (1.5 %)	
Black or African American	93 (26.6 %)	260 (27.5 %)	119 (28.7 %)	108 (52.9 %)	
More than One Race	8 (2.3 %)	20 (2.1 %)	7 (1.7 %)	10 (4.9 %)	
Native Hawaiian or Pacific Islander	1 (0.3 %)	0 (0 %)	1 (0.2 %)	0 (0 %)	
Prefer Not to Answer	17 (4.9 %)	58 (6.1 %)	43 (10.4 %)	26 (12.7 %)	
White or Caucasian	224 (64.0 %)	579 (61.3 %)	238 (57.5 %)	52 (25.5 %)	
Missing	0 (0 %)	1 (0.1 %)	0 (0 %)	0 (0 %)	
Caregiver Ethnicity					$\chi^2_3 = 44.2$, p < 0.001[b]
Not Hispanic	311 (88.9 %)	843 (89.2 %)	336 (81.2 %)	157 (77.0 %)	
Hispanic	25 (7.1 %)	82 (8.7 %)	71 (17.1 %)	43 (21.1 %)	
Missing	14 (4.0 %)	20 (2.1 %)	7 (1.7 %)	4 (2.0 %)	
Caregiver Worried about Serious Financial Problems at Baseline					$\chi^2_3 = 304$, p < 0.001[b]
Never/Almost never/Sometimes	305 (87.1 %)	759 (80.3 %)	260 (62.8 %)	53 (26.0 %)	
Frequently/Always	45 (12.9 %)	186 (19.7 %)	154 (37.2 %)	151 (74.0 %)	
Any Household Members with Chronic Illness?					$\chi^2_3 = 52.3$, p < 0.001[b]
Yes	240 (68.6 %)	754 (79.8 %)	349 (84.3 %)	188 (92.2 %)	
Caregiver Sex					$\chi^2_3 = 0.49$, p = 0.921[b]
Female	330 (94.3 %)	897 (94.9 %)	396 (95.7 %)	194 (95.1 %)	
Male	19 (5.4 %)	46 (4.9 %)	18 (4.3 %)	10 (4.9 %)	
Missing	1 (0.3 %)	2 (0.2 %)	0 (0 %)	0 (0 %)	
Caregiver Frequency of Smoking					$\chi^2_3 = 9.62$, p = 0.022[c]
Not at all	312 (89.1 %)	844 (89.3 %)	361 (87.2 %)	166 (81.4 %)	
Less than daily	13 (3.7 %)	40 (4.2 %)	14 (3.4 %)	6 (2.9 %)	
Daily	24 (6.9 %)	55 (5.8 %)	37 (8.9 %)	29 (14.2 %)	
Missing	1 (0.3 %)	6 (0.6 %)	2 (0.5 %)	3 (1.5 %)	
Mandate Restricted Gatherings in County at Baseline?					$\chi^2_3 = 1.73$, p = 0.631[b]
No mandate limiting gatherings found	41 (11.7 %)	103 (10.9 %)	39 (9.4 %)	24 (11.8 %)	
Mandate limiting gatherings found	272 (77.7 %)	797 (84.3 %)	349 (84.3 %)	170 (83.3 %)	
Missing	37 (10.6 %)	45 (4.8 %)	26 (6.3 %)	10 (4.9 %)	
Get COVID-19 Information from Healthcare Authorities?					$\chi^2_3 = 22.6$, p < 0.001[b]
Yes	210 (60.0 %)	653 (69.1 %)	314 (75.8 %)	144 (70.6 %)	

Notes. As shown in Table 2, we aggregated across sparse cells for several of the categorical covariates included in our statistical analyses (e.g., race). [a]Kruskal-Wallis test; [b]Pearson test; [c]Proportional odds likelihood ratio test.

Table 2

Measurement of Plausible Confounders Included as Adjustment Variables in Statistical Models Representing Caregiver, Household, and Community Characteristics at Enrollment (May through July 2020).

Construct	Measurement Approach	Levels
Caregiver and Household Characteristics		
Caregiver race	Caregiver report (condensed to 4 levels to avoid sparse cells)	0 = White/Caucasian; 1 = Black/African American; 2 = American Indian/Alaskan Native or Asian or Native Hawaiian/ Pacific Islander or More than one race; 3 = Prefer not to say
Caregiver ethnicity	Caregiver report	0 = Not Hispanic; 1 = Hispanic
Caregiver sex	Caregiver report	0 = Female; 1 = Male
Caregiver smoking status	Caregiver report	0 = Not a smoker; 1 = Current smoker
Caregiver pandemic-related financial worry	Caregiver report	0 = Never, almost never, or sometimes; 1 = Frequently or always
Household member with chronic illness[a]	Caregiver report	0 = None; 1 = One family member; 2 = Multiple family members
Household crowding	Caregiver report	Ratio of number of household members to rooms in house
Household uses healthcare authorities (e. g., CDC, doctor, WHO) as source for COVID-19 information	Caregiver report	0 = Yes; 1 = No
Community Characteristics		
Neighborhood social deprivation	Area Deprivation Index (Kind and Buckingham, 2018) comparing household's neighborhood deprivation to other U.S. neighborhoods based on four indicators (income, education, employment, and housing quality)	Percentile scores ranging from 1 to 100, with higher scores indicative of greater disadvantage
Regional pandemic severity at enrollment	County cumulative COVID-19 deaths per 100,000 at enrollment based on data from the Coronavirus Resource Center (Dong et al., 2020)	Numeric value ≥0
County mandates restricting social gatherings at enrollment	Based on data from Covid Data Tracker (US Department of Health and Human Services, 2020)	0 = Gathering restriction mandate found; 1 = No gathering restriction mandate found
County political leanings	Percentage of voters in household's county who voted for Donald Trump (Republican candidate) minus percentage who voted for Hilary Clinton (Democratic candidate) during the 2016 U.S. presidential election (McGovern et al., 2020)	Negative values indicate greater support for Clinton and positive values indicate greater support for Trump

Note. 0 indicates the reference level in analyses with categorical variables with modal values assigned reference value. CDC = Centers for Disease Control and Prevention; WHO = The World Health Organization.

[a] A chronic health condition was considered present if a caregiver reported a family member having any of the following: asthma, autoimmune conditions, cancer, chronic obstructive pulmonary disorder, congestive heart failure, coronary artery or heart disease, cystic fibrosis, emphysema, heart attack, high cholesterol, hypertension or high blood pressure, peripheral vascular disease, sleep apnea, or diabetes (Type I or Type II).

worry predicted whether households had any SARS-CoV-2 infections during the follow-up. Caregivers were trained by study medical staff to collect fortnightly nasal swabs and end-of-study peripheral blood from household members, which were analysed for SARS-CoV-2 using quantitative polymerase chain reaction (PCR) and serology, respectively (Fulkerson et al., 2022). Caregivers reported whether any household members had COVID-19 symptoms in 28 weekly surveys. If any family member developed COVID-19 symptoms, as determined by an automated algorithm, additional household-wide biospecimen collection was performed (Fulkerson et al., 2022).

2.2.3. Moderator and Adjustment Variables

Caregivers reported at enrollment their levels of concern about "serious" pandemic-related financial trouble. A binary variable was derived indicating whether caregivers had high levels of financial concern, defined as worrying "frequently (multiple times per day)" or "always or almost always (every day for much of the day)" in the past week.

We adjusted for plausible confounders at both the community and household levels. Twelve plausible confounders (Table 2) were identified using a directed acyclic graph (Textor et al., 2016) and adjusted in analyses.

2.3. Statistical approach

Prospective associations with outside-the-home social interaction were estimated with generalized mixed-effects models (GLMM). Parameters were estimated using maximum likelihood, allowing households with partly missing outcome data to remain in analyses assuming that missingness was random conditional on observed data (Little and Rubin, 2002).

We planned to model overall outside-the-home social interaction as a 4-level ordinal outcome. However, our planned analyses revealed

violations of the parallel-slopes assumption (Ananth and Kleinbaum, 1997). Allowing separate associations of COVID-19 with each level of the ordinal outcome would have yielded an overly complex model. Therefore, we proceeded with simpler binary logistic GLMMs to evaluate the odds of engaging in "a lot less than normal" outside-the-home interaction. Throughout the study, the Centres for Disease Control and Prevention recommended limiting "the number of contacts with persons outside the immediate household" (p. 1861) (Honein et al., 2020), typically requiring substantially reduced social interaction (Andrejko et al., 2022). Thus, this binary outcome gauged compliance with guidelines calling for limited social exposure.

Time was coded in months from follow-up commencement (15-May-2020). Fixed time trajectories were estimated using restricted cubic splines with four knots placed at equally spaced quantiles (0.05, 0.35, 0.65, and 0.95) allowing for nonlinear trajectories. Multiple-df associations were estimated using likelihood ratio χ^2 tests. Pairwise contrasts ($c = 6$) comparing the four levels of COVID-19 illness worry were reported as adjusted odds ratios (aOR) with Šidák corrected 95 % confidence intervals (CIs) to limit familywise error. Our models included random coefficients for the intercept and linear time slope (between-person variability in initial outcome levels and the linear rate of change, respectfully) and the correlation among random intercepts and slopes.

Binary logistic regression was used to estimate the odds of having any SARS-CoV-2 infections in the household over the 28-week follow-up. Beyond the variables listed in Table 2, we adjusted the association between COVID-19 illness worry and SARS-CoV-2 infection for the number of biospecimens households provided.

In addition to testing our a priori moderator (pandemic-related financial concerns), we evaluated whether the associations of COVID-19 worry differed across the two most commonly self-reported racial groups (Black/African American vs. White/Caucasian) and ethnicity

(Hispanic vs. non-Hispanic). Prior research identified race and ethnicity as markers of social processes contributing to heterogeneity in pandemic mitigation compliance (Andersen et al., 2022).

We calculated *E*-values for all statistically significant (α = 0.05) contrasts, quantifying (as risk ratios) the strength of residual confounding needed to make estimates non-significant. An E-value of 2.0, for instance, indicates that unmeasured confounders would have had to cause at least a twofold increase/decrease in risk for both the exposure and outcome to nullify the association (Mathur and VanderWeele, 2020). As outcomes were common (supplement section 2), adjustments were applied to make the aOR estimates better approximations of risk ratios before calculating E-values (Mathur and VanderWeele, 2020).

R (version 4.2.3) was used for all analyses, with GLMMs estimated using the GLMMadaptive package (Rizopoulos, 2022) (version 0.8–5) and E-values using the EValue package (version 4.1.3) (Mathur and VanderWeele, 2020). Analytic code is available: https://brunwasser.github.io/heros04/index.html.

2.4. Role of the funding source

Funders had no role in data collection, analysis, interpretation, manuscript writing, or the decision to submit for publication.

3. Results

Caregivers were predominantly female (95.1 %). The vast majority identified as White/Caucasian (57.1 %), or Black/African American (30.3 %) (Table 1). Overall, caregivers provided 17,042 data points for the overall outside-the-home social interaction outcome: median = 11 (Q1 = 3, Q3 = 14). Missing data were common, ranging from 20 to 48 % across assessments, with caregivers worrying always/almost always about COVID-19 having greater likelihood of missing data (Supplemental Table 2.3). In total, 1469 households provided ≥1 viable nasal or blood biospecimen (39,600 total; median = 26 [Q1 = 14, Q3 = 40]). Of households providing biospecimens, 250 (17.0 %) had ≥1 infection with 708 total infections (178.79 per 10,000 tests).

3.1. Overall outside-the-home social interaction

The prospective association between COVID-19 worry and reporting "a lot less than normal" outside-the-home social interaction was modified by time ($\chi^2[df = 9] = 26.84, p = .002$). The time trajectory was nonlinear with the odds of limiting social interaction decreasing with U. S. COVID-19 death rates in late spring and summer 2020. Subsequently, the odds of limiting social interaction tended to increase, coinciding

with the U.S.'s deadliest COVID-19 surge (October 2020–January 2021) (Ritchie et al., 2020). This rebound in compliance during the latter months of the study was strongest for those who worried about COVID-19 always/almost always at enrollment (Fig. 1A). At follow-up outset, predicted probabilities of reporting "a lot less than normal" social interaction were near 50 %, falling to below 20 % in early fall 2020 for all but the highest COVID-19 worry group.

There was a general tendency for caregivers with higher COVID-19 worry at enrollment to have increased odds of limiting outside-the-home social interaction, with associations strengthening over time. At follow-up outset (15-May-2020), the CIs for all pairwise comparisons contained the null (estimates provided in Fig. 2). Four months later (9-Sep-2020), caregivers who had reported always/almost always worrying about COVID-19 at enrollment had greater odds of limiting overall outside-the-home social interaction than those who worried never/almost never, sometimes, and frequently. These associations were maintained eight months into the follow-up period (25-Dec-2020).

3.2. Discretionary social interaction

There was a nonlinear time association whereby the odds of households engaging in discretionary social interaction rapidly increased in the late spring/summer 2020 and then decreased with the onset of the second pandemic wave (Fig. 1B). Most households, regardless of COVID-19 worry levels, reported engaging in discretionary social activities from the late summer 2020 through early winter 2021. There was an association between COVID-19 worry and the odds of family members engaging in discretionary social interaction ($\chi^2[df = 3] = 25.11, p < .001$), but insufficient statistical evidence that time modified the association ($\chi^2[df = 9] = 15.20, p = .09$). Relative to those reporting frequent COVID-19 worry at enrollment, there were elevated odds of discretionary activities among households with caregivers who worried never/almost never and sometimes. Additionally, households of caregivers who worried never/almost never had greater odds of discretionary social interaction than those with caregivers who worried sometimes (Fig. 3 provides estimates).

3.3. SARS-CoV-2 infections

There was an overall association between COVID-19 worry and the odds of having any household SARS-CoV-2 infections ($\chi^2[df = 3] = 14.44, p = .003$), with a tendency for lower levels of COVID-19 worry to predict greater odds of infection. Caregivers who worried never/almost never about COVID-19 at enrollment had elevated odds of infection relative to those worrying frequently: aOR = 2.53, 95 % CI [1.31, 4.91], e-value = 1.55 (Fig. 4).
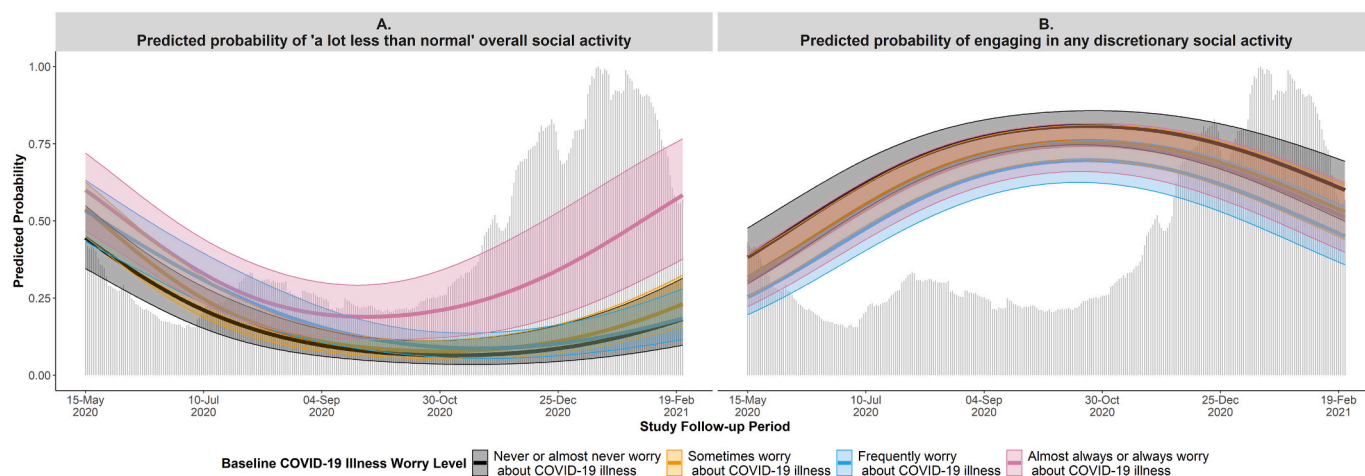

Fig. 1. Predicted trajectories of caregiver compliance with limiting outside-the-home social interaction over the course of the study follow-up period (May 2020 through Feb 2021) by caregiver COVID-19 illness worry level.
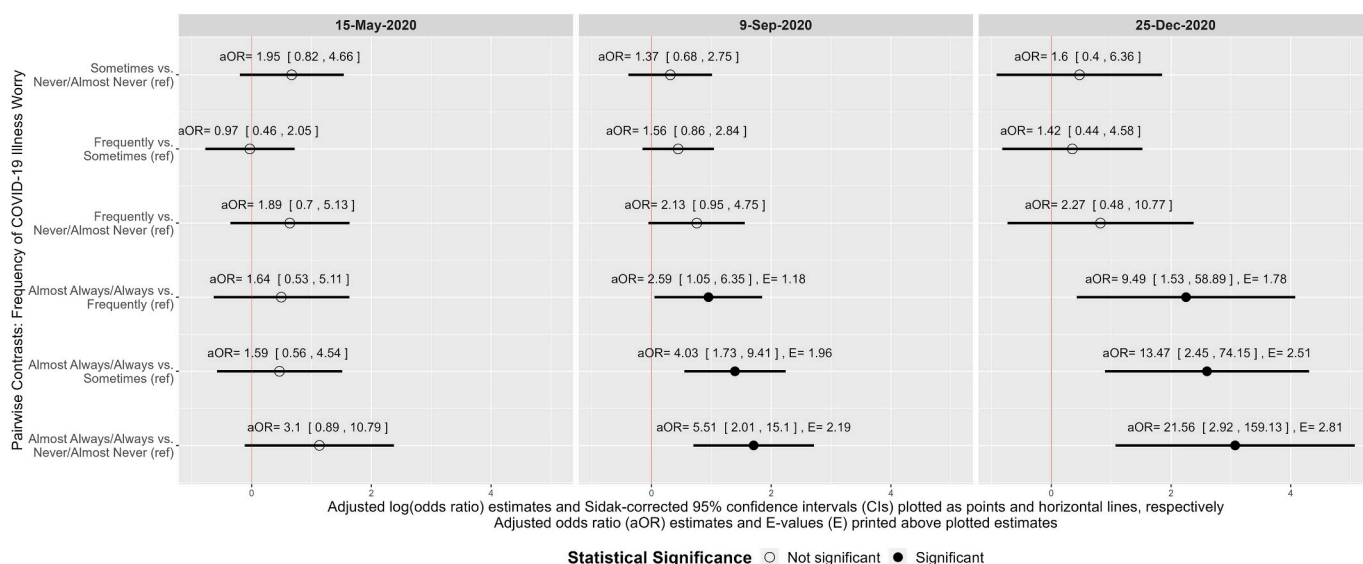
Fig. 2. Associations of caregiver COVID-19 illness worry with caregiver outside-the-home social interaction over the course of the study follow-up period (May 2020 through Feb 2021).
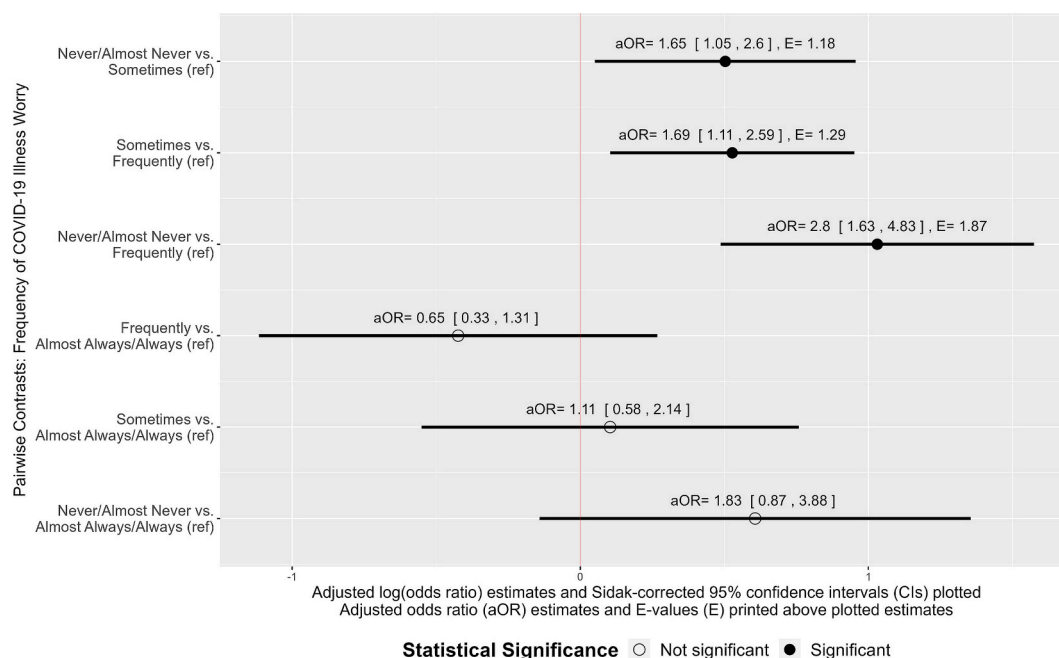

Fig. 3. Associations of caregiver COVID-19 illness worry with household discretionary outside-the-home social activities over the course of the study follow-up period (May 2020 through Feb 2021).

3.4. Effect modification

There was insufficient statistical evidence to support the hypothesis that pandemic-related financial concerns modified the association of COVID-19 worry with outside-the-home social interaction ($\chi^2[df = 3] = 1.24, p = .74$) and infection ($\chi^2[df = 3] = 3.04, p = .39$). However, there was evidence that the associations with limiting overall social interaction ($\chi^2[df = 3] = 9.83, p = .02$) and engaging in discretionary social activities ($\chi^2[df = 3] = 22.56, p < .001$) were stronger for households with White/Caucasian caregivers relative to those with Black/African American caregivers. Households with White/Caucasian caregivers with low worry levels were less likely to limit outside-the-home social interaction relative to both households of White/Caucasian caregivers with high worry levels, and households of Black/African

American caregivers regardless of worry levels. Levels of outside-the-home social interaction did not vary markedly across COVID-19 worry levels among households with Black/African American caregivers. Modification by race was particularly pronounced for discretionary social activities (supplement section 3). There was insufficient evidence to conclude that racial identity modified the association of COVID-19 worry with the odds of household SARS-CoV-2 infection ($\chi^2[df = 3] = 3.29, p = .35$). There was also insufficient evidence that ethnicity modified associations of COVID-19 worry on any of the three outcomes.

4. Discussion

This study provides, to our knowledge, novel evidence that caregiver COVID-19 worry predicted the household's longitudinal trajectory of
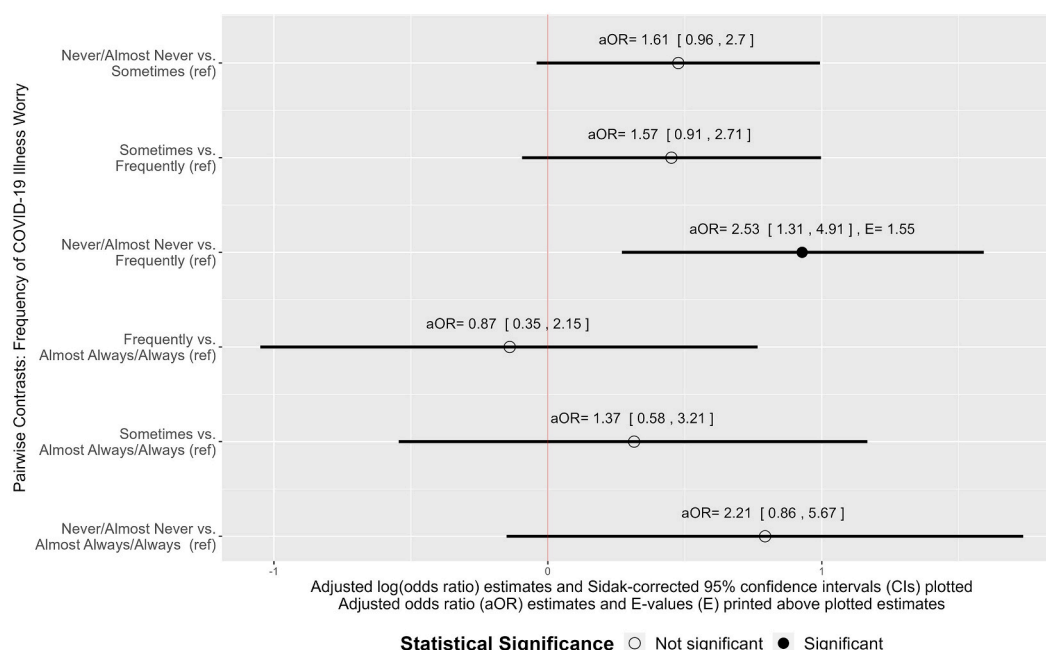
Fig. 4. Associations of caregiver COVID-19 illness worry with the odds of any household member having a SARS-CoV-2 infection at any point during the study follow-up period (May 2020 through Feb 2021).

outside-the-home activities and likelihood of SARS-CoV-2 infection during the early pandemic.

Higher levels of COVID-19 worry were predictive of greater likelihood of limiting both overall and discretionary outside-the-home social interaction over the follow-up. Associations with overall social interaction were not statistically significant at the outset of the follow-up but strengthened over time, becoming particularly pronounced during the U. S.'s deadliest pandemic wave. There were marked reductions in the probability of limiting outside social interaction in the early months of the study regardless of enrollment COVID-19 worry levels. However, caregivers who worried always/almost always had rapidly increasing probability of compliance with limiting social interaction with the onset of the second pandemic wave, rebounding to compliance levels reported at study outset. Caregivers with lower COVID-19 worry levels reported less dramatic increases in compliance during the second wave and, despite remarkably high U.S. death rates, were less compliant with recommended social exposure limitations at the end of the study compared to the beginning. This pattern is consistent with high COVID-19 worry levels reducing susceptibility to pandemic fatigue (Franzen and Wöhner, 2021).

The prospective association of COVID-19 worry with discretionary social activities (going to gatherings or out to eat) was sustained throughout the follow-up, with lower levels of COVID-19 worry predictive of more engagement in discretionary activities. There was insufficient evidence that time modified these associations. Regardless of COVID-19 worry levels, the probability of engaging in discretionary social interaction increased in the early months of the study with the end of the first pandemic wave followed by subsequent decreases with the onset of the second wave. Importantly, engaging in discretionary social activities was common throughout most of the follow-up period, even among households of caregivers with high COVID-19 worry.

There was a significant prospective association of COVID-19 worry with SARS-CoV-2 infection, with higher levels of worry generally predictive of lower likelihood of household infection. Households of caregivers who reported never/almost never worrying about COVID-19 illness had significantly higher odds of infection than those who worried frequently. Given the high level of morbidity and mortality caused by the SARS-CoV-2 infection in the early stages of the pandemic, even a 31

% increase in odds (the smallest value in the 95 % confidence interval) could have had significant public health impact. Unmeasured confounders would have had to increase risk by 55 % for both the exposure and outcome to make this estimate nonsignificant.

We did not find evidence supporting the hypothesis that pandemic-related financial concern modified the association of COVID-19 worry with social interaction or odds of infection. We expected caregivers with the greatest financial concerns to have higher employment-related ("essential") social exposure regardless of their COVID-19 illness worry, thus weakening the expected protective associations of COVID-19 worry with social exposure and infection. However, it is plausible that pandemic-related unemployment was contributing to financial concerns for some caregivers while also reducing employment-related social interaction, which would counter the hypothesized moderating influences.

Prospective associations between COVID-19 illness worry and both overall and discretionary social exposure activities were stronger in households with White/Caucasian caregivers than households with Black/African American caregivers. At high levels of COVID-19 worry, there was little difference between households of caregivers identifying as Black/African American and White/Caucasian in the odds of outside-the-home social activities; however, at low levels of COVID-19 worry, households with White/Caucasian caregivers were particularly unlikely to limit social interaction, especially discretionary social interaction. The modifying influence of self-reported race should be interpreted cautiously as we did not specify an a priori hypothesis about direction of association. Further, although racial identity is a marker of important social determinants (e.g., discrimination), racial categories are highly heterogeneous social constructs that do not readily implicate specific mediators (Ioannidis et al., 2021). It could be that there are important cultural or environmental differences across the two racial identities that influenced compliance. Future research identifying social processes contributing to low compliance among households with White/Caucasian caregivers with low worry may be important for enhancing mitigation efforts. Notably, there was insufficient evidence that racial identity modified associations with household infection.

The public health implications of this study are complex. The results suggest that COVID-19 worry could have adaptive value in terms of

increasing mitigation compliance and reducing odds of infection. However, these findings must be viewed in conjunction with a substantial body of evidence linking excessive COVID-19 worry to poor health outcomes, likely offsetting benefits (Alimoradi et al., 2022). In this study, associations of COVID-19 worry with overall outside-the-home social interaction were clearest for households with caregivers who worried "every day for much of the day". This degree of worry is typical of an anxiety disorder (American Psychiatric Association, 2013) and unlikely to be optimal even if there is reduced transmission risk. Prior scholarship suggests substantial negative associations between caregiver anxiety and depression during the pandemic with family functioning and child wellbeing (Feinberg et al., 2022; Westrupp et al., 2023).

Prior scholarship drawing on established health behaviour theories emphasized the need for public health messaging that balances efforts to foster threat recognition (i.e., understanding of threat severity and perception of vulnerability) with a sense that one can successfully take actions to avoid the danger (i.e., efficacy) (Jørgensen et al., 2021; Demirtaş-Madran, 2021). Absent a sense of efficacy, fear appeals may elicit counterproductive cognitions (e.g., denial and fatalism) that inhibit protective behaviours (Stolow et al., 2020). Ideally, public health messaging should aim to promote functional anxiety: i.e., worry/fear that motivates adaptive protective behaviours without eliciting overwhelming and impairing emotions and dissipates when reasonable protective actions have been implemented (Solymosi et al., 2021).

Our data are consistent with prior findings that adherence to guidelines calling for limited social exposure is difficult to maintain (pandemic fatigue) (Franzen and Wöhner, 2021). High levels of worry may have lessened pandemic fatigue in this study: households of caregivers with the highest worry levels showed the greatest rebound in mitigation compliance during the second wave. Thus, the potential value of COVID-19 worry in promoting mitigation behaviours likely varies depending on the fluctuating severity of the public health threat. This underscores the importance of frequent longitudinal measurement of protective behaviours.

This study had important limitations. First, we relied exclusively on caregiver report of household social exposure activities; however, self-reported social interaction fluctuated in a predictable manner with pandemic severity, providing evidence of construct validity. Second, owing to violations of statistical assumptions, we deviated from our planned analyses, aggregating across levels of an ordinal variable to create a binary outcome, resulting in information loss. However, the simpler binary outcome model addressed an important public health question with fewer statistical assumptions. Third, caregivers reporting worry and social exposure activities were predominantly female, which is notable given sex differences in mitigation compliance (Dev et al., 2022). Fourth, as is common in longitudinal studies, missing outcome data were common with probabilities of missingness differing across levels of the exposure variable. Importantly, our models included several covariates that were strongly predictive of missingness, improving the plausibility of the assumption that data were missing randomly conditional on observed data. Fifth, as with any observational study, there were likely unobserved confounders; however, *E*-values indicated that it would have taken substantial residual confounding to alter conclusions. Lastly, this study did not weigh the expected benefits of social distancing on SARS-CoV-2 exposure against adverse effects on other public health outcomes, including impairments in child social, emotional, physical, and educational development (Viner et al., 2022; Cortés-Albornoz et al., 2023; Essler et al., 2024; Oliveira et al., 2024).

These limitations are outweighed by important strengths. First, we are unaware of other surveillance studies that prospectively—and with great frequency—collected both survey data related to social exposure activities and biospecimens. Second, the study had a large sample size with participants from 12 different U.S. regions. Third, the study took place prior to vaccine availability when society relied almost exclusively on behavioural containment strategies. Finally, we merged the HEROS data with publicly available datasets allowing for adjustment of household and regional characteristics.

5. Conclusions

This surveillance study of households with children provided evidence that levels of caregiver COVID-19 worry generally predicted better adherence to public health guidelines calling for limited outside social interaction and reduced odds of SARS-CoV-2 infection. Future research should evaluate the extent to which the likely benefits of worry (reduced odds of infection) are offset by anxiety-related morbidity and adverse effects of social distancing. Development of public health messaging strategies that foster threat recognition and protective behaviours without impairing anxiety is critical.

Disclaimer

Drs. Fulkerson's and Togias' authorship does not constitute endorsement by the National Institute of Allergy and Infection Diseases, the National Institutes of Health, or any other Agency of the United States Government.

Data statement

Data from participants in the HEROS study will be stored for future analyses that will be limited to studies of SARS-CoV-2 infection as per the intent of this public health surveillance study. Investigators interested in utilizing data from the HEROS study will be required to complete a proposal form that will be reviewed by the NIAID HEROS publication committee to ensure that it fulfills the criteria for this public health surveillance study for investigations focused on SARS-CoV-2 infection. The protocol chair for HEROS will submit a request for approved study proposals which allows for deposition of summary (high level general) data with a 'controlled access guard' so that a future investigator would need to ask NIAID for permission to access the COVID-19 collected summary data and will be required to indicate that data analysis will be restricted to COVID-19 research. Statistical analyses, code, and output are available at: https://brunwasser.github.io/heros04/index.html. All instruments are available at https://www.vumc.org/heros/survey-instruments.

CRediT authorship contribution statement

Steven M. Brunwasser: Writing – original draft, Visualization, Supervision, Software, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Tebeb Gebretsadik:** Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Anisha Satish:** Writing – review & editing, Writing – original draft, Conceptualization. **Jennifer C. Cole:** Writing – review & editing, Visualization. **William D. Dupont:** Writing – review & editing, Visualization, Project administration, Methodology, Conceptualization. **Christine Joseph:** Writing – review & editing, Visualization, Resources, Project administration, Methodology, Investigation, Funding acquisition. **Casper G. Bendixsen:** Writing – review &

editing, Visualization, Resources, Project administration, Methodology, Investigation, Funding acquisition. **Agustin Calatroni:** Writing – review & editing, Visualization, Validation, Supervision, Software, Project administration, Methodology, Data curation. **Samuel J. Arbes:** Writing – review & editing, Visualization, Supervision, Project administration, Methodology. **Patricia C. Fulkerson:** Writing – review & editing, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Joshua Sanders:** Writing – review & editing, Validation, Software, Data curation. **Leonard B. Bacharier:** Writing – review & editing, Resources, Investigation, Funding acquisition. **Carlos A. Camargo:** Writing – review & editing, Resources, Investigation, Funding acquisition. **Christine Cole Johnson:** Writing – review & editing, Resources, Funding acquisition. **Glenn T. Furuta:** Writing – review & editing, Resources, Investigation, Funding acquisition. **Rebecca S. Gruchalla:** Writing – review & editing, Resources, Investigation, Funding acquisition. **Ruchi S. Gupta:** Writing – review & editing, Resources, Investigation, Funding acquisition. **Gurjit K. Khurana Hershey:** Writing – review & editing, Resources, Investigation, Funding acquisition. **Daniel J. Jackson:** Writing – review & editing, Resources, Investigation, Funding acquisition. **Meyer Kattan:** Writing – review & editing, Resources, Investigation, Funding acquisition. **Andrew Liu:** Writing – review & editing, Resources, Investigation, Funding acquisition. **George T. O'Connor:** Writing – review & editing, Resources, Investigation, Funding acquisition. **Katherine Rivera-Spoljaric:** Writing – review & editing, Resources, Investigation, Funding acquisition. **Wanda Phipatanakul:** Writing – review & editing, Resources, Methodology, Investigation. **Marc E. Rothenberg:** Writing – review & editing, Resources, Investigation, Funding acquisition. **Max A. Seibold:** Writing – review & editing, Visualization, Resources, Project administration, Methodology, Investigation, Funding acquisition. **Christine M. Seroogy:** Writing – review & editing, Resources, Investigation, Funding acquisition. **Stephen J. Teach:** Writing – review & editing, Resources, Investigation, Funding acquisition. **Edward M. Zoratti:** Writing – review & editing, Resources, Investigation, Funding acquisition. **Alkis Togias:** Writing – review & editing, Resources, Investigation, Funding acquisition. **Tina V. Hartert:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Author Initials	Royalties or Licenses	Consulting Fees	Payment/honoraria for lectures, presentations, speakers bureaus, manuscript writing, or educational events	Payment for Expert testimony	Stock or stock options	Patents planned, issued or pending	Receipt of equipment, materials, drugs, medical writing, gifts or other services	Data Safety Monitoring Board Member
DJJ		Areteia, Avillion, AstraZeneca, GlaxoSmithKline, Genentech, Regeneron, and Sanofi						Pfizer
LBB	Elsevier	Sanofi, Regeneron, Genentech, GlaxoSmithKline, DBV technologies, Teva, Medscape, Kinaset, OM Pharma, AstraZeneca, and Recludix	Sanofi, Regeneron, GlaxoSmithKline				Sanofi/ Regeneron	DBV Technologies, AstraZeneca, Vertex, Aravax
MER	UptoDate, Ception Therapeutics (Reslizumab), Mapi Trust (PEESS instrument)	Bristol Myers Squibb, Regeneron/Sanofi, Astra Zeneca, Nexstone One, Celldex, Revolo Biotherapeutics, Guidepoint		Tucker Ellis	Pulm One, Spoon Guru, ClostraBio, Serpin Pharm, Allakos, Celldex, Nextstone One, Santa Ana Bio	EoE Diagnostic Panel; U.S. Patent 9,345,763		
MAS			Speaker with Honoraria: Rutgers University, (Denver Allergy Rounds, National Jewish Health), Johns Hopkins University, Colorado Allergy and Asthma Society Meeting					
RGupta		Genentech, Novartis, Aimmune LLC, Allergenis LLC, Food Allergy Research & Education				Patent: Yobee (U.S. Patent No. 11,103,544)		
SJT	UptoDate Inc							
TVH		Sanofi, Infectious Diseases Respiratory Forum						Pfizer
WP		Regeneron, Sanofi, Genentech, Novartis, GSK, Astra Zeneca						

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.pmedr.2024.102936.

Data availability

Please see the Data Statement for conditions of data sharing.

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