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Methods Article

Association of cognitive deficits with sociodemographic characteristics among adults with post-COVID conditions: Findings from the United States household pulse survey

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Abstract

People infected with coronavirus disease-19 (COVID-19) may continue to experience symptoms for several weeks or even months after acute infection, a condition known as long COVID. Cognitive problems such as memory loss are among the most commonly reported symptoms of long COVID. However, a comprehensive evaluation of the risks of cognitive decline following COVID-19 infection among different sociodemographic groups has not been undertaken at the national level in the USA. We conducted a secondary analysis on the datasets from the U.S. Census Bureau Household Pulse Survey, encompassing data collected from 1 June 2022 to 19 December 2022. Based on a cohort of 385 370 individuals aged 18 years or older, we employed logistic regression analysis to examine the association between self-reported cognitive deficits and different sociodemographic factors among individuals with long COVID conditions. We have demonstrated that individuals with long COVID had a significantly higher risk of cognitive deficits compared to those with no history of COVID infection. Cognitive deficits vary across sociodemographic groups. In individuals without long COVID, men, older adults, and those with higher education reported fewer cognitive deficits, while Hispanics and residents of the South reported more. Long COVID had similar impacts across genders and regions but appeared to have the smallest impact on Hispanics compared to other racial groups. Conversely, the effects of long COVID were most significant in older adults and individuals with higher education. The state-level analysis further suggests potential variation in long COVID's effects across different states. The risks of cognitive deficits among adults with post-COVID conditions are substantial. Various sociodemographic groups can have different risks of developing cognitive deficits after experiencing long COVID. The findings of this large-scale study can help identify sociodemographic groups at higher risk of cognitive deficits, facilitate medical interventions, and guide resource allocation to target populations at risk and prioritize areas with a high rate of cognitive decline.

Keywords: long COVID; cognitive deficit; household pulse survey; sociodemographic groups; education attainment level

Introduction

Coronavirus disease-19 (COVID-19) caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has posed a major challenge to public health worldwide. As of July 2023, there have been more than 760 million confirmed cases of COVID-19, including 6.9 million deaths worldwide [1]. While recent unprecedented progress in clinical research and vaccine development has significantly helped the prevention of COVID-19, accumulating evidence suggests that COVID survivors experience persistent symptoms after initial infection [2–4]. Many survivors are often diagnosed with post-acute sequelae of COVID-19, or simply long COVID, broadly defined as persistent symptoms and clinical abnormalities lasting beyond the first 30 days of infection [5, 6]. Long COVID can affect multiple organ systems, including heart, brain, kidney, and gastrointestinal tract [3, 7–10]. In 2021, long COVID was recognized as a condition that could result in a disability under the Americans with Disabilities Act [11]. While current studies consistently demonstrate that the severity of acute symptoms is a significant risk factor for long COVID, they have yielded controversial results on how the risk varies among different demographic groups. For example, Hastie et al. claimed that the risk of long COVID was higher in females, older adults, and white ethnicity [4]. In contrast, Wu et al. found no significant association between long COVID and sociodemographic factors [12]. These controversial findings could be due to the fact that long COVID reflects a wide spectrum of symptoms, and each symptom may manifest differently in various demographic groups. For example, symptoms such as sleep disorders and headaches appear more pronounced in younger adults, while others, such as anxiety and dyspnea, are more prevalent in adults older than 70 years [13]. Because long COVID manifests as a heterogeneous problem, it would be better to focus on specific symptoms when studying their associated risk factors. Our study

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focuses on cognitive symptoms characterized as loss of memory and impaired concentration, one of the most common and distressing features of long COVID conditions [14].

Recent neuroimaging studies have demonstrated that COVID infection may cause widespread structural abnormalities in the brain, which may help explain the lasting cognitive dysfunction among people with long COVID conditions [15, 16]. The relationship between cognitive impairment and COVID care sites was assessed within a cohort of 740 individuals aged 18 years and above, all of whom had contracted COVID-19 [17]. According to the study, 7 months after their COVID-19 infection, 15% of patients who had been hospitalized, 10% of those requiring emergency department admission, and 8% of outpatients exhibited signs of impaired working memory [17]. A large study involving around 81 000 individuals, primarily from the UK, has reported consistent findings concerning the influence of COVID infection on cognitive function. The study indicates an elevated risk of cognitive decline that correlates with the severity of acute COVID infection. Notably, patients who required hospitalization and ventilator support displayed the most significant cognitive regression [18]. A recent study employed the US Department of Veterans Affairs healthcare databases to estimate risks and burdens of neurological disorders at 12 months following initial COVID infection. It was demonstrated that individuals experiencing ongoing long COVID symptoms after the initial onset performed significantly worse than those who had fully recovered, suggesting a common occurrence of memory problems among individuals with long COVID conditions [19].

Overall, the existing literature has demonstrated that long COVID patients exhibit neurocognitive impairments, including memory deficits, potentially due to structural and functional changes in the brain after COVID infection. However, most studies utilized European cohorts, as demonstrated in the review and meta-analysis [20]. While there are a few studies utilizing US cohorts, they typically have only incorporated relatively small sample sizes or limited diversity in demographic groups [17, 18, 21]. A comprehensive evaluation of the risks of cognitive problems among individuals with long COVID condition has not been undertaken at the national level in the USA. Beginning in June 2022, the National Center for Health Statistics collaborated with the United States Census Bureau to include long COVID-related questions in the experimental Household Pulse Survey (HPS) [22]. This online survey makes the first large-scale dataset about the prevalence of self-reported long COVID, providing a unique opportunity to study the impacts of long COVID on cognitive functions among the US population at the nationwide level. In this study, by leveraging the responses from this national survey, we assess the prevalence of self-reported cognitive deficits among adult COVID survivors in the USA and compare the risks of severe cognitive deficits across different sociodemographic groups.

Materials and methods

Data source

The HPS was initially launched in April 2020 and aims to quickly collect real-time data to explore the impacts of COVID-19 on American households and individuals [23]. It is a 20 min online survey randomly selecting people aged 18 years or older to participate. Unique phone numbers and e-mail addresses are assigned to only one household in a de-duplication process. Households were randomly sampled from the US Census Bureau's Master Address File and were sent the survey via text or e-mail. As of August 2023, the HPS continues with a 2-week on, 2-week off collection and distribution approach. The survey asks questions related to physical and mental health, transportation, and childcare, as well as detailed demographic information of individuals. Starting from June 2022, a set of questions to assess the prevalence of long COVID was added to the survey [22]. The questions asked include "Did you have any symptoms lasting 3 months or longer that you did not have prior to having coronavirus or COVID-19?" While the survey yielded a low response rate of about 6%, its inclusion of long COVID-related questions and a number of sociodemographic variables allows us to study the association between people's cognitive status and their sociodemographic characteristics among people with long COVID conditions at the US population level.

Data collection

We downloaded seven microdata files from HPS data collection phases 3.5 to 3.7, spanning the time frame between 1 June 2022 and 19 December 2022 [24], which include all the HPS data with long COVID information at the time of this study. A consolidated dataset was generated by merging these microdata files. The dataset included survey responses from 392 073 individuals. After excluding the individuals with missing responses to the COVID-related questions, we obtained a cohort of 385 370 individuals. With regards to the cognitive outcome, we examined the survey responses to the question in the cognition domain: "Do you have difficulty remembering or concentrating? (1) No—no difficulty; (2) Yes—some difficulty; (3) Yes—a lot of difficulty; and, (4) Cannot do at all." This question was recommended by the United Nations to identify disability in national censuses [25]. Following the United Nations' guidelines, current literature identifies people who answer "a lot of difficulty" or "cannot do at all" as having the disability (e.g. [26, 27]). In this study, we categorize the cognitive outcome into two levels for further analysis. Individuals who answer "no difficulty" or "some difficulty" are categorized as not having severe cognitive deficits, while individuals who answer "a lot of difficulty" or "cannot do it at all" are classified as having severe cognitive deficits. We also retrieved self-reported survey responses regarding individuals' sociodemographic status, including gender at birth, race/ethnicity, age (based on the year of birth), educational attainment, and region and state of residence, to determine their association with the self-reported cognitive deficits among individuals. It was demonstrated that these sociodemographic factors were associated with long COVID conditions based on a large-scale study involving the Scottish population [4]. In light of this, we chose to incorporate these variables into this study to investigate their potential association.

The HPS does not include pre-pandemic data. To examine pre-pandemic trends, we utilized the Current Population Survey (CPS) data obtained via IPUMS, covering January 2016 to December 2022 [28]. While the CPS does not include specific questions about long COVID, it includes questions assessing cognitive impairments similar to those in the HPS. We calculated the monthly prevalence of adults reporting difficulty remembering or concentrating and compared it to trends identified in the HPS post-COVID with cognitive deficit within the US population.

Data analysis

All data analyses and visualization were performed using R, version 4.2.2 [29]. All *P*-values were two-sided and *P*-values less than 0.05 were considered statistically significant. First, for assessing the long COVID prevalence, chi-square tests and Cramér's V statistics were used to investigate group differences in relation to

long COVID, categorized by various sociodemographic variables including gender, age, race/ethnicity, educational attainment level, and region of residence.

We then used a binary logistic regression model to quantify the association between the dichotomous outcome of cognitive deficit and long COVID status. Both univariate logistic regression model and the adjusted model accounting for other potential covariates (i.e., gender, age, race/ethnicity, education level, and regions) were run. We next conducted multivariable logistic regression analysis to further assess various sociodemographic factors associated with cognitive deficit, using cognitive deficit status as the dependent variable. We included individuals with no COVID and those with long COVID, represented by a binary independent variable. Sociodemographic factors and their interactions with long COVID status were also included as independent variables. Odds ratios for each sociodemographic factor and their interactions with long COVID status were calculated to quantify their influence on the possibility of cognitive deficit. When selecting reference groups, we used a natural baseline as the standard for comparison whenever possible. For example, we chose the youngest group "age 18–34" as the reference for age categories and "high-school education" as the baseline for comparing higher education levels. For variables without an obvious baseline, such as gender, race/ethnicity, and region, we selected the most frequent group as the reference to enhance model interpretability.

In analyzing the dataset of over 385 000 survey responses, we employed chi-squared tests, Cramér's V statistics, and logistic regression method. While these methods are well-established in statistical analysis, their application in this study was uniquely adapted to examine the effects of long COVID on cognition across diverse sociodemographic groups. Chi-squared tests, with Cramér's V for effect size estimation, were used as preliminary screening tools to identify significant associations between cognitive outcomes and categorical variables. Logistic regression was then applied to model these relationships further, focusing on identifying predictive sociodemographic factors that could inform targeted interventions for the most at-risk populations. By adapting traditional methods in this context, our approach provides meaningful public health insights that are tailored to the demographic characteristics within the data.

Results

Characteristics of survey participants

Among the 385 370 participants in our dataset, 212 992 (55.3%) reported no previous COVID infection. Out of the remaining 172 378 individuals who reported previous COVID infection, 50 038 participants experienced long COVID symptoms lasting for more than 3 months, comprising 29.0% of the infected group and 13.0% of all survey participants (Table 1). Five categorical variables, namely gender at birth, race/ethnicity, age, educational attainment, and region of residence, were derived from the response categories in the survey. We then disaggregated the individuals into their respective categories and conducted chi-squared tests to investigate group differences in relation to long COVID status, as summarized in Table 1.

The overall strength of association between long COVID and these sociodemographic groups, measured by Cramér's V, along with individual odds ratios are listed in Supplementary data, Table S1. The results have demonstrated that long COVID disproportionally affects females: 69.1% of participants reporting long COVID are females, compared to only 54.1% among those without long COVID, indicating a strong association between long COVID status and gender (χ^2 (df=1,N=172378) = 3283.8, $P < 0.0001$). The difference suggests that males are less likely to experience long COVID than females [odds ratio (OR) = 0.55, $P < 0.0001$]. Analysis on race/ethnicity suggests that long COVID is most common among the non-Hispanic, multiracial groups (OR = 1.38, $P < 0.0001$) and least common among non-Hispanic Asian (OR = 0.73, $P < 0.001$). To examine age differences, we created four major age groups and classified the participants into these groups: young adults (18–34 years), early middle-aged (35–49 years), late middle-aged (50–64 years), and old adults (65+ years), according to the general developmental stage in adult life span [30, 31]. Only 15.9% of long COVID cases are reported by adults aged 65 years and older, while this age group represents 27.2% of the survey participants. This discrepancy suggests that older adults are less likely to report long COVID, compared to young adults (OR = 0.93, $P < 0.0001$). In addition, long COVID is least common among individuals with a graduate degree (19.2%), compared to those without a college degree (OR = 0.52, $P < 0.0001$). Lastly, 33.4% of long COVID patients reside in the South region, significantly higher than in the West and Northeast regions, where the odds ratios are 0.95 and 0.84 ($P < 0.0001$), respectively.

Association between cognitive deficits and long COVID

We evaluated the association between cognitive deficit and the long COVID status (Table 2). After excluding nonrespondents on the cognitive outcome question, we obtained a cohort of 335 395 individuals. Compared to individuals who never had COVID, those who have experienced long COVID have a significantly higher odds of experiencing severe cognitive deficit, as indicated by the univariate model [OR = 3.37, 95% confidence interval (CI) 3.26–3.49]. Even after accounting for sociodemographic variables, the long COVID group still shows a higher risk of cognitive deficit compared to the group who had never been infected (adjusted OR = 2.87, 95% CI 2.78–2.97). However, people who had previous COVID infection but did not report long COVID symptoms only have a slightly increased risk of cognitive deficit (adjusted OR = 1.08, 95% CI 1.05–1.12).

We further examined the association between the severity of COVID acute infection and the odds of reporting severe cognitive deficit. While people with an asymptomatic course of COVID-19 infection were not associated with increased odds of cognitive deficit (OR = 1.01, $P = 0.75$), people who had mild, moderate, or severe symptoms during the acute infection stage were significantly more likely to report cognitive disability (Supplementary data, Table S2). The significance of the association increases with the severity of symptoms. Compared to those who had never been infected with COVID, people with mild, moderate, or severe symptoms had 1.24, 1.32, and 3.07 times the odds of having cognitive deficit (all P-values are smaller than 0.0001), respectively (Supplementary data, Table S2). To provide a more comprehensive perspective and examine trends of cognitive deficits before and after COVID-19, we incorporated data from the CPS via IPUMS [28].

As shown in Fig. 1, the percentage of adults reporting difficulty remembering or concentrating remained relatively stable before April 2020. Post-COVID, the prevalence increased with the smooth locally estimated scatterplot smoothing curve demonstrating a marked upward trend. This finding corroborates the observed association between COVID infection and increased cognitive deficits.

Table 1. Summarized sociodemographic characteristics of survey participants.

	Never infected, $n = 212\,992$	No long COVID, $n = 122\,340$	Long COVID, $n = 50\,038$	Total, $n = 385\,370$	Chi-squared
Gender at Birth, *N* (%)					
Female	118 652 (55.7)	66 184 (54.1)	34 569 (69.1)	219 405 (56.9)	χ^2 (1,172378) = 3283.8
Male	94 340 (44.3)	56 156 (45.9)	15 469 (30.9)	165 965 (43.1)	$P < 0.0001$
Race/ethnicity, *n* (%)					
Non-Hispanic White	162 224 (76.2)	95 535 (76.5)	36 375 (72.7)	292 134 (75.8)	χ^2 (4,172378) = 1002
Non-Hispanic Black	16 690 (7.8)	7,465 (6.1)	3,571 (7.1)	27 726 (7.2)	$P < 0.0001$
Non-Hispanic Asian	10 212 (4.8)	5828 (4.8)	1412 (2.8)	17 452 (4.5)	
Non-Hispanic, multi-race	7968 (3.7)	4569 (3.7)	2679 (5.4)	15 216 (3.9)	
Hispanic	15 898 (7.5)	10 943 (8.9)	6001 (12.0)	32 842 (8.5)	
Age, *n* (%)					χ^2 (3,172378) = 509.76
18–34	29 380 (13.8)	26 541 (21.7)	10 124 (20.2)	66 045 (17.1)	$P < 0.0001$
35–49	49 385 (23.2)	39 449 (32.2)	16 886 (33.7)	105 720 (27.4)	
50–64	61 434 (28.8)	32 337 (26.4)	15 088 (30.2)	108 859 (28.2)	
65 and above	72 793 (34.2)	24 013 (19.6)	7940 (15.9)	104 746 (27.2)	
Education, *n* (%)					χ^2 (3,172378) = 3572.8
High school and below	30 647 (14.4)	14 153 (11.6)	8066 (16.1)	52 866 (13.7)	$P < 0.0001$
Some college/associate	66 523 (31.2)	34 583 (28.3)	19 596 (39.2)	120 702 (31.3)	
Bachelor's degree	59 606 (28.0)	38 441 (31.4)	12 767 (25.5)	110 814 (28.8)	
Graduate degree	56 217 (26.4)	35 163 (28.7)	9609 (19.2)	100 989 (26.2)	
Region, *n* (%)					χ^2 (3,172378) = 197.05
South	68 646 (32.2)	38 831 (31.7)	16 ,706 (33.4)	124 183 (32.2)	$P < 0.0001$
West	68 015 (31.9)	37 818 (30.9)	15 354 (30.7)	121 187 (31.4)	
Midwest	45 590 (21.4)	26 317 (21.5)	11 307 (22.6)	83 214 (21.6)	
Northeast	30 741 (14.4)	19 374 (15.8)	6671 (13.3)	56 786 (14.7)	

Note: The numbers inside the parenthesis indicate the percentages of individuals in each subcategory.

Table 2. Logistic regression analysis of associations between severe cognitive deficit and COVID infection.

	Severe cognitive deficits, *n*		Univariate		Adjusted	
	Yes	No	OR (95% CI)	*P*-value	OR (95% CI)	*P*-value
Never infected	9415	175 436	1.0	Reference	1.0	Reference
No long COVID	5998	100 933	1.11 (1.07–1.14)	<0.0001	1.08 (1.05–1.12)	<0.0001
Long COVID	6683	36 930	3.37 (3.26–3.49)	<0.0001	2.87 (2.78–2.97)	<0.0001

Note: Odds ratio calculation is referent to people who never had COVID.
n, the number of people; OR, odds ratio; CI, confidence interval; adjusted, model controlled for gender, race/ethnicity, age, education, and region.

Association between cognitive deficit and sociodemographic factors

The risks of cognitive deficit are different among various sociodemographic groups (Fig. 2 and Supplementary data, Table S3).

Compared to females, males are less likely to experience severe cognitive deficits at the baseline level (OR = 0.72, $P < 0.0001$). The interaction effect between long COVID and gender has an OR of 1.05 with a CI that includes 1, suggesting that the effect of long COVID on cognitive deficit does not significantly differ by gender. Compared to non-Hispanic whites, Blacks (OR = 0.75, $P < 0.0001$) and Asians (OR = 0.69, $P < 0.0001$) have significantly lower odds of cognitive deficits. Conversely, multi-race individuals and Hispanics are more likely to report cognitive deficits (OR = 1.44 and 1.18, respectively). The interaction between long COVID and race/ethnicity is significant for the Hispanic category, with an odds ratio of 0.82. This suggests that long COVID has a smaller impact on cognitive deficits for this group compared to White individuals, but no significant differences are observed for other racial/ethnic groups. Among the four age groups observed, young adults aged 18–34 years have the highest odds of reporting severe cognitive deficit at baseline (no COVID infection). In contrast, older adults show a progressively lower likelihood of cognitive deficits, with the oldest group having a significantly reduced risk compared to the youngest (OR = 0.26, $P < 0.0001$). However, when long COVID is present, its impact on cognitive deficits is much stronger in older adults, significantly amplifying the risk. As a result, the oldest group's reduced risk diminishes substantially, with an odds ratio of 0.87 relative to the youngest group. For education, higher education levels are associated with a reduced likelihood of cognitive deficits, with individuals holding a graduate degree being 62% less likely than those with less than high school education. Interestingly, the interaction effects suggest that long COVID's impact on cognitive deficits is stronger among individuals with higher education levels. Finally, for region comparison, individuals in the West, Midwest, and Northeast regions are less likely to experience cognitive deficits than those in the South region at the baseline level, but the interaction effects indicate that long COVID's influence on cognitive deficits does not vary significantly across regions.

Discussion

In the analysis of 385 370 survey respondents between June and December of 2022, we estimated that approximately 29% of

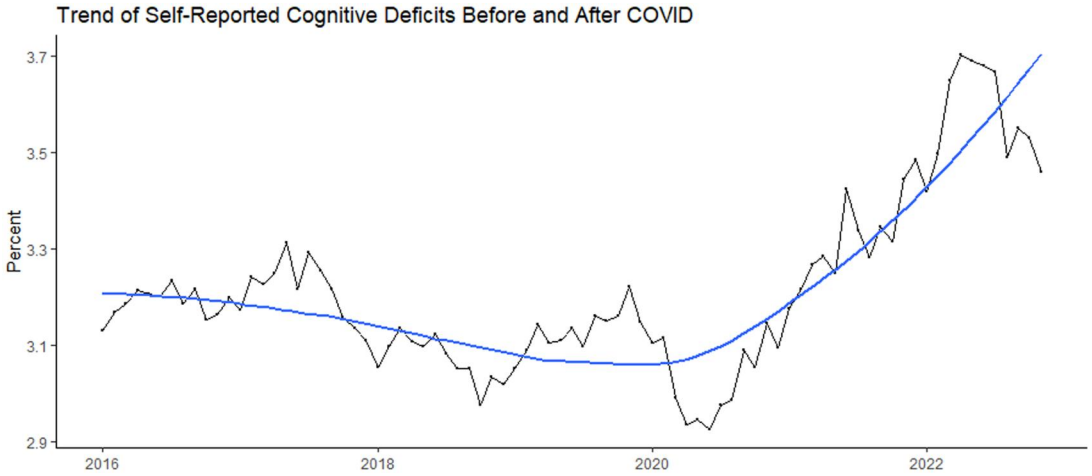

Figure 1. Trends in self-reported difficulty in remembering or concentrating before and after COVID onset

Note: The figure illustrates the overall percentage of self-reported cognitive difficulties among all CPS survey participants, comparing trends before and after the onset of the COVID-19 pandemic.

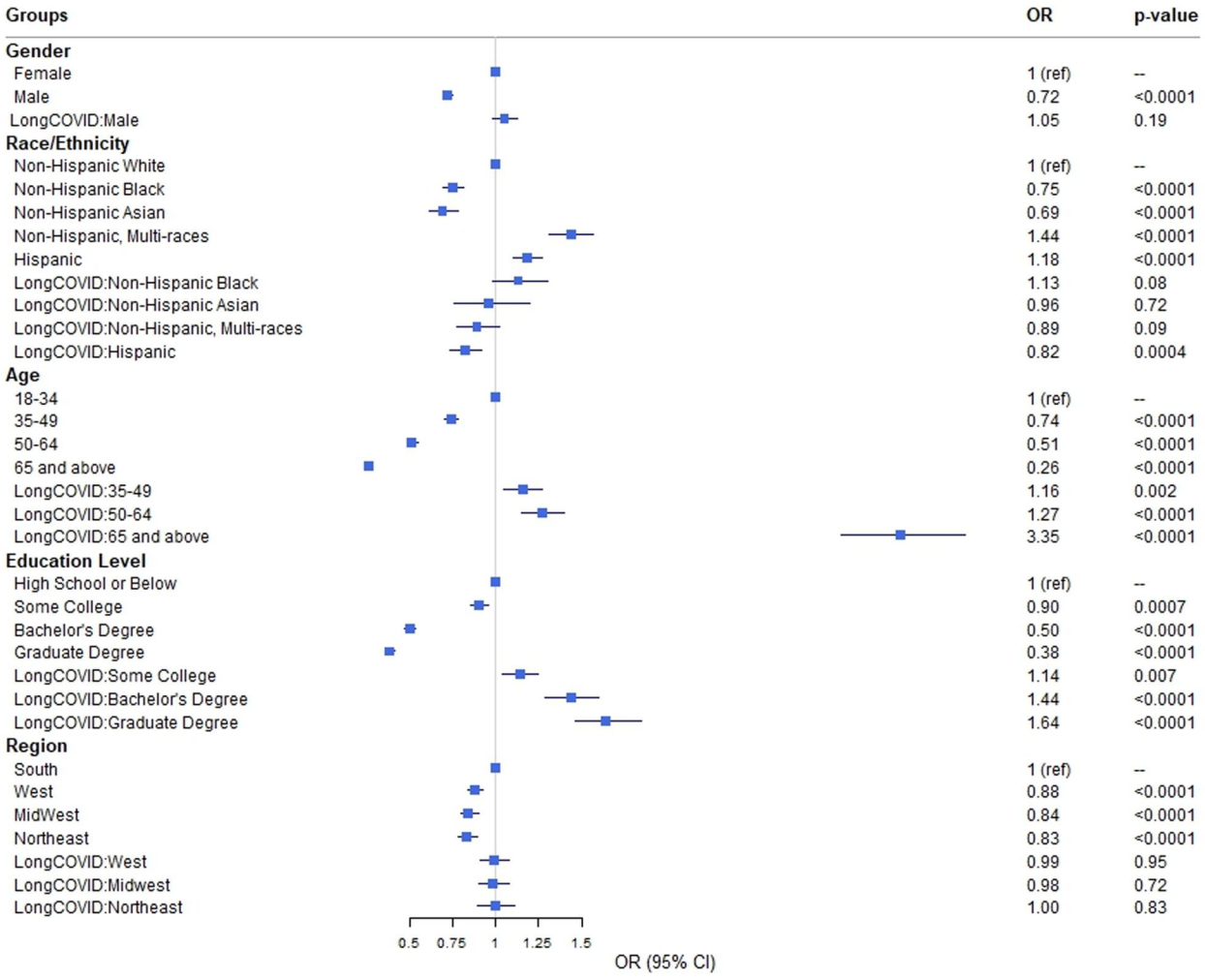

Figure 2. Forest plot representing odds ratio of different sociodemographic variables

Note: Odds ratios are calculated with adjusted logistic regression analyses that are controlled for the other categorical variables in the plot.

individuals who had previously contracted COVID also experienced long COVID symptoms lasting more than 3 months. The estimation of long COVID prevalence in the US national level is lower than that reported by a Scottish study, where more than 42% of COVID survivors experienced persistent symptoms after 6 months [4]. It is important to highlight that the questionnaire utilized in the Scottish study included a total of 33 symptoms, all classified as long COVID conditions. In contrast, the House Pulse Survey which our study relied on includes only 12 symptoms. Therefore, the difference in how long COVID conditions are defined and the range of persistent symptoms between the Scottish study and ours could potentially contribute to the divergent results. Our results also demonstrate the prevalence of long COVID tends to be low in the oldest age group (65+ years), consistent with a recent study based on a population-representative sample of 3042 US adults [32]. The lower prevalence of long COVID among older people can be due to several factors such as survivor bias, lower rates of virus exposure, and higher rates of vaccination of old adults [33].

Our study suggests that people with long COVID are at increased risk of cognitive deficits in memory and concentration, and the risk correlates with the severity of COVID symptoms during the acute infection phase. More specifically, for asymptomatic patients, they do not have an increased risk compared to those who never got infected. These findings corroborate with the current existing studies investigating the impact of COVID on cognitive status [34]. Furthermore, we have examined the association between different sociodemographic factors and cognitive deficits in long COVID patients and found that the risk of cognitive deficits after long COVID is independent of gender, as the interaction effects between long COVID and gender were not significant, suggesting that the impact of long COVID on cognitive deficits does not differ between males and females. In a recent study of 72 mild-to-moderate COVID survivors, Henneghan *et al*. found no gender difference in the overall cognitive function measured by a neuropsychological test [35]. Therefore, our finding on gender effect aligns with this prior study. In addition, our results suggest that uninfected individuals in the 65+ age group have the lowest risk of cognitive deficits, compared to other age groups. This observation could partly reflect the reporting bias, where the survey participants in this age group may underreport cognitive deficits due to normalization of age-related changes. However, anosognosia—a lack of awareness of cognitive impairments—could also contribute to underreporting, potentially masking the true burden of cognitive deficits in this age group [36]. Future studies using objective cognitive assessments could help clarify the extent to which anosognosia influences self-reported cognitive outcomes in older adults. Nevertheless, the interaction effects between long COVID and age indicate that long COVID disproportionately affects different age groups, with individuals in the 65+ age group experiencing the most significant increase in cognitive deficits when long COVID is present. This finding offsets the reduced baseline risk in the oldest group and highlights their heightened vulnerability to the cognitive effects of long COVID. These effects may be driven by underlying biological susceptibilities, as well as compounding effects such as social isolation and reduced physical activity [37].

Among different race and ethnicity groups, this study indicates that Black and Asian individuals had a lower baseline likelihood of cognitive deficits compared to White individuals, while Hispanic and multiracial groups exhibited a higher likelihood. The interaction effects suggest that long COVID's impact on cognitive outcomes does not differ significantly across most racial/ethnic groups, except for the Hispanics, where the risk was slightly attenuated. Some prior studies on the association of long COVID with memory disorders did not include subjects from diverse races/ethnicity, potentially limiting the scope of their findings [38, 39]. There may be multiple factors for the racial disparity in cognitive outcomes shown in this study. One possibility is that the biological effects of COVID-19 may differ due to genetic differences in various racial groups, consistent with a review on the genetic insight into COVID [40]. In addition, our results show that education can act as a protective factor for cognition, with individuals holding higher degrees experiencing significantly lower risks of cognitive deficits. The protective role of education aligns with the cognitive reserve theory, which posits that individuals with greater cognitive reserves due to education can better withstand neurological disruptions [41, 42]. Interaction effects reveal that long COVID's cognitive impact is stronger among individuals with higher education levels. While this result might seem counterintuitive, it could reflect heightened self-awareness of cognitive changes among highly educated individuals or their ability to articulate these deficits more clearly in self-reported surveys.

We further examined whether there were differences in the prevalence of self-reported cognitive deficit among long COVID patients across various US states. We calculated the percentages of long COVID patients reporting severe cognitive deficits in each state and used a color-shaded US map to visualize the results (Fig. 3a). Kentucky (19.6%) and West Virginia (20.0%) had the highest rates of cognitive deficits among individuals with long COVID symptoms. In contrast, Connecticut (11.6%) and Hawaii (12.3%) exhibited the lowest percentages (Supplementary data, Table S4). We performed a similar analysis for individuals uninfected by COVID (Fig. 3b). We have found that Washington D.C (3.4%) and New Jersey (4.0%) have the lowest percentages, whereas Arizona (7.8%) and West Virginia (8.5%) have the highest baseline rates.

As shown in Fig. 3, the prevalence map of cognitive deficits for individuals who never had COVID differs notably from the map for those with long COVID. In addition to the expected lower overall frequency of cognitive deficits in all states, these differences suggest that sociodemographic factors do not merely act as independent risk factors for cognitive deficits, but also moderate the effects of long COVID on cognition. This result highlights regional variability across different US states and supports other findings from this study, demonstrating that individuals' sociodemographic characteristics contribute to their cognitive outcomes.

The COVID-19 pandemic remains a constantly evolving situation. As more treatment for acute COVID becomes available and the number of individuals receiving vaccines and boosters increases, the epidemiology of long COVID may change over time [43]. Therefore, it is important to conduct further research to evaluate the potential impact of vaccination on reducing the risk of cognitive deficits among patients who have breakthrough infection, as well as to identify which sociodemographic groups may benefit the most from vaccination. This information can help guide public health planning and vaccine distribution efforts. Furthermore, while the scope of this study focuses on individuals aged 18 years and above, future research can be conducted to study cognitive decline among children with long COVID as well. Cognitive deficits can have a significant impact on children's academic and social functioning, potentially affecting their future opportunities. Understanding the extent of cognitive decline in this population group will help identify risk factors

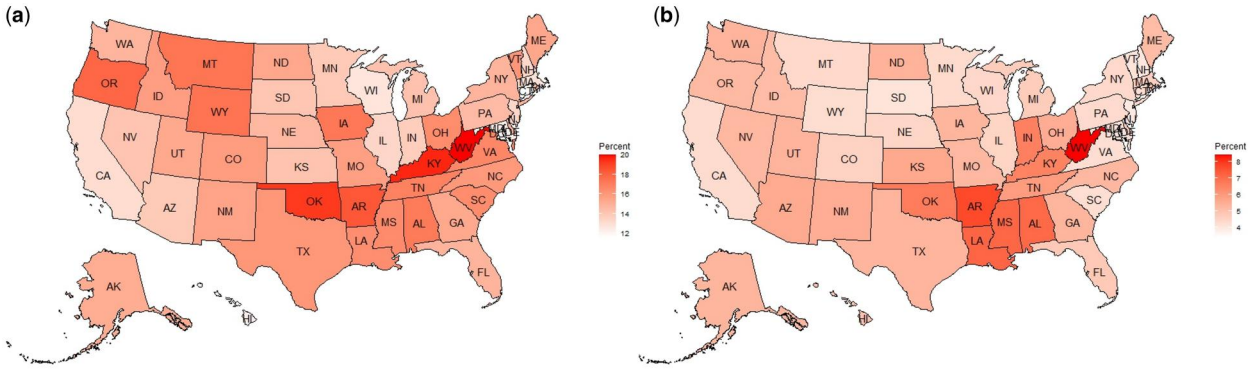

Figure 3. Prevalence of self-reported cognitive deficit in various US states among individuals (a) who reported long COVID; (b) who have not been infected by COVID

Note: The shading of each state in the US map corresponds to the percentage of people reporting severe cognitive deficits in the state.

and guide the development of interventions, such as cognitive rehabilitation, to improve outcomes for affected children. Therefore, it is important to conduct research on the long-term effects of COVID in all age groups to address the broader impact of the disease.

Limitations

This study has several limitations. First, the study relies on self-reported survey data to assess long COIVD symptoms and cognitive deficits. Compared to objective cognitive tests, self-reported responses are susceptible to individual interpretation and may not accurately reflect true cognitive deficits. Research highlights discrepancies between self-reported and objective cognitive assessments. For instance, a study of ICU (intensive care unit) COVID-19 survivors found that subjective impairments were linked to anxiety and depression, while objective measures were related to age and cognitive reserve, with little overlap between the two [44]. Similarly, another study showed no significant relationship between self-reports of "brain fog" and objectively measured cognitive dysfunction [45]. However, some studies have demonstrated associations between self-reported cognitive issues and objective performance on tests measuring memory, attention, and processing speed [46]. These findings highlight the importance of incorporating both subjective and objective measures in future studies to deepen understanding of cognitive deficits in long COVID and inform targeted interventions. Second, the Household Pulse Survey has a relatively low response rate of about 6% and the survey data, which raises concerns about potential sampling bias and its impact on the generalizability of our findings. A low response rate can result in an overrepresentation of certain groups who are more motivated to participate in the survey, such as those experiencing more severe symptoms, and those who may face technological barriers to survey participation can be underrepresented. Consequently, while our analysis offers valuable insights into the associations between sociodemographic factors and cognitive deficits in individuals with post-COVID conditions, these findings should be interpreted with caution, particularly in terms of their applicability to the general population. Finally, although the study demonstrates strong associations between individuals' long COVID status and their cognitive outcome, we cannot establish a causal relationship between long COVID and cognitive deficit. Other confounding variables, such as individuals' preexisting health conditions, may also play a role in their cognitive outcome. Not considering pre-existing symptoms prior to COVID infection could result in an overestimation of the impact of long COVID. Therefore, it is important to supplement this study with other types of research, such as longitudinal studies, to better understand the impacts of long COVID on cognitive functions.

Conclusions

Long COVID has become a worldwide health issue. This study based on a large cohort representative of the US adult population has found significant differences in the cognitive outcomes associated with COVID infections among various sociodemographic groups. Individuals who are older or highly educated are more vulnerable to cognitive deficits if they experience post-COVID conditions, highlighting the importance of considering both biological and non-biological factors in understanding differential cognitive outcomes of COVID infection. The findings of this study can help identify sociodemographic groups at higher risk of cognitive deficits, prompting further investigation into regional variation. Such studies may guide future diagnoses, interventions, and treatments to improve cognitive outcomes among people with post-COVID conditions.

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Author contributions

Daniel J. Wu (Conceptualization [lead]; Data curation [lead]; Formal analysis [lead]; Methodology [equal]; Supervision [supporting]; Writing—original draft [lead]; Writing—review and editing [lead]) and Nianjun Liu (Conceptualization [supporting]; Formal analysis [supporting]; Methodology [supporting]; Supervision [lead]; Writing—original draft [equal]; Writing—review and editing [equal])

Supplementary data

Supplementary data is available at *Biology Methods and Protocols* online.

Conflict of interest statement. None declared.

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Data availability

The microdata files containing individual responses to the Household Pulse Survey are available for download from https://www.census.gov/programs-surveys/household-pulse-survey/data/datasets.html. The processed datasets derived from these microdata files, used in this analysis, are publicly available for download at https://github.com/djw3627/LongCOVID. For additional inquiries, please contact the corresponding author.

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