Total Survey Error Analysis: National Immunization Survey Adult COVID Module COVID-19 Vaccination Coverage Estimates

Elizabeth Allen[1], Vicki Pineau[1], Kirk Wolter[1], Jason Boim[1], James A. Singleton[2], Michael Chen[2], David Yankey[2], Jennifer Kriss[2], Yi Mu[2]

[1]NORC at the University of Chicago, 4350 East-West Highway, Bethesda MD 20814

[2]National Center for Immunization and Respiratory Diseases, Centers for Disease Control and Prevention, 1600 Clifton Road, Atlanta, GA 30329

Abstract

The difference between an estimated survey outcome and the true population value can be impacted by a variety of sources. This overall difference is defined as the total survey error which arises from both sampling and nonsampling errors, such as nonresponse error, sample-frame coverage error, and measurement error. In this analysis, we will present results from a total survey error evaluation of national estimates of the proportion of adults reporting receipt of ≥1 dose of a COVID-19 vaccine in the U.S. as reported each week by the National Immunization Survey Adult COVID Module (NIS-ACM) since April 2021. We will examine the potential stages in which survey error can occur in the NIS-ACM process and seek to measure the error associated with each survey stage. External data sources, such as the American Community Survey, the National Health Interview Survey, and COVID-19 vaccine administration data from CDC will be used to assess and quantify the potential sources of error.

Key Words: COVID-19 Vaccination Coverage; Total Survey Error

The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of the Centers for Disease Control and Prevention.

1. Introduction

The National Immunization Survey (NIS) is a family of random digit dialing surveys conducted by NORC at the University of Chicago for the National Center for Immunization and Respiratory Diseases (NCIRD) at the Centers for Disease Control and Prevention (CDC) to estimate vaccination coverage for children of various ages. Beginning April 2021, CDC added the NIS-Adult COVID Module[1] (NIS-ACM), which is used by CDC for weekly and monthly monitoring of vaccination coverage, barriers to vaccination, vaccine hesitancy, and social attitudes and behaviors associated with COVID-19. This activity was reviewed by CDC and was conducted consistent with applicable federal law and CDC policy (e.g., 45 C.F.R. part 46.102(l)(2), 21 C.F.R. part 56; 42 U.S.C. §241(d); 5 U.S.C. §552a; 44 U.S.C. §3501 et seq.).

NIS-ACM surveys adults 18+ years and utilizes a sample design that allows for weekly and monthly national, state and selected local area estimation. The NIS-ACM uses the NIS-Child sample and interviews the adult respondent after any interviews are completed for children under the age of 18, where applicable. One of the key features of the NIS-ACM is the ability to capture rich demographic and behavioral information that other data sources, such as immunization information systems (IIS) and state and local health departments, are unable to collect. Additionally, this survey has a large weekly and monthly sample size, allowing for analyses of smaller subgroups of interest. The final estimates are created using survey weights, which include multiple steps. The first step creates base weights, defined as the inverse of the probability of selection. The base weights are then adjusted to account for survey nonresponse. These weights are then raked to population demographic totals (e.g., race/ethnicity, sex, age group). After initial review of the weighted estimates, a further calibration was applied to adjust the raked weights to the number of persons with 1 or more COVID-19 vaccination doses reported to CDC by jurisdictions. This allowed the NIS-ACM estimates of those with 1 or more doses to align with the COVID-19 administration data published in the CDC COVID Data Tracker (CDC, 2022). This final step adjusted the raked weights to vaccination status by age group and vaccination status by sex within estimation area.

While the sample design and weighting process allow for estimation of vaccination coverage, there is still potential error added at each stage of the survey process (sampling, data collection, weighting). This was noticeable with the initial estimates produced in May 2021 based on the weights raked to population demographics but not to the COVID-19 vaccine administration data. Graph 1 presents estimates of vaccination coverage for receipt of 1 or more doses of COVID-19 vaccination (1 or more COVID-19) from early May through late December 2021 for the NIS-ACM as well as the benchmark 1 or more COVID-19 vaccination coverage reported in the CDC COVID Data Tracker (CDC, 2022). The COVID Data Tracker disseminates information on the number of cases, deaths, hospitalizations, and vaccinated population, which is updated daily, based on inputs from multiple data sources. In early May, NIS-ACM overestimated 1 or more COVID-19 vaccination coverage relative to the COVID Data Tracker by approximately 12 percentage points. The absolute differences between the ACM survey estimates and the COVID Data Tracker administrative estimates diminished over the period, with estimates converging towards one another. After the final weights were further calibrated to the COVID-19

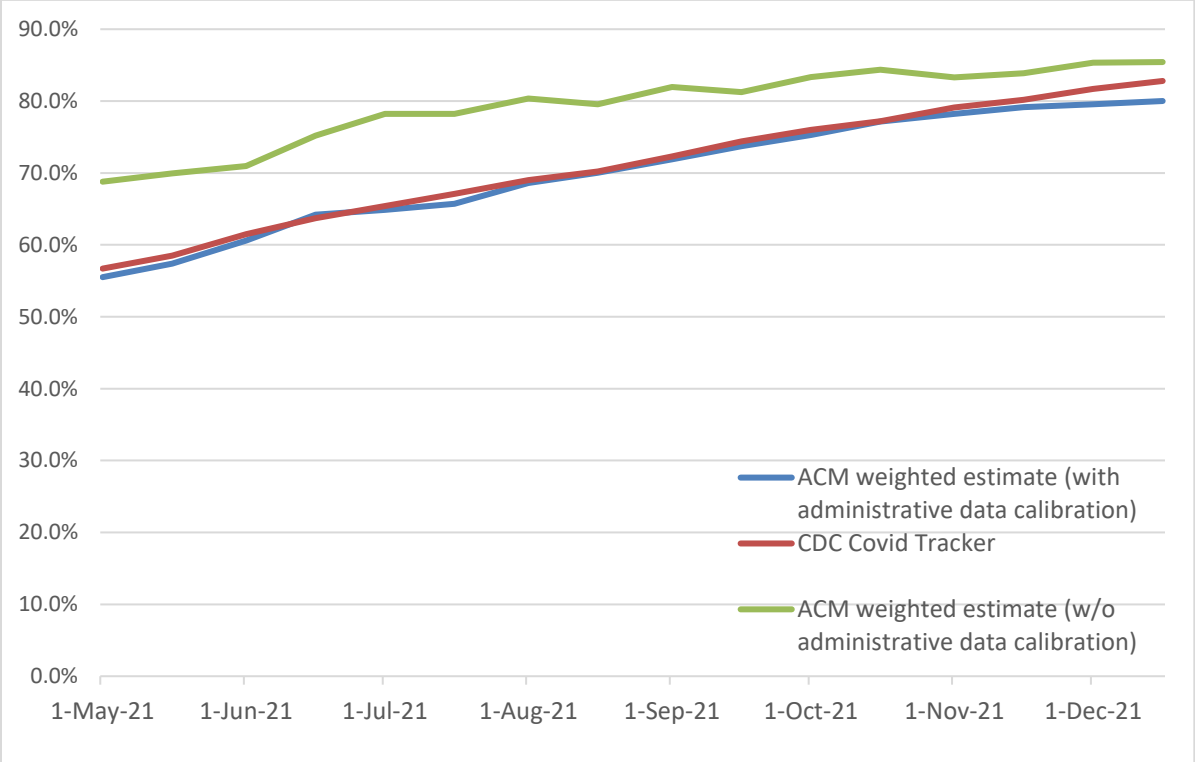
[1] https://data.cdc.gov/Vaccinations/National-Immunization-Survey-Adult-COVID-Module-NI/udsf-9v7b

vaccine administration data, estimates were typically within 1 percentage point of the COVID Data Tracker. These final calibrated weights are used for estimates published by CDC (e.g., see COVIDVaxView Interactive! | CDC).

Total Survey Error (TSE) is the difference between the estimate of an outcome of interest measured in a survey and the true value of that outcome in a population, including both sampling and nonsampling error. Sampling error is determined by the sample size, survey design, and estimation method. Nonsampling error arises primarily from noncoverage of the target population by the survey sampling frame, nonresponse to the survey, and recall or other reporting error in measured outcomes. The focus of this analysis is on the nonsampling error at each of these three stages.

The remainder of this paper is divided into four sections: one each for coverage error, nonresponse error, and reporting error, with a final section that summarizes the findings and identifies next steps to be taken to further understand the TSE in 1 or more COVID-19 vaccination coverage estimates.

Graph 1. COVID-19 Vaccination (≥ 1 dose) Coverage for Adults ≥18 years: Early May – December 2021*, NIS-ACM



* Weighted Estimates using demographically post-stratified weights for each survey. Estimates reported in the presentation may differ somewhat from officially reported estimates for various reasons. For the ACM, estimates published by CDC also include a weighting calibration to the COVID-19 vaccine administration data included as population control totals.

2. Coverage Error

Sampling frame coverage errors arise in a survey when the sampling frame does not include the entire target population or includes elements outside of the target population, the latter

which is likely a minor issue for this survey. The NIS-ACM uses a single-frame cell-phone Random-Digit-Dial (RDD) design, which omits direct representation of adults in landline only and phoneless households. To account for the excluded population groups, the NIS-ACM weighting methodology makes adjustment to the weights by raking the weights to select demographic characteristics of the population of adults. The assumption embedded in this procedure is that the vaccination coverage in the population not represented on the sampling frame equals the coverage in the population represented on the frame. However, it is possible that estimated vaccination coverage of adults in the omitted domains experience different vaccination coverage than the domains of those included in the survey, namely, cell-phone-only (CPO) adults and dual-user adults, which may introduce bias into the estimator of the vaccination coverage rate.

In this section, we attempt to understand the potential bias that could have been introduced by sampling frame population coverage error. The benchmark used for this portion of analysis was the wireless estimates produced from the National Health Interview Survey (Blumberg & Luke, 2021). The proportion of adults in cell-phone households (i.e., CPO and dual-user domains combined) covers 97.3% of all adults in the target population. Of those included in the survey frame, 69.9% live in households with only a cell-phone, and 30.1% live in a household with both a cell-phone and a landline.

Table 2.1 displays the proportion of adults in the population that are covered by the survey frame for the first half of 2021. As can be seen in table below, the key demographic by age group, race/ethnicity, and sex, there is overall very high population coverage rates. The one group with lower coverage in the cell-phone frame is adults who are 65 years of age and older, with a population coverage rate of 89.1%. All other subgroups had a sampling frame coverage rate of 94% or higher.

Ideally, an additional comparison would be to review the vaccination coverage of those with 1 or more COVID-19 vaccination doses for those in landline only households and from the phoneless population. At the time of this analysis, this information was not available.

Table 2.1 NHIS Wireless Estimate of Sampling Frame Coverage, by Subgroup of Interest

Category	NHIS Wireless Estimate of Coverage
Overall	97.3
Age group	
18-24	96.6
25-29	98.0
30-34	98.3
35-44	97.3
45-64	96.5
65+	89.1
Race/Ethnicity	
Hispanic	95.0
White, non-Hispanic	95.8

Black, non-Hispanic	93.8
Asian, non-Hispanic	94.7
Other or multiple race, non-Hispanic	94.2
Sex	
Male	95.9
Female	94.7

3. Nonresponse Error

There are multiple reasons why someone may choose not to respond to a survey. The leverage saliency theory (Groves, Singer, & Corning, 2000) models the probability of someone responding to a survey. There are multiple survey attributes that could influence someone's decision to participate in a survey, such as

- Survey topic: interest and/or saliency of topic to respondent,
- Sponsorship: who is funding the research,
- Incentive: monetary or nonmonetary,
- Survey mode: enjoyment/aversion to direct interaction with interviewer.

In this context, it could be surmised that those who are vaccinated, or more prone to getting a severe case of COVID, might have a higher interest in the survey topic, and more likely to respond to the survey. Conversely, those who are unvaccinated and are not planning on getting vaccinated may be less likely to respond to the survey.

Nonresponse error in NIS-ACM estimates of 1 or more COVID-19 vaccination coverage is the error arising because responses are not obtained for all adults sampled. Nonresponse arises at three steps in the survey process, as follows: (1) failure to resolve the selected telephone number as an occupied household or some other known entity, (2) failure to screen the household for survey eligibility, and (3) failure to complete the interview of an eligible adult. We do not observe the vaccination statuses of adults who do not complete the interview.

NIS-ACM treats the error due to nonresponse using weight adjustments that correct for known differences between responding and nonresponding adults based on observable characteristics. Specifically, weighting cells are defined based on sample frame information known for both respondents and nonrespondents, and weights are adjusted by a factor inversely proportional to the response rates[2] within each cell. Calibration of the weights to demographic population totals also serves to adjust for differences between the responding sample and the population. Additionally, a final calibration to known vaccination counts reported to CDC is implemented.

The weighting and calibration adjustment methods assume that nonresponse is a missing at random process (Rubin, 1976), or that the conditional distribution of the vaccination

[2] The NIS-ACM CASRO response rate was 22.1% on April 30, 2022.

coverage on the characteristics used to form the weighting cells and calibration dimensions is the same whether or not the data are missing. This assumption, while widely used for weighting nonresponse adjustments, is generally untestable since we do not observe vaccination status for nonrespondents. Thus, further methods are needed to assess the potential impact of nonresponse error on survey estimates after conducting weighting adjustments.

Tables 3.1 to 3.6 show the distributions of key demographic variables of interest, for the 2020 1-Year American Community Survey (ACS) and the design-weighted pool of NIS-ACM respondents. This comparison highlights areas where the pool of NIS-ACM respondents either over- or under-represents the population of interest.

Table 3.1 shows the distributions by age group and reveals that design-weighted respondents have a higher proportion of young adults ages 18-29 compared to the ACS (3.4 percentage points, p-value<0.0001), which is used as our benchmark and is ultimately what is used in the final weighting steps for the NIS-ACM. Conversely, the two older age groups, aged 50-64 and 65+ years, have lower representation in the NIS-ACM sample compared to the ACS, at -3.2 percentage points and -3.7 percentage points respectively. Note that age group is used in raking the final weights and in the vaccine administrative data calibration step.

Table 3.1 Comparison of NIS-ACM Design-Weighted Sample and the American Community Survey, by Age Group.

Age Group	American Community Survey	Design-Weighted NIS-ACM Distribution (Feb-2022)	Difference (ACM-ACS)
18-29	17.6%	21.0%	3.4%*
30-39	15.6%	17.3%	1.7%
40-49	14.1%	15.9%	1.8%
50-64	27.8%	24.6%	-3.2%*
65+	24.9%	21.2%	-3.7%*

*Statistically significantly different at the p=0.05 level.

Table 3.2 shows the design-weighted distribution by sex of NIS-ACM respondents closely aligns with the corresponding ACS distribution, with differences of less than 1 percentage point, neither of which is statistically significant. Note that sex is also used in raking the final weights and in the vaccine administrative data calibration step.

Table 3.2 Comparison of NIS-ACM Design-Weighted Sample and the American Community Survey, by Sex.

Sex	American Community Survey	Design-Weighted NIS-ACM Distribution (Feb-2022)	Difference (ACM-ACS)
Female	51.4%	52.2%	0.8%
Male	48.6%	47.8%	-0.8%

Table 3.3 compares the race/ethnicity distributions and reveals that the Hispanic population in the NIS-ACM is underrepresented in the pool of respondents compared to the population distribution in the ACS by 5.2 percentage points, which is statistically significant. Conversely, the Non-Hispanic White (NH White) population is overrepresented by 2.8 percentage points, also statistically significant. Note that race/ethnicity is used in raking the final weights, but not in the vaccine administrative data calibration step.

Table 3.3 Comparison of NIS-ACM Design-Weighted Sample and the American Community Survey, by Race/Ethnicity.

Race/Ethnicity	American Community Survey	Design-Weighted NIS-ACM Distribution (Feb-2022)	Difference (ACM-ACS)
Hispanic	17.2%	12.0%	-5.2%*
NH White Only	62.2%	65.0%	2.8%*
NH Black Only	12.0%	12.3%	0.3%
NH Asian Only	6.0%	6.5%	0.5%
NH Other Races and Multiple Races	2.7%	4.2%	1.5%

*Statistically significantly different at the p=0.05 level.

As seen in table 3.4, respondents living in counties within an MSA are slightly overrepresented by 2.6 percentage points in the NIS-ACM relative to the ACS, while those living in non-MSA counties are slightly underrepresented by the same amount.

Table 3.4 Comparison of NIS-ACM Design-Weighted Sample and the American Community Survey, by MSA Status.

MSA	American Community Survey	Design-Weighted NIS-ACM Distribution (Feb-2022)	Difference (ACM-ACS)
MSA	85.2%	87.8%	2.6%*
Non-MSA	14.8%	12.2%	-2.6%*

*Statistically significantly different at the p=0.05 level.

Table 3.5 shows the comparative distributions for the Social Vulnerability Index (SVI). The SVI rank is defined at the county level and takes into account socio-demographics of each county (CDC/ATSDR, 2022). Those counties with a high SVI rank have more vulnerable populations and have lower overall vaccination coverage estimated. We find no significant differences in the design-weighted distributions for the 3-level SVI categorization, all being within 1.5 percentage point.

Table 3.5 Comparison of NIS-ACM Design-Weighted Sample and the American Community Survey, by Social Vulnerability Index.

SVI Rank	American Community Survey	Design-Weighted NIS-ACM Distribution (Feb-2022)	Difference (ACM-ACS)
Low	27.4%	27.9%	0.5%
Medium	38.6%	39.6%	1.0%
High	34.0%	32.5%	-1.5%

Finally, in table 3.6, comparative distributions are presented based on the political leaning of the county of residence for the respondent. The political leaning of each county was based on the percent of vote that Biden (Democrat) or Trump (Republican) received for the 2020 presidential election. If 55% or more of the 2020 presidential election vote in a given county was for Trump, then the county was deemed Republican leaning. Similarly, if 55% or more of the vote was for Biden, then county was deemed Democrat-leaning. Otherwise, the county was deemed not Republican or Democrat leaning. The political grouping for each respondent is based on the county of residence as reported in the NIS-ACM interview, and not how the respondent self-identifies (which was not asked during the survey). As with SVI rank, we find no statistically significant over- or under-representation based on these three categories, and the respondent distribution is within 1.2 percentage points of the ACS distribution.

Table 3.6 Comparison of NIS-ACM Design-Weighted Sample and the American Community Survey, by Political Grouping.

Political Grouping	American Community Survey	Design-Weighted NIS-ACM Distribution (Feb-2022)	Difference (ACM-ACS)
Republican-Leaning Counties	31.0%	29.9%	-1.1%
Not Republican or Democrat Leaning	24.6%	24.5%	-0.1%
Democrat-Leaning Counties	44.4%	45.6%	1.2%

4. Measurement Error

Measurement error is error incurred for a specific variable when the value reported in the survey interview differs from the respondent's true value. During the telephone interview, measurement error can occur based on the answer from the respondent. There are multiple reasons for this, such as

- Respondent recall error,
- Social desirability,
- Satisficing, i.e., wanting to give the interview the "correct" answer,
- Question wording may be estimating a different construct than intended.

For the NIS-ACM, there are no plans to directly conduct an administrative record check to compare respondent reports of 1 or more COVID-19 vaccinations to administrative health record; however alternate evaluations could be used to help assess measurement error. For example, we can use the measurement error that has been found in other NIS modules to help inform our understanding of potential measurement error in the NIS-ACM. The NIS-Flu, which has parental reports of influenza vaccinations for children aged 6 months – 17 years, has shown a net over-reporting estimate of approximately 4 percentage points relative to vaccine provider records (Santibanez, Singleton, Zhai, & Kah, 2018). A similar study comparing household level and vaccine provider reports of flu vaccinations for teens aged 13-17 estimated a parental over-reporting of NIS-Flu of more than 10 percentage points relative to vaccine provider reports, although there was some evidence of incomplete ascertainment of flu vaccination by providers (Lu, Dorell, Yankey, & Santibanez, 2012).

Several experiments or analyses are currently underway to investigate the impact of reporting/measurement error on 1 or more COVID-19 results. First, a question wording experiment is planned for the NIS-Child COVID-19 Module (NIS-CCM) that will help determine if question wording could be influencing the parental reporting of COVID-19 vaccines. A review of parental reports of teen COVID-19 vaccinations compared to the NIS-Teen provider record check is also being conducted. This will assess the accuracy of respondent reported vaccination compared to administrative records. Lastly, work is being funded by CDC to compare adult COVID-19 self-report with administrative records in the state of Colorado. This will also provide additional information about respondent reporting of COVID-19 vaccination, and the magnitude of over- or under-reporting by respondents.

5. Summary and Next Steps

The goal of the analysis reported in this paper was to begin to investigate at what stage survey error and potential bias could be introduced during the NIS-ACM survey process. Specifically, this analysis focused on the three stages where nonsampling error could be introduced: coverage error, nonresponse error, and measurement error.

The cell-phone sampling frame has broad coverage of the population of interest, namely adults 18 years of age and older. With the exception of those 65 and older, the cell-phone frame covers more than 95% of the population for many different demographic subgroups.

Differential nonresponse is likely one of the drivers of overestimation in the early NIS-ACM 1 or more COVID-19 vaccination coverage estimates before final weighting calibration to the COVID-19 vaccine administration data. While the coverage of our sample indicates reasonable alignment with the ACS benchmarks (as shown in section 3), it is unknown if other social-behavioral demographics and vaccine hesitancy are skewed higher in the NIS-ACM respondent pool compared to the nonrespondent pool. Some reasons to think this may be the case could be topic saliency and the current political environment. The former covers those who are vaccinated, likely to get vaccinated, or concerned about getting a severe case of COVID-19, and therefore may be more likely to respond to the survey. There are known vaccination coverage differences by political party affiliation (Ye, 2021), and potential distrust in government agencies in the current political environment, both of which could influence a respondent to not complete the survey.

Reporting error may also be a contributing factor, either as over- or under-reporting based on findings in other NIS survey studies of children and teens that compared household

level and provider level vaccination reporting for influenza vaccines. Some of the key next steps in understanding and quantifying this error are listed here:

1. Comparison of parental-report to vaccination records.
   - Initial assessment based on NIS-Teen provider record check (PRC) for 2021, which will compare parental reports of COVID-19 vaccination received by adolescents with PRC results.
   - Assessment of adult self-report vaccination status compared to medical records and IIS data in the state of Colorado.
2. Potential vaccination question experiment will shed light on the impact of question wording.
3. Additional TSE analyses
   - Benchmarking to the reported COVID-19 vaccine administration data allows assessment of the potential for overall bias.
   - Continue to review and assess possible sources of error and bias at each stage of the survey process as new external data sources and benchmarks become available.

6. References

Blumberg, S.J., Luke, J.V. (2021) Wireless substitution: Early release of estimates from the National Health Interview Survey, January-June 2021. National Center for Health Statistics.

Centers for Disease Control and Prevention/ Agency for Toxic Substances and Disease Registry/ Geospatial Research, Analysis, and Services Program. CDC/ATSDR Social Vulnerability Index 2018 Database US.
https://www.atsdr.cdc.gov/placeandhealth/svi/data_documentation_download.html
Accessed on September 6, 2022.

Centers for Disease Control and Prevention. COVID Data Tracker. Atlanta, GA: US Department of Health and Human Services, CDC; 2022, September 07. https://covid.cdc.gov/covid-data-tracker

Groves, R. M., Singer, E., & Corning, A. (2000). Leverage-saliency theory of survey participation: description and an illustration. *The Public Opinion Quarterly, 64*(3), 299-308.

Lu, P.-j., Dorell, C. G., Yankey, D., & Santibanez, T. A. (2012). A Comparison of parent and provider reported influenza vaccination status of adolescents. *Vaccine*, 3278-3285.

Santibanez, T. A., Singleton, J. A., Zhai, Y., & Kah, K. E. (2018). Examining the Agreement Between Parent and Provider Report of Child Influenza Vaccination Status, *AAPOR.*

Ye, X. (2021). Exploring the relationship between political partisanship and COVID-19 vaccination rate. *Journal of Public Health*.