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A nationwide study of risk factors for long COVID and its economic and mental health consequences in the United States

Daniel Kim [1,2]

Abstract

Background In the United States, concerns have been increasingly raised over the future public health and economic burden of long COVID including disability and declines in labor force participation. However, only a handful of U.S. studies have explored sociodemographic or socioeconomic characteristics that put people at risk of long COVID or have investigated its economic and mental health sequelae.

Methods Using repeated cross-sectional data on over 375,000 adults including nearly 50,000 adults with long COVID pooled from U.S. nationally-representative Household Pulse Survey data collected between September and November 2022 and between August and October 2023, I fit age- and gender-adjusted and multivariable modified Poisson regression models to examine multiple sociodemographic and socioeconomic factors as predictors of long COVID. I further estimate the risks of unemployment, financial hardship, and anxiety and depression among working-aged adults and adults with current long COVID symptoms, and estimate the economic burden of lost wages due to long COVID.

Results Nearly one in seven adults (~35 million) and working-aged adults (~30 million) reported having a history of long COVID by late 2022 and late 2023. In age- and gender-adjusted models and fully-adjusted multivariable models, I find several factors predict long COVID including lower household income, and being Hispanic, female, gay/lesbian or bisexual. I also find having long COVID is linked to higher risks of recent unemployment, financial hardship, and anxiety and depressive symptomatology, with evidence of dose-response relationships.

Conclusions Overall, an estimated 24 million working-aged adults with long COVID had been or may still be at risk of adverse socioeconomic and mental health outcomes. The lost earnings due to long COVID among working-aged adults are estimated to total $211 billion in 2022 and $218 billion in 2023. These findings highlight the substantial public health and economic implications of long COVID among Americans.

Plain Language Summary

Long COVID is a long-term health problem in people with a history of likely or confirmed SARS-CoV-2 infection (the virus that causes COVID-19). U.S. Census Bureau data on over 375,000 adults were used to identify risk factors for long COVID and its harmful effects. Nearly one in every seven adults reported a history of long COVID in late 2023, months after the emergency phase of the pandemic was declared over. Those with lower income and who are Hispanic, female, and gay/lesbian or bisexual are at higher risk of long COVID. Long COVID is also linked to higher risks of job loss, financial hardship, and anxiety and depression. Overall, 24 million working-aged adults with long COVID were at risk of these negative outcomes. Lost earnings due to long COVID among working-aged adults totaled $218 billion in 2023. These findings show the important public health and economic consequences of long COVID among Americans.

As the number of confirmed cases of COVID-19 has well exceeded 100 million in the United States and continues to accrue[1], concerns have been increasingly raised over the future public health and economic burden of long COVID including disability and concomitant declines in labor force participation. Long COVID (also known as post-COVID-19 condition or post-acute sequelae of COVID-19) is a condition characterized by long-term health problems in individuals with a history of probable or confirmed SARS-CoV-2 infection, usually 3 months from the onset of COVID-19 with symptoms that last for at least 2 months and cannot be explained by an alternative diagnosis[2]. By yielding symptoms affecting daily functioning, long COVID can plausibly affect one's ability to work, leading to loss of employment income and inducing financial strain. Through impacting physical and mental functioning[3], long COVID can contribute to mental health disorders including anxiety and depression[4]. Yet only a handful of US

[1]Department of Public Health and Health Sciences, School of Community Health and Behavioral Sciences, Northeastern University, Boston, MA, USA. [2]School of Public Policy and Urban Affairs, Northeastern University, Boston, MA, USA. e-mail: d.kim@northeastern.edu

population-based studies have explored sociodemographic and socioeconomic predictors of long COVID and economic and health sequelae, and such studies remain primarily limited to relatively small samples[5–11].

The present study was undertaken to use nationally-representative data from the US Census Bureau's Household Pulse Survey (HPS) on over 375,000 adults including nearly 50,000 adults with long COVID to investigate key sociodemographic and socioeconomic characteristics as risk factors for long COVID among adults, to explore the associations of long COVID with unemployment, financial hardship, and mental health outcomes, and to estimate the economic burden of lost wages from long COVID in the United States, both in 2022 and 2023 to investigate trends over time. Those with lower income and who are Hispanic, female, and gay/lesbian or bisexual are at higher risk of long COVID. Long COVID is linked to higher risks of job loss, financial hardship, and anxiety and depression, and lost earnings due to long COVID among working-aged adults totaled $211 billion in 2022 and $218 billion in 2023, indicating the substantial public health and economic consequences of long COVID among Americans.

Methods

Study population

Repeated cross-sectional data were pooled from nationally-representative HPS surveys in data collection Phase 3.6 administered from September 14—November 14, 2022 and pooled data from HPS surveys in Phase 3.10 administered from August 23—October 30, 2023[12]. The HPS used the Census Bureau's Master Address File as the source of sampled housing units. The HPS was conducted online by Qualtrics, with survey response rates ranging from 3.9 to 5.6% in Phase 3.6 and from 6.4 to 7.3% in Phase 3.10[13]. The study population consisted of US adults aged 18+ years. Analyses of employment and financial hardship as outcomes were limited to adult participants of working age (aged 18–64 years). For the primary sample analyzed in multivariable models, data were available on 154,430 adults including 113,192 working-aged adults (representative of 197 million American adults) surveyed in late 2022 and 220,664 adults surveyed in late 2023.

Outcomes

The first set of models examined the risks of 1) long COVID in the full samples; 2) long COVID among those with confirmed/diagnosed COVID-19 infection based on a positive rapid point-of-care test, self-test, or laboratory test for COVID-19 or being told by a doctor or other health care provider of having COVID-19; and 3) confirmed/diagnosed COVID-19 infection in the full sample. The risk of long COVID is a function of the risk of becoming infected with COVID and the risk of progressing from acute infection to long COVID. Long COVID was defined in the HPS as reporting any symptoms lasting 3 months or longer that were not present prior to having COVID-19 including fatigue, difficulty concentrating and forgetfulness, "brain fog", shortness of breath, joint or muscle pain, heart palpitations, changes to taste/smell, and inability to exercise[13].

The second set of models examined 4 recent outcomes in the full sample and among those still reporting long COVID symptoms: whether the respondent was employed in the past week; experienced financial hardship, defined as household difficulty (somewhat/very difficult vs. not at all/a little difficult) to pay for usual household expenses including food, rent/mortgage, and loans, within the previous week; and the frequency of experiencing anxiety symptoms and depressive symptoms (using the 2-item Generalized Anxiety Disorder-2 (GAD-2) and Patient Health Questionnaire-2 (PHQ-2)) over the previous 2 weeks, with scores of 3–6 vs 0–2 being employed previously to screen for anxiety and depressive disorders[10]. Based on a cut-off score of ≥3, the GAD-2 demonstrated optimal sensitivity and specificity (sensitivity = 0.71, specificity = 0.69), and the PHQ-2 exhibited peak sensitivity and adequate specificity (sensitivity = 0.64, specificity = 0.85). Internal consistency reliability has been demonstrated to be high for both measures (Cronbach's α = 0.81 and 0.83 for the GAD-2 and PHQ-2 scales, respectively)[14].

Predictors

The first set of models included the following predictors: age group, gender (male, female, transgender, other), sexual orientation (straight, gay/lesbian, bisexual, other), race and Hispanic ethnicity (Hispanic, non-Hispanic White, Black, Asian, and Other), marital status, education, household income in 2021, household size, presence of children in the household, receipt of a COVID-19 vaccine (either primary series or booster in the 2022 surveys, and either vaccine receipt within the past year or earlier in the 2023 surveys), and health insurance status[13].

In the second set of models, the main predictors were long COVID status (yes, no) in the full sample and the extent to which current long COVID symptoms reduced the ability to carry out day-to-day activities (a lot, a little, not at all) compared to before having COVID-19.

All fully-adjusted models further controlled for state of residence and self-reported non-receipt of the COVID-19 booster due to a COVID-19 infection (the latter in the 2022 surveys only).

Statistical analysis

Using data from Phase 3.6, age- and gender-adjusted and multivariable modified Poisson regression models (that can approximate yet circumvent issues with log-binomial models) controlling for all predictors simultaneously ("fully-adjusted models") were fit to estimate adjusted PRs from generalized estimating equations that accounted for survey weights and repeated measures within individuals in order to provide robust standard errors based on sandwich estimators[15]. Multiple imputation using 25 multiply imputed datasets and the MCMC algorithm without rounding under a missing at random assumption[16] was used to handle missing data on predictor variables, which ranged from 0.6% for marital status, 0.8% for vaccination receipt, 1.1% for gender, 1.4% for sexual orientation, 18.0% for household income, to 20.9% for health insurance status. For outcome variables, multiple imputation was not able to be implemented using the MCMC algorithm; data were missing in 0.33% for long COVID, 2.4% for unemployment, 5.6% for financial hardship, 11.0% for anxiety, and 11.1% for depression. The first set of multivariable-adjusted models of predictors of long COVID were then estimated using survey data from Phase 3.10.

Estimation of economic burden of lost wages

The estimated economic burden of long COVID from lost wages was calculated in part by adopting a similar approach to others[17], with the components used in the calculation shown in Table 1 for the survey phases in 2022 and 2023. The 2021 Bureau of Labor Statistics labor force participation rate for those aged 18–64 y was derived using age group-specific labor force participation rates[18] and applied to the HPS-derived estimated number of adults aged 18–64 y with long COVID who still reported having long COVID symptoms, disaggregated by household income category. From the HPS data, I also employed estimates of the distribution of adults not working due to long COVID by income category. I used published 2021 U.S. national survey estimates of work time being reduced by 25.9% due to long COVID[19], and for each income category combined the estimated FTEs of lost work due to reduced working time with the lost FTEs for the HPS-derived number of adults choosing not to work recently because of long COVID, under the assumption that the distribution of reduced working hours with long COVID by income mirrored the distribution of not working at all due to long COVID by income. For each income category, the estimated total FTE of lost work was then multiplied by the midpoint of income for the corresponding income category below $200k/year and by the estimated median income of $275k/year in the $200k+/year income bracket, and then summed across income categories to yield an annual estimate of lost earnings due to long COVID in both late 2022 and late 2023 (Table 1).

All analyses were conducted using SAS (version 9.4; SAS Institute, Cary, NC). All data were publicly available and anonymized and after the

Table 1 | Estimated lost earnings due to long COVID among U.S. adults aged 18–64 years in 2022 and 2023

Component	HPS Phase 3.6		HPS Phase 3.10		Data source
	Sept. 14—Nov. 14 2022		Aug. 23—Oct. 30, 2023		
Estimated total # and % distribution of adults aged 18–64 y with current long COVID symptoms	a: 14,508,809		a: 10,914,616		Household Pulse Survey sample data
	% distribution by income		% distribution by income		
	<$25k	11.54%	<$25k	9.84%	
	$25k–34,999	9.04%	$25k–34,999	7.66%	
	$35k–49,999	11.20%	$35k–49,999	10.63%	
	$50k–74,999	17.47%	$50k–74,999	17.51%	
	$75k–99,999	14.33%	$75k–99,999	14.49%	
	$100k–149,999	17.81%	$100k–149,999	19.07%	
	$150k–199,999	7.21%	$150k–199,999	8.60%	
	$200k+	11.40%	$200k+	12.20%	
Estimated labor force participation rate aged 18–64 y	b: 76.15%		b: 76.15%		U.S. Bureau of Labor Statistics (2021 estimate)[18]
Estimated total number and % distribution of adults not working due to long COVID	c: 435,473		c: 246,970		Household Pulse Survey sample data
	% distribution by income		% distribution by income		
	<$25k	27.02%	<$25k	15.54%	
	$25k–34,999	17.30%	$25k–34,999	8.35%	
	$35k–49,999	15.98%	$35k–49,999	10.73%	
	$50k–74,999	11.70%	$50k–74,999	15.63%	
	$75k–99,999	8.84%	$75k–99,999	18.15%	
	$100k–149,999	9.20%	$100k–149,999	14.73%	
	$150k–199,999	3.11%	$150k–199,999	6.06%	
	$200k+	6.85%	$200k+	10.81%	
Estimated number of adults working with long COVID	d: (a × b) − c = 10.6 million		d: (a × b) − c = 8.1 million		
	Freq. distribution by income		Freq. distribution by income		
	<$25k	1,157,150	<$25k	779,193	
	$25k–34,999	923,966	$25k–34,999	615,768	
	$35k–49,999	1,167,720	$35k–49,999	857,081	
	$50k–74,999	1,879,028	$50k–74,999	1,416,592	
	$75k–99,999	1,544,467	$75k–99,999	1,159,702	
	$100k–149,999	1,927,288	$100k–149,999	1,548,710	
	$150k–199,999	783,406	$150k–199,999	700,140	
	$200k+	1,229,960	$200k+	987,322	
Average % reduced work time due to long COVID	e: 25.92% [CI: 18.09%, 35.65%]		e: 25.92% [CI: 18.09%, 35.65%]		Understanding America Study COVID-19 Survey (mid-2021)[19]
Estimated total FTEs of lost work time	f: (d × e) + c = 3.19 million [CI: 2.4 million, 4.2 million]		f: (d × e) + c = 2.34 million [CI: 1.7 million, 3.1 million]		
	Freq. distribution by income		Freq. distribution by income		
	<$25k	860,947	<$25k	363,179	
	$25k–34,999	551,127	$25k–34,999	195,074	
	$35k–49,999	509,314	$35k–49,999	250,809	
	$50k–74,999	372,791	$50k–74,999	365,426	
	$75k–99,999	281,609	$75k–99,999	424,308	
	$100k–149,999	293,195	$100k–149,999	344,301	
	$150k–199,999	99,243	$150k–199,999	141,586	
	$200k+	218,133	$200k+	252,607	
Annual income	g: Average salary within income category		g: Average salary within income category		*2022 estimate based on income percentiles derived from the U.S. Census Bureau Annual Social and Economic (ASEC) Supplement by the University of Minnesota Population Center[31]
	<$25k	$12.5k	<$25k	$12.5k	
	$25k–34,999	$30k	$25k–34,999	$30k	
	$35k–49,999	$42.5k	$35k–49,999	$42.5k	
	$50k–74,999	$62.5k	$50k–74,999	$62.5k	
	$75k–99,999	$87.5k	$75k–99,999	$87.5k	
	$100k–149,999	$125k	$100k–149,999	$125k	
	$150k–199,999	$175k	$150k–199,999	$175k	
	$200k+	$275k*	$200k+	$275k*	
Estimated annual lost earnings due to long COVID	f × g: $210.9 billion [CI: $155.9 billion, $279.2 billion]		f × g: $218.3 billion [CI: $159.3 billion, $291.6 billion]		

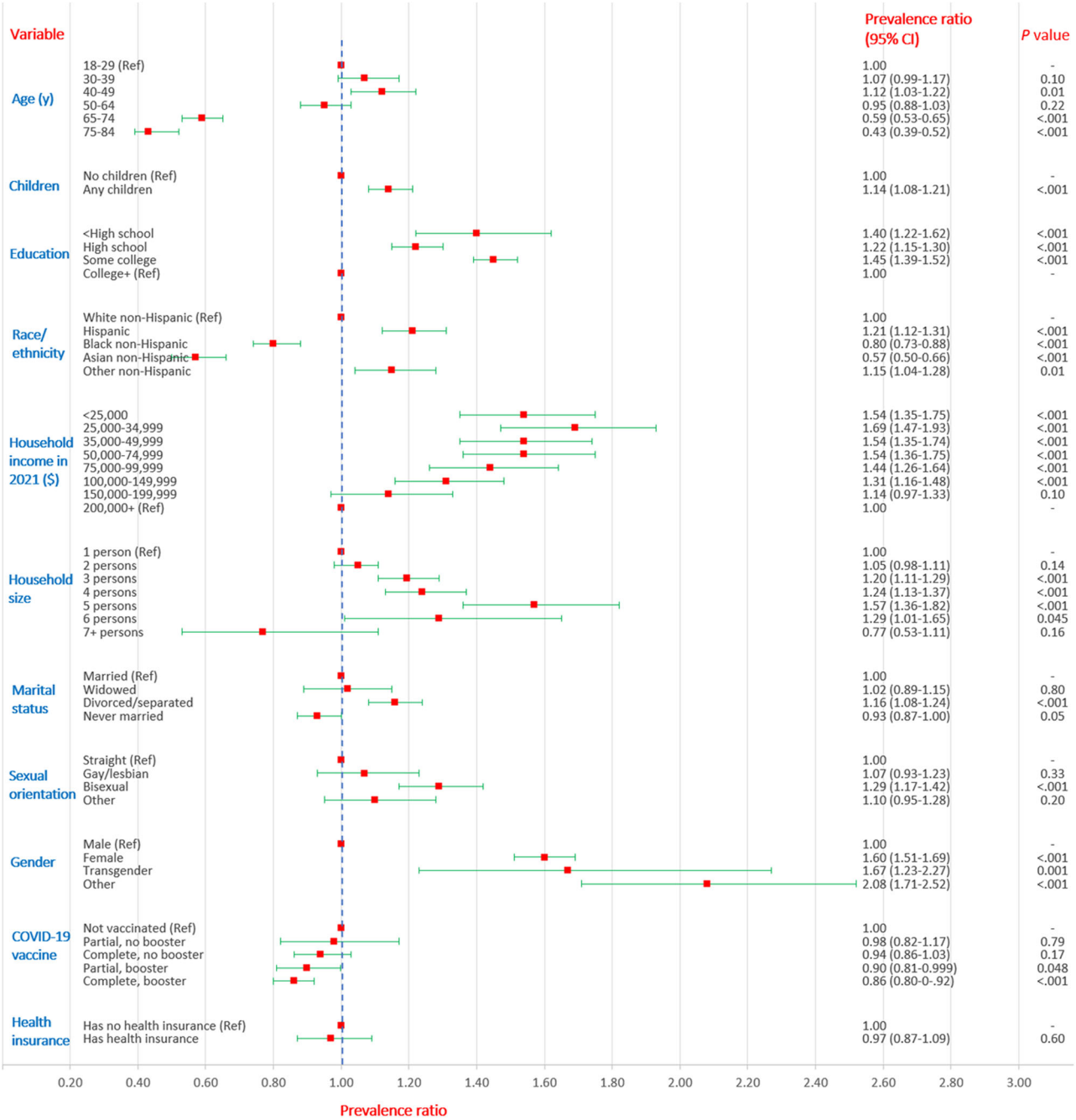

Fig. 1 | Age- and gender-adjusted risks of long COVID according to sociodemographic and socioeconomic characteristics among 154,430 adults, 2022. Data were collected from the U.S. Census Bureau Household Pulse Survey, September–November 2022. The figure shows the associations between various sociodemographic and socioeconomic characteristics and the risk of long COVID among adults in the study population, taking into account age and gender. All estimates shown correspond to prevalence ratio point estimates with 95% confidence intervals. 'Partial' refers to receipt of one dose of a two-shot primary vaccine series. 'Complete' refers to completion of the primary vaccine series (2 doses of a two-shot series or a single dose series).

author sought ethics approval were deemed exempt by the Institutional Review Board at Northeastern University from ethical compliance.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Results

Characteristics of the full samples

Supplementary Table 1 shows the unweighted and weighted characteristics of the full samples aged 18+ years alongside characteristics for the U.S. general population. The composition of the unweighted HPS samples were generally older, more educated, and White compared to the U.S. population. With weighting, these differences were attenuated (e.g., for geographic region) but not eliminated (Supplementary Table 1).

Risk of long COVID in the full sample in 2022 (n = 154,430)

In the age- and gender-adjusted model, compared to those aged 18–29 years, adults aged 30–39 years and 40–49 years had 7–12% higher risks of long COVID, while adults aged 65+ years had 41–57% lower risks (Fig. 1). Higher risks were also observed among those with any (vs. no) children in the household, of Hispanic and other (vs. White non-Hispanic)

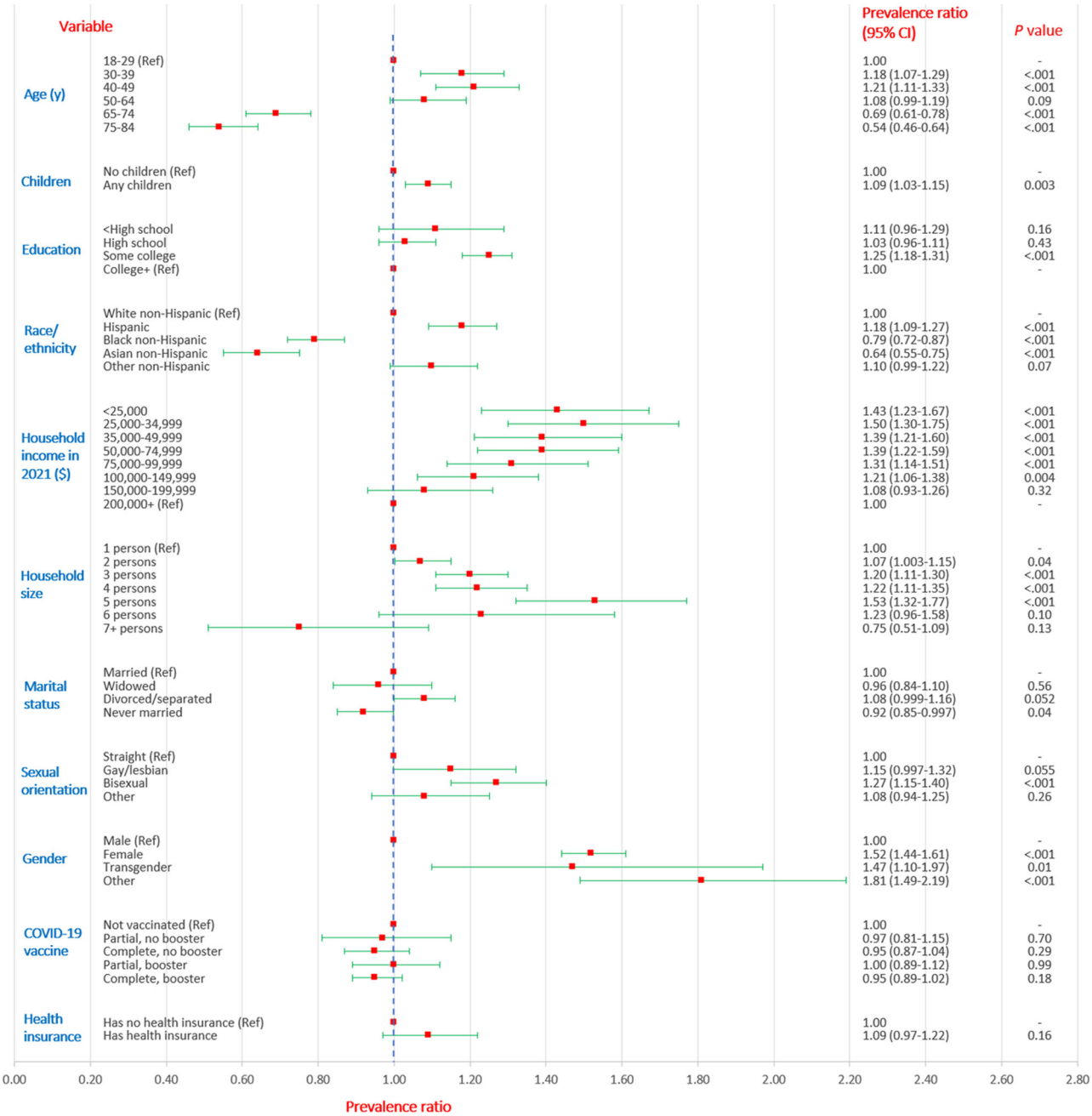

Fig. 2 | Multivariable-adjusted risks of long COVID according to sociodemographic and socioeconomic characteristics among 154,430 adults, 2022. Data were collected from the U.S. Census Bureau Household Pulse Survey, September–November 2022. The figure shows the associations between various sociodemographic and socioeconomic characteristics and the risk of long COVID among adults in the study population, taking into account all of these characteristics. All estimates shown correspond to prevalence ratio point estimates with 95% confidence intervals. All models were also adjusted for state of residence and non-receipt of a COVID-19 vaccine booster due to COVID-19 infection. 'Partial' refers to receipt of one dose of a two-shot primary vaccine series. 'Complete' refers to completion of the primary vaccine series (2 doses of a two-shot series or a single dose series).

race/ethnicity, of lower income, in larger households, and who were divorced/separated (vs. married), gay/lesbian or bisexual (vs. straight), and female (60% higher risk), transgender (67% higher risk), or other gender (vs. male) (all age and gender-adjusted prevalence ratios, PRs = 1.07–2.08; nearly all $P < 0.05$). Black and Asian adults and never married adults were at 20–43% lower risk and 7% lower risk than White adults and married adults, respectively (all $P < 0.05$). Individuals who had completed the primary vaccination series plus a booster against COVID-19 exhibited a 14% lower risk than the unvaccinated group ($P < 0.001$) (Fig. 1).

In the fully-adjusted multivariable model, similar overall patterns were generally observed although some estimates were attenuated compared to estimates from the age- and gender-adjusted model. Compared to those aged 18–29 years, adults aged 30–39 years and 40–49 years had 18–21% higher risks of long COVID, while adults aged 65+ years had 31–46% lower risks (Fig. 2). Higher risks were also observed among those with any (vs. no) children in the household, of Hispanic and other (vs. White non-Hispanic) race/ethnicity, of lower income, in larger households, and who were divorced/separated (vs. married), gay/lesbian or bisexual (vs. straight), and female (52% higher risk), transgender (42% higher risk), or other gender (vs. male) (all multivariable-adjusted prevalence ratios, PRs = 1.07–1.81; nearly all $P < 0.05$). Black and Asian adults and never married adults were at 21–36% lower risk and 8% lower risk than White adults and married adults,

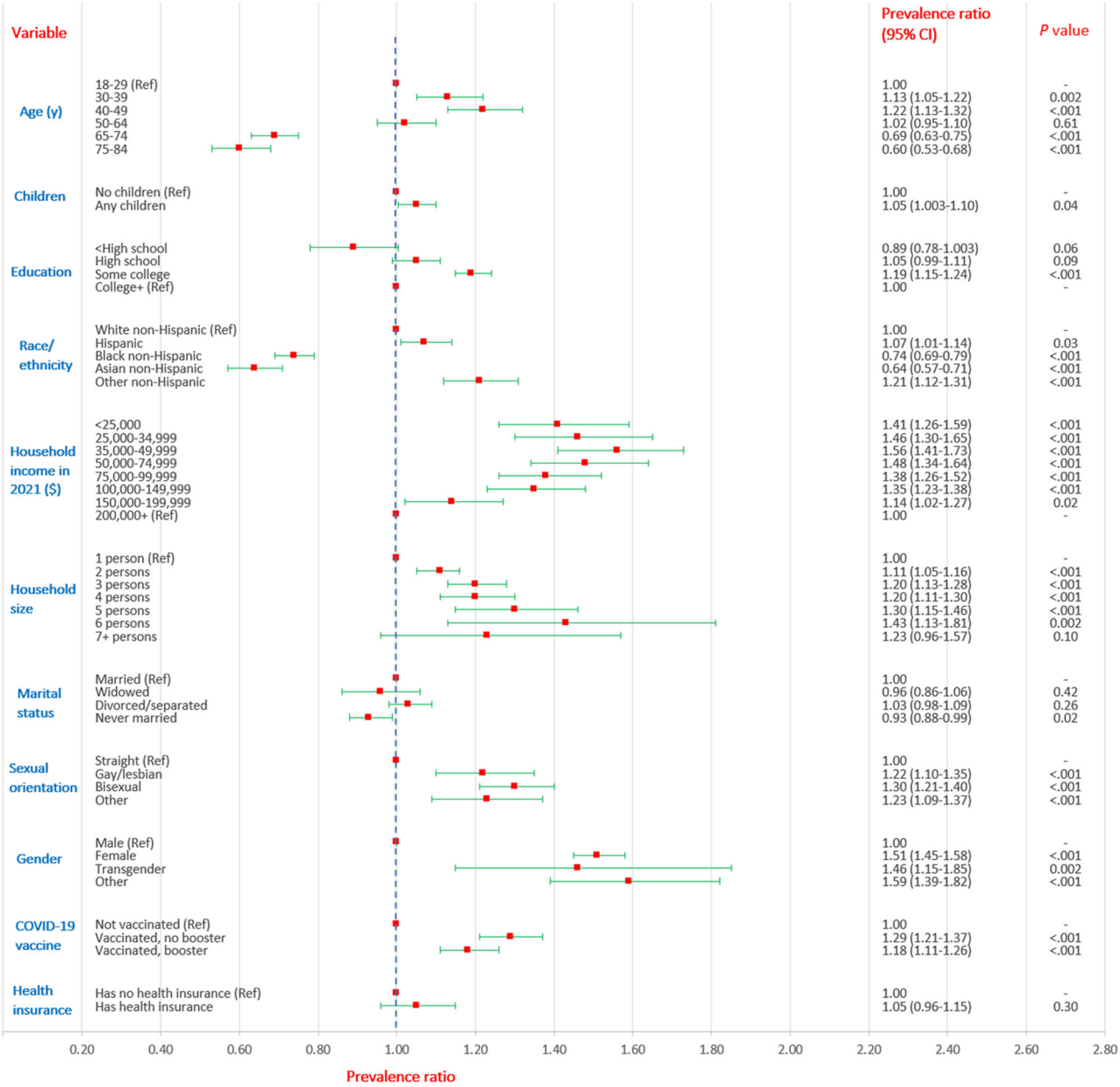

Fig. 3 | Multivariable-adjusted risks of long COVID according to socio-demographic and socioeconomic characteristics among 220,664 adults, 2023. Data were collected from the U.S. Census Bureau Household Pulse Survey, August–October 2023. The figure shows the associations between various socio-demographic and socioeconomic characteristics and the risk of long COVID among adults in the study population, taking into account all of these characteristics. All estimates shown correspond to prevalence ratio point estimates with 95% confidence intervals. All models were also adjusted for state of residence. 'Vaccinated, no booster' refers to receipt of a vaccine more than a year ago. 'Vaccinated, booster' refers to receipt of a vaccine within the past year.

respectively (all $P < 0.05$). No vaccinated groups exhibited lower risks than the unvaccinated group (all $P > 0.05$) (Fig. 2).

Risk of long COVID in the full sample in 2023 (n = 220,664)

In the fully-adjusted multivariable model using the most recent HPS data in late 2023, similar overall patterns were generally observed as in 2022. Compared to those aged 18–29 years, adults aged 30–39 years and 40–49 years had 13–22% higher risks of long COVID, while adults aged 65+ years had 31–40% lower risks (Fig. 3). Higher risks were also observed among those with any (vs. no) children in the household, of Hispanic and other (vs. White non-Hispanic) race/ethnicity, of lower income, in larger households, gay/lesbian or bisexual (vs. straight), and female (51% higher risk), transgender (46% higher risk), or other gender (vs. male) (all multivariable-adjusted prevalence ratios, PRs = 1.05–1.59; nearly all $P < 0.05$). Black and Asian adults and never married adults were at 26–36% lower risk and 7% lower risk than White adults and married adults, respectively (all $P < 0.05$). Unlike the associations observed for 2022, those who were divorced/separated (vs. married) had a weaker elevated risk of long COVID, and vaccinated groups had higher risks than the unvaccinated group ($P < 0.001$) (Fig. 3).

Risk of long COVID among those with diagnosed COVID-19 infection in 2022 (n = 72,882)

Modeling the risk of long COVID among those confirmed/diagnosed with COVID-19 infection in both the age- and gender-adjusted model and the fully-adjusted multivariable model showed similar patterns (e.g., with

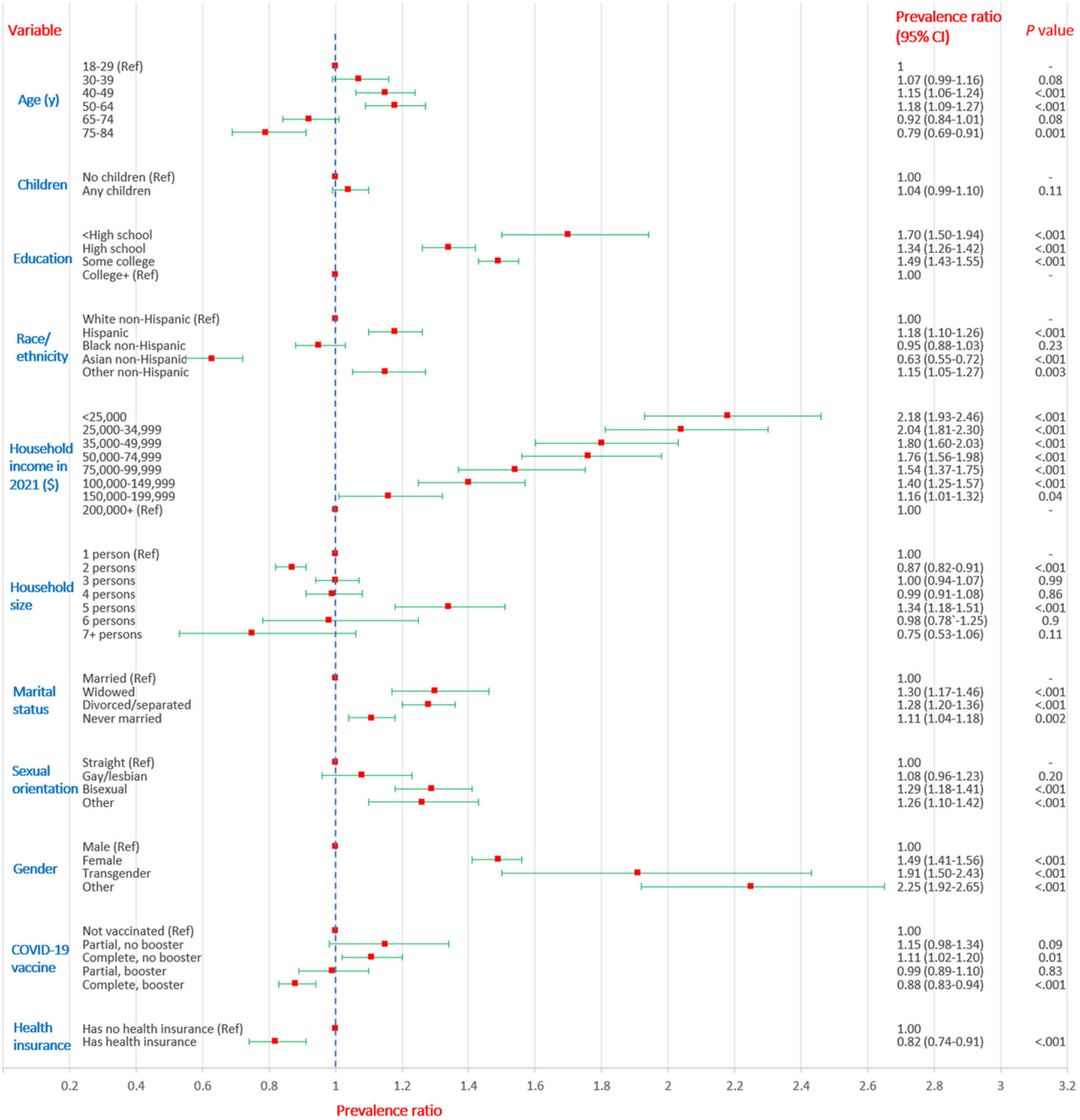

Fig. 4 | Age- and gender-adjusted risks of long COVID according to sociodemographic and socioeconomic characteristics among 72,882 adults with COVID-19 infection, 2022. Data were collected from the U.S. Census Bureau Household Pulse Survey, September–November 2022. The figure shows the associations between various sociodemographic and socioeconomic characteristics and the risk of long COVID among adults with confirmed/diagnosed COVID-19 infection, taking into account age and gender. All estimates shown correspond to prevalence ratio point estimates with 95% confidence intervals. 'Partial' refers to receipt of one dose of a two-shot primary vaccine series. 'Complete' refers to completion of the primary vaccine series (2 doses of a two-shot series or a single dose series).

females having 37–49% higher risks than males; Figs. 4 and 5), with a few exceptions: Having a child in the household was not associated with long COVID, whereas inverse associations between educational attainment and long COVID were consistently observed. Being widowed was linked to 13–30% higher risks, and no association was observed for never being married in the fully-adjusted model. Those who completed their primary vaccination series but did not receive a booster had 11–14% higher risks than the unvaccinated (Figs. 4 and 5), while in the age- and gender-adjusted model those who received a booster had a 12% lower risk than the unvaccinated ($P < 0.001$) (Fig. 4).

Risk of confirmed/diagnosed COVID-19 infection in the full sample in 2022 (n = 154,430)

Modeling the risk of confirmed/diagnosed COVID-19 infection in both the age- and gender-adjusted model and the fully-adjusted multivariable model exhibited analogous patterns to the risk of long COVID (Figs. 6 and 7). However, being older more consistently predicted a lower risk of COVID-19, and lower education and income were associated with lower risks rather than higher risks. For gender, only females showed an elevated risk of confirmed/diagnosed infection than males. All vaccinated groups had 3–16% lower risks than unvaccinated adults (all $P < 0.05$) (Fig. 6 and 7).

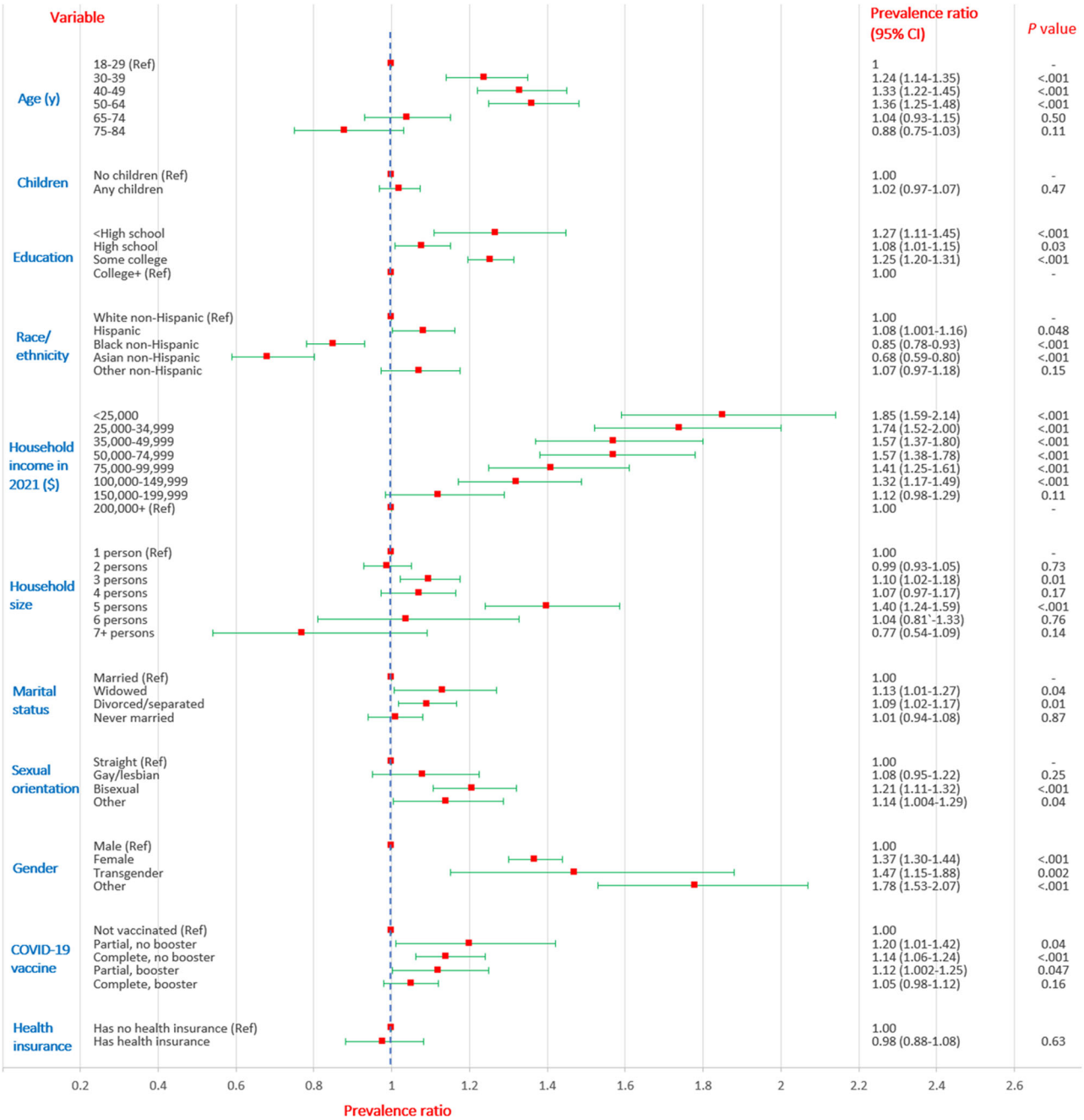

Fig. 5 | Multivariable-adjusted risks of long COVID according to sociodemographic and socioeconomic characteristics among 72,882 adults with COVID-19 infection, 2022. Data were collected from the U.S. Census Bureau Household Pulse Survey, September–November 2022. The figure shows the associations between various sociodemographic and socioeconomic characteristics and the risk of long COVID among adults with confirmed/diagnosed COVID-19 infection, taking into account all of these characteristics. All estimates shown correspond to prevalence ratio point estimates with 95% confidence intervals. All models were also adjusted for state of residence and non-receipt of a COVID-19 vaccine booster due to COVID-19 infection. 'Partial' refers to receipt of one dose of a two-shot primary vaccine series. 'Complete' refers to completion of the primary vaccine series (2 doses of a two-shot series or a single dose series.

Risks of unemployment, financial hardship, and anxiety and depression among working-aged adults (n = 113,192) and among adults with current long COVID symptoms in 2022 (n = 10,348)

Those who reported having long COVID had a higher likelihood of not being employed, experiencing financial hardship, and reporting recent anxiety or depressive symptoms (PRs ranging from 1.20–1.71 in the age- and gender-adjusted model and 1.05–1.52 in the fully-adjusted model; all $P < 0.05$ except for current employment in the fully-adjusted model; Figs. 8 and 9). Among those with current symptoms, there was evidence of dose-response relationships, with those reporting the highest (vs. no) impact on daily functioning having a more than two-fold higher risk of recent depressive symptoms (age-and gender-adjusted PR = 2.59; 95% = 2.21–3.04, $p < 0.001$; Fig. 8; fully-adjusted PR = 2.21; 95% = 1.88–2.59, $p < 0.001$; Fig. 9).

Estimated population at risk and economic burden of lost wages

Based on the study sample, 14.8% of US adults aged 18+ years (35.22 million; 95% CI = 34.29–36.15 million) and 15.1% of working-aged adults aged 18–64 years (30.65 million; 95% CI = 29.75–31.53 million) had developed long COVID by November 2022. An estimated 14.3% of US adults aged 18+ years (35.03 million; 95% CI = 34.23–35.83 million) and 14.8% of working-aged adults aged 18–64 years (29.93 million; 95%

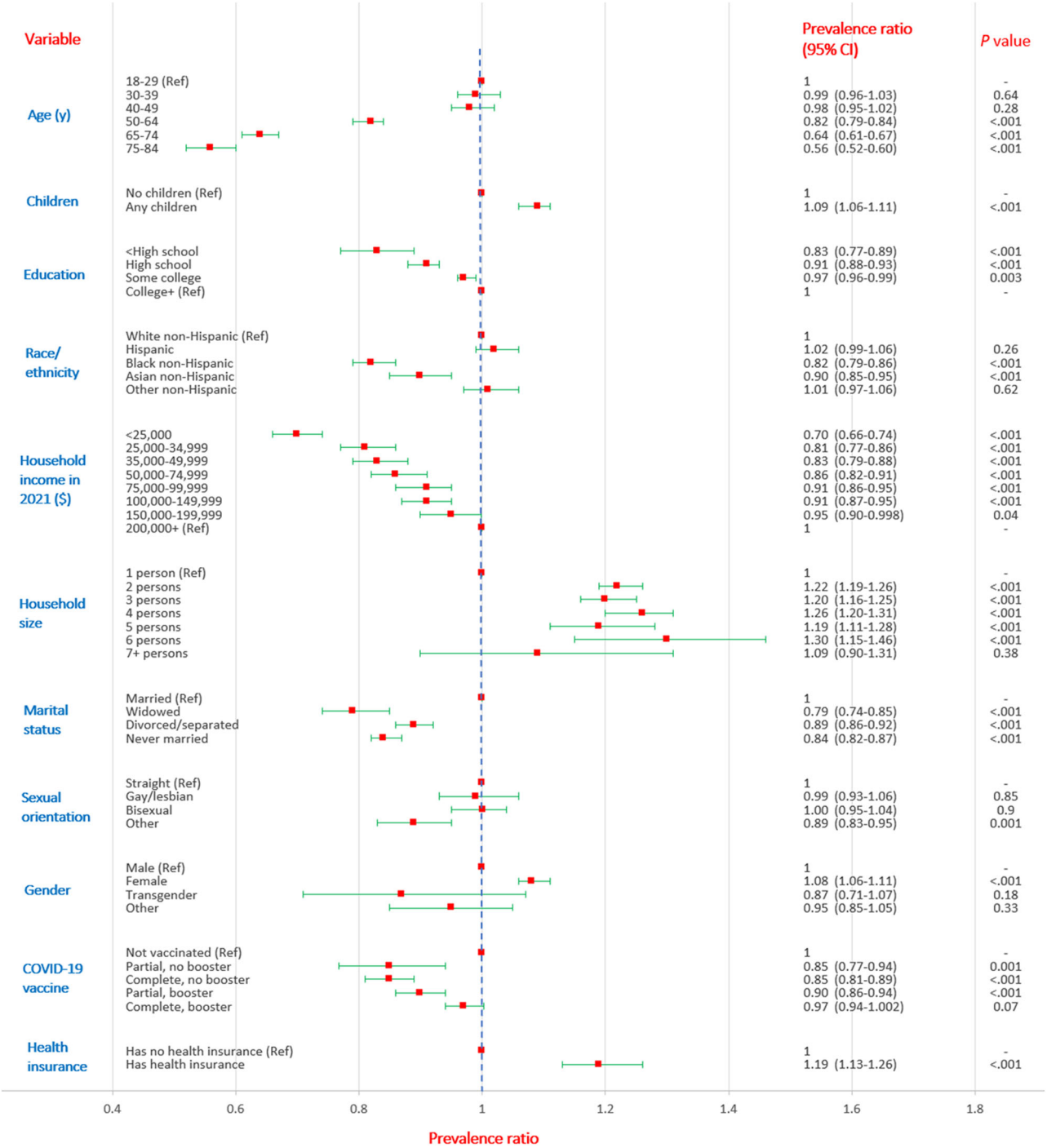

Fig. 6 | Age- and gender-adjusted risks of COVID-19 infection according to sociodemographic and socioeconomic characteristics among 154,430 adults, 2022. Data were collected from the U.S. Census Bureau Household Pulse Survey, September–November 2022. The figure shows the associations between various sociodemographic and socioeconomic characteristics and the risk of confirmed/diagnosed COVID-19 infection among adults in the study population, taking into account account age and gender. All estimates shown correspond to prevalence ratio point estimates with 95% confidence intervals. 'Partial' refers to receipt of one dose of a two-shot primary vaccine series. 'Complete' refers to completion of the primary vaccine series (2 doses of a two-shot series or a single dose series).

CI = 29.20–30.66 million) had a history of long COVID by November 2023. The estimated percentages of those with long COVID still experiencing symptoms and reporting a modest to considerable impact on daily functioning were 55.3% and 24.6%, respectively. Assuming the same percentages in those no longer experiencing symptoms, this translates into an estimated 28 million adults aged 18+ years and 24 million working-aged adults with long COVID who had been or may still be at risk of adverse outcomes. Given that cases of COVID from new infections and re-infections continue to accrue, these numbers of susceptible individuals will only escalate over time.

An estimated 14.5 million adults aged 18+ years and 10.9 million adults aged 18–64 years with long COVID still had current symptoms in the fall of 2022 and fall of 2023, respectively. Assuming a 76.15% labor force participation rate, while accounting for 435,473 adults in 2022 and 246,970 adults in 2023 that reported not working recently because of long COVID, an estimated 10.6 million adults and 8.1 million adults were working with

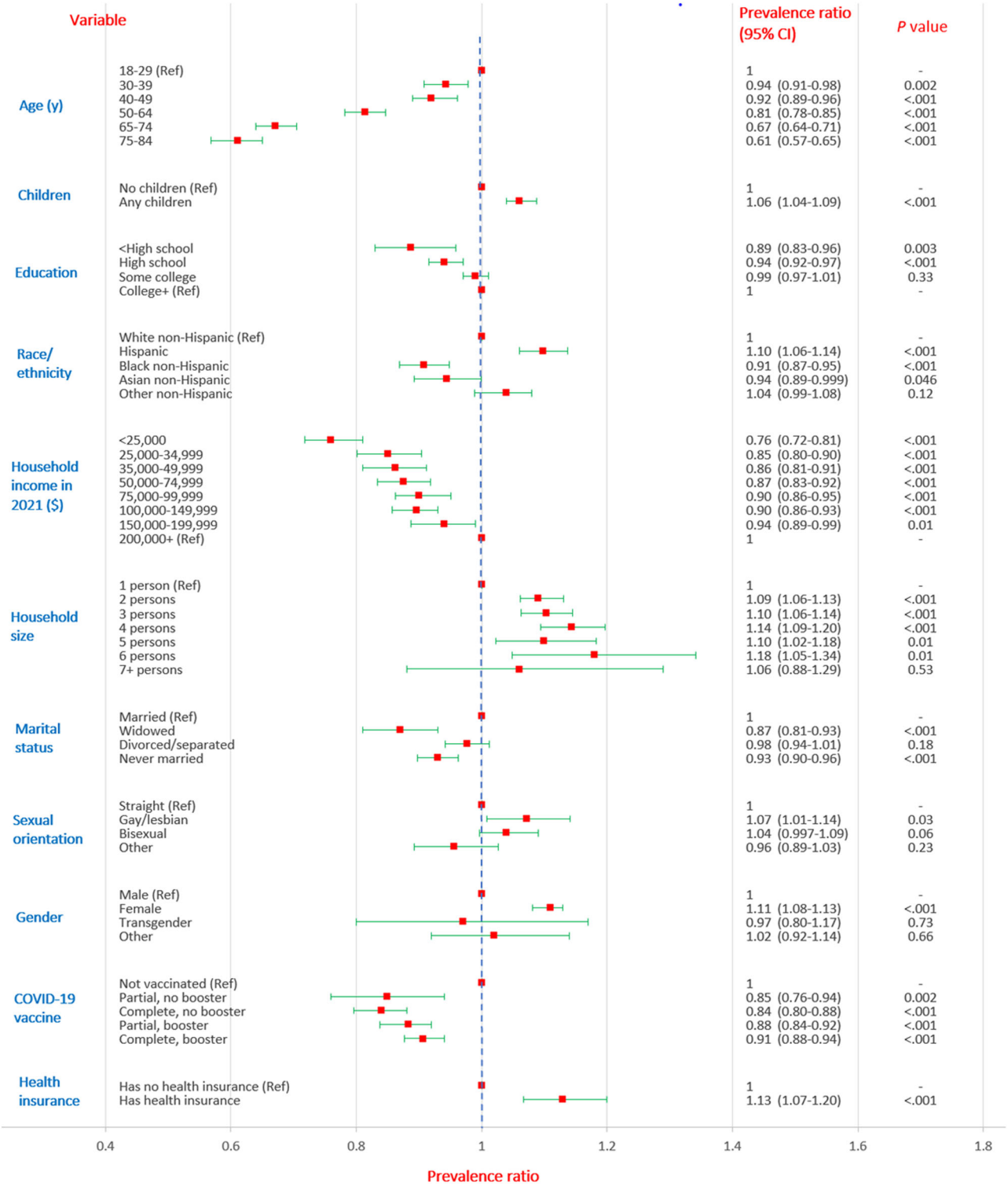

Fig. 7 | Multivariable-adjusted risks of COVID-19 infection according to sociodemographic and socioeconomic characteristics among 154,430 adults, 2022. Data were collected from the U.S. Census Bureau Household Pulse Survey, September–November 2022. The figure shows the associations between various sociodemographic and socioeconomic characteristics and the risk of confirmed/diagnosed COVID-19 infection among adults in the study population, taking into account all of these characteristics. All estimates shown correspond to prevalence ratio point estimates with 95% confidence intervals. All models were also adjusted for state of residence and non-receipt of a COVID-19 vaccine booster due to COVID-19 infection. 'Partial' refers to receipt of one dose of a two-shot primary vaccine series. 'Complete' refers to completion of the primary vaccine series (2 doses of a two-shot series or a single dose series).

long COVID in late 2022 and late 2023, respectively (Table 1). The total full-time equivalents (FTEs) of lost work either due to not working at all or 25.9% (CI: 18.1–35.6%) reduced working hours because of long COVID amounted to 3.2 million (CI: 2.4 million—4.2 million) FTE and 2.3 million (CI: 1.7 million—3.1 million), respectively. Using the reported household income of respondents in 2021, this translated into an estimated $211 billion (CI: $156 billion—$279 billion) and $218 billion (CI: $159 billion—$292 billion) annually in lost earnings due to long COVID for American adults aged

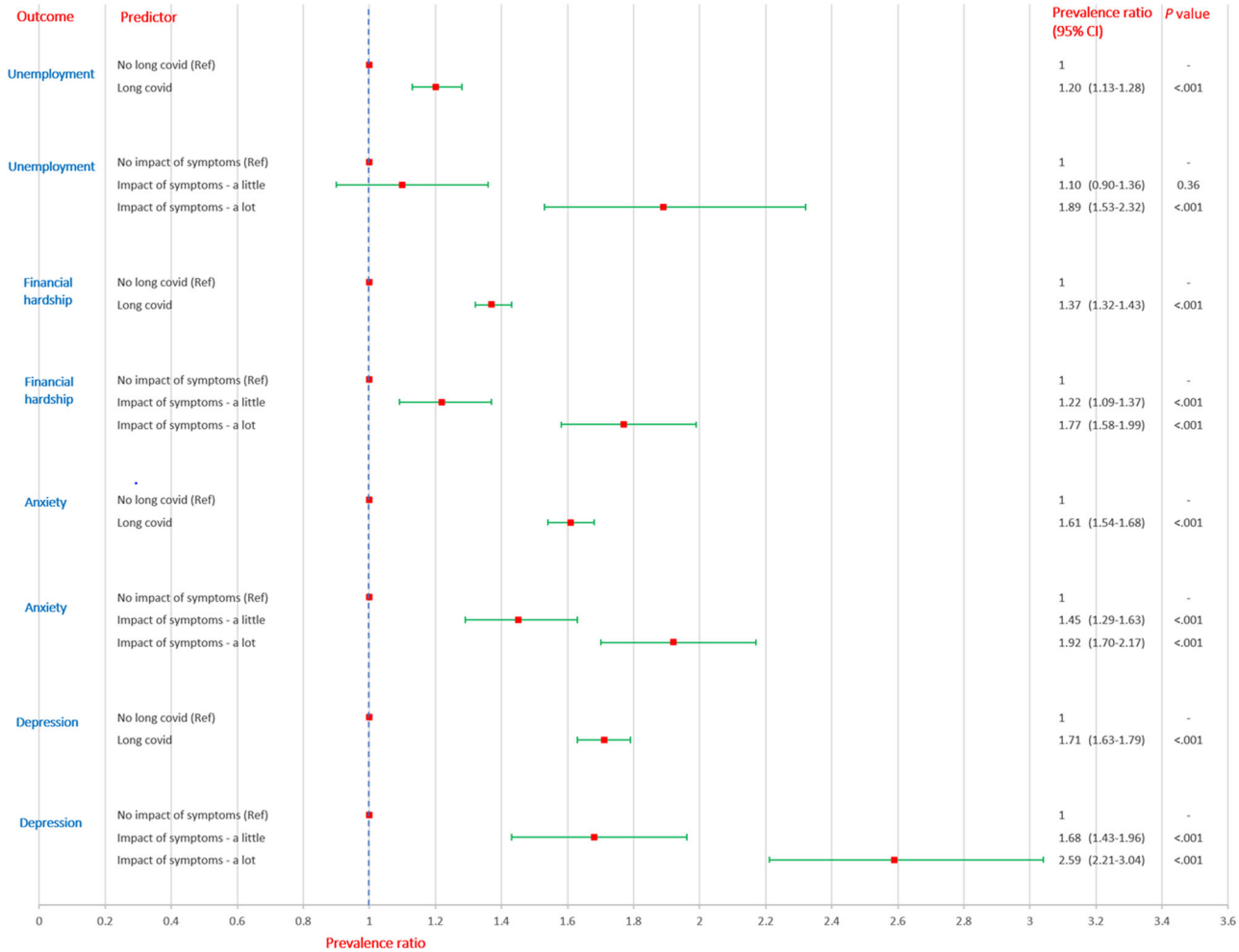

Fig. 8 | Age- and gender-adjusted risks of unemployment, financial hardship, and anxiety and depressive symptomatology according to long COVID status and according to impact of long COVID symptoms on daily functioning during the COVID-19 pandemic, 2022. Data were collected from the U.S. Census Bureau Household Pulse Survey, September–November 2022. The figure shows the risks of unemployment, financial hardship, and anxiety and depressive symptomatology among 154,430 adults and according to the impact of long COVID symptoms on daily functioning among 10,388 adults with symptoms in the study population, taking into account age and gender. All estimates shown correspond to prevalence ratio point estimates with 95% confidence intervals. The analyses of unemployment and financial hardship were restricted to 113,192 working-aged adults (aged 18–64 years). The impact of long COVID symptoms variable measured the extent to which current symptoms reduced the ability to carry out day-to-day activities compared with the period before having COVID-19.

18–64 years in the fall of 2022 and 2023, respectively (Table 1)—considerably higher than a previous $168 billion estimate for adults aged 16–64 years[17].

Discussion

To the author's knowledge, this study represents one of the largest multivariable analyses to date using U.S. nationally-representative data to explore key sociodemographic and socioeconomic predictors and mental health and economic sequelae and to estimate the economic burden of lost wages from long COVID as well as to examine trends in these estimates over time. The large sample size enabled a comprehensive examination of potential risk factors including marital status and gender and the discovery of novel associations such as for sexual orientation. Several characteristics predicted greater long COVID risks including being aged 30–49 years, of lower education and household income, living in a larger household, and being Hispanic, female, gay/lesbian or bisexual, and divorced/separated. Receipt of a COVID-19 vaccine (with or without a booster) was linked to lower risks of infection. Overall, similar patterns for predictive relationships were observed in the age- and gender-adjusted models and fully-adjusted models, and similar associations with long COVID were identified in fully-adjusted models in 2022 vs. 2023, supporting the generalisability of the findings over time.

Other epidemiologic studies of risk factors for long COVID have observed associations that are generally consistent with these findings. For example, adults aged 65+ years (vs. those aged 25–34 years) were similarly characterized by lower risk of long COVID[6]. Four studies[6,7,9,10] likewise found that females were at higher risk of long COVID than males, and two studies[7,9] identified similar patterns of inverse associations between socioeconomic position (measured by either income or educational attainment) and long COVID. Consistent with the present study, three studies[6,7,9] found that Black and Asian non-Hispanic (vs. White non-Hispanic) Americans were at lower risks of long COVID, and three studies linked Hispanic ethnicity to a higher risk of long COVID[8–10], while another study observed that Hispanic Americans had lower risks of long COVID than White non-Hispanic Americans but was based on age- and sex-adjusted models[6]. Like in the current study, having health insurance was linked to a higher risk of long COVID[6], whereas being unvaccinated was associated with higher risks of long COVID[6,7]. Notably, while two other large studies on long COVID also employed data from the Household Pulse Survey[9,10], those analyses relied on a more limited list of predictor variables that were co-adjusted and

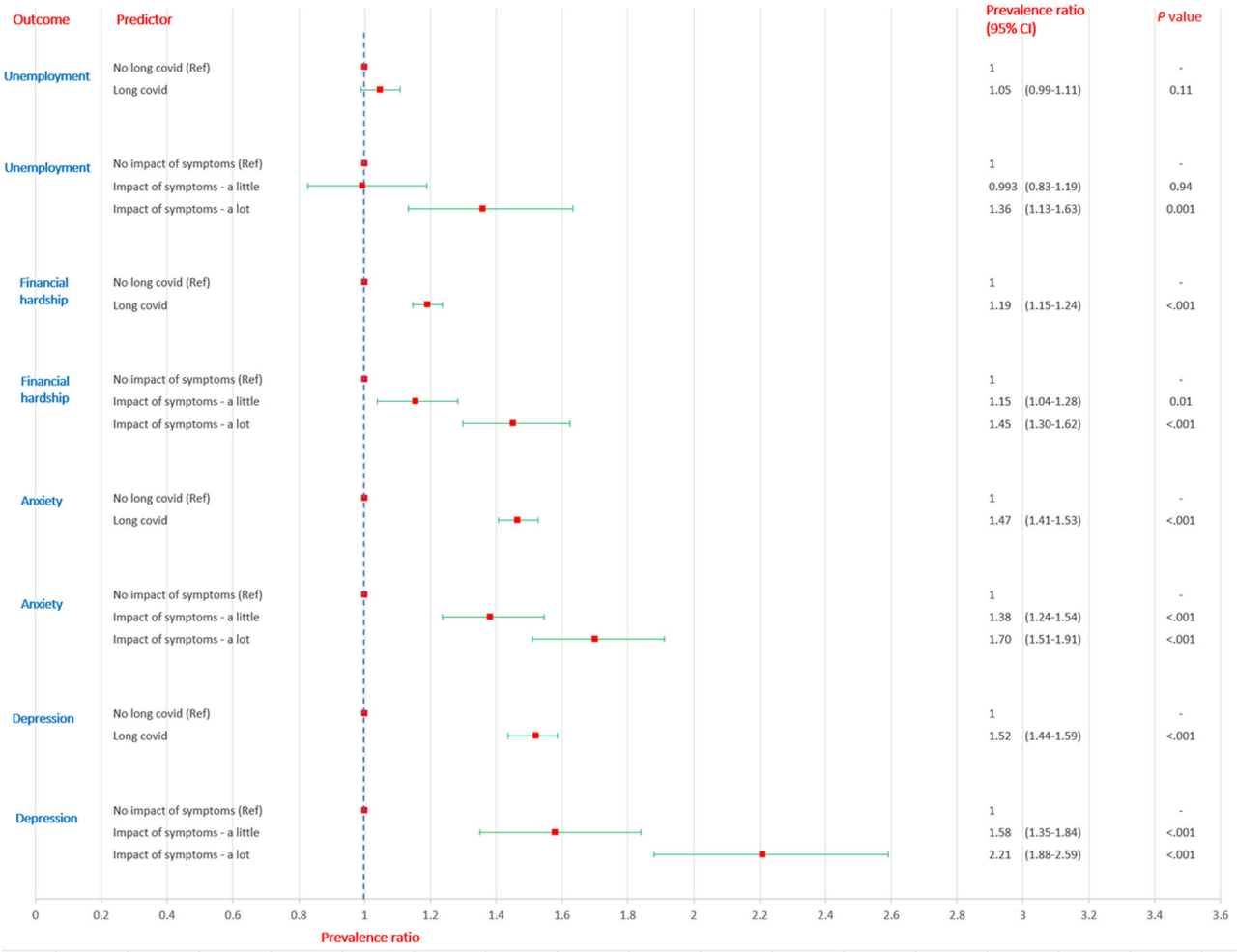

Fig. 9 | Multivariable-adjusted risks of unemployment, financial hardship, and anxiety and depressive symptomatology according to long COVID status and according to impact of long COVID symptoms on daily functioning during the COVID-19 pandemic, 2022. Data were collected from the U.S. Census Bureau Household Pulse Survey, September–November 2022. The figure shows the risks of unemployment, financial hardship, and anxiety and depressive symptomatology among 154,430 adults and according to the impact of long COVID symptoms on daily functioning among 10,388 adults with symptoms in the study population, taking into account age, gender, race and Hispanic ethnicity, education, household income in 2021, sexual orientation, children in the household, household size, receipt of a COVID-19 vaccine, health insurance coverage, state of residence, and non-receipt of a vaccine booster due to COVID-19 infection. All estimates shown correspond to prevalence ratio point estimates with 95% confidence intervals. The analyses of unemployment and financial hardship were restricted to 113,192 working-aged adults (aged 18–64 years). The impact of long COVID symptoms variable measured the extent to which current symptoms reduced the ability to carry out day-to-day activities compared with the period before having COVID-19.

did not control for several key factors including household income[9] or both education and income[10].

The lack of an apparent association between COVID-19 vaccination and long COVID from the fully-adjusted multivariable model in the present study seems inconsistent with the study's finding of an inverse association between vaccination and confirmed/diagnosed COVID-19 infection. Nonetheless, it is possible that selection bias may have contributed to the former findings—for example, if those who received the COVID-19 vaccine were more likely to have uncontrolled characteristics (e.g., COVID-19 re-infections) that put them at higher risk of long COVID. Meanwhile, in the age- and gender-adjusted model, having received a full primary series and booster for the COVID-19 vaccine predicted a lower risk of long COVID. It is possible that the fully-adjusted model had associated bias towards the null due to its control for factors along the causal pathway between COVID-19 vaccination and long COVID and/or due to the introduction of collider bias.

Future studies to further explore these findings and delineate any underlying bias are warranted. The higher associations of long COVID among those with health insurance (vs. no insurance) might also be explained by selection based on a higher likelihood of insured individuals being confirmed with COVID-19 through a test at point-of-care and diagnosed by a health care provider.

Potential mechanisms to explain why females may be at higher risk of long COVID than males have been proposed. These mechanisms include biological differences (e.g., lower production of pro-inflammatory interleukin-6 after viral infection) and higher levels of psychological stress in females brought on by the COVID-19 pandemic[20], with recent evidence that psychological distress is linked to post-COVID conditions[21]. Likewise, higher stress levels experienced by those who are divorced/separated (vs. married)[22] or transgender (vs. male)[23] might help to account for their associated higher risks of long COVID.

Furthermore, treatment with nirmatrelvir-ritonavir (Paxlovid) has been linked to large reductions in risks of long COVID such as neurocognitive and psychiatric complications of COVID-19[24]. If those of lower socioeconomic position, who are of Hispanic ethnicity, transgender, or of gay/lesbian or bisexual orientation are less likely to seek and receive such treatment, this could explain the linkages between these characteristics and higher risks of long COVID.

Even after accounting for sociodemographic and socioeconomic factors, the current study found that having long COVID predicted higher risks of recent unemployment, financial hardship, and anxiety and depressive symptomatology using 2-item validated scales. For all of these outcomes, there were stronger relationships at higher levels of impacts of symptoms on daily functioning, compatible with causal relationships. Previous U.S. population-based studies have likewise found long COVID to predict a lower odds of employment[7] and higher risk of anxiety[11].

Limitations of this study include its cross-sectional design, which precludes the ability to draw causal inferences due to bias from reverse causation or residual confounding by factors such as comorbid conditions and reinfections[25]. Due to this inability to draw causal inferences, the models would more aptly be described as prediction models, although the majority of the predictor variables are relatively time-invariant in nature (e.g., educational attainment) and hence are unlikely to have led to confounding that would require temporal considerations. While adjustment was made for receipt of a vaccine booster due to a COVID-19 infection, confounding by indication could explain the null and positive associations between vaccination and long COVID. The measure of being vaccinated and boosted in late 2023 was also limited by the survey item asked then, such that differential misclassification is possible and could explain in part the positive associations with long COVID among those vaccinated (vs. unvaccinated). Although sampling weights accounted for non-response and there is evidence that weighting adjustments mitigated non-response bias[26], such bias could have led to bias towards or away from the null. Because some weighted sample characteristics (e.g., old age, high educational attainment) that differed from the U.S. general population were found to predict lower risks of long COVID, prevalence estimates may be more conservative and represent underestimates. Finally, the estimated costs associated with lost work from long COVID underestimates the total economic burden of long COVID because it does not account for reductions in quality of life or health care costs associated with long COVID and its physical and mental health sequelae, which could be in excess of $500 billion annually[17,27].

The findings from this study highlight the anticipated substantial health and economic burden of long COVID among American adults. Notably, while the estimated total number of working-aged adults reporting currently having long COVID symptoms was sizably lower in the fall of 2023 than in the fall of 2022, the estimated economic burdens were comparable. This may be attributed to the fact that long COVID appeared to increasingly affect higher income groups by the fall of 2023. Should these estimates be confirmed in longitudinal studies, future efforts should focus on identifying biological and social explanations and mediating pathways, and on targeting risk stratification and risk reduction in those at higher risk of long COVID. The scale of long COVID and its sequelae necessitates large-scale governmental funding to address long COVID research priorities and a robust and coordinated policy response strategy[28], as well as ongoing national surveillance of the prevalence and health and economic burden of long COVID, despite the emergency phase of the COVID-19 pandemic being declared over. Candidate public health interventions to mitigate adverse sequelae of long COVID could include enhanced uptake by higher-risk groups of COVID-19 vaccines and non-pharmaceutical interventions including mask-wearing and improved ventilation to reduce the risk of acute infection[29,30], and expanded access to paid sick leave and disability insurance[17].

Data availability

The data used are available in a public, open access repository through the United States Census Bureau (https://www.census.gov/programs-surveys/household-pulse-survey/data.html).

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Author contributions

D.K. was responsible for conceptualization, methodology, formal analysis, data curation, acquisition of resources, project administration, and writing (original draft preparation, review, and editing).

Competing interests

The author declares no competing interests.

Additional information

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Correspondence and requests for materials should be addressed to Daniel Kim.

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