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Self-Reported Hand Washing Behaviors and Foodborne Illness: A Propensity Score Matching Approach†

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ABSTRACT

Hand washing is a simple and effective but easily overlooked way to reduce cross-contamination and the transmission of foodborne pathogens. In this study, we used the propensity score matching methodology to account for potential selection bias to explore our hypothesis that always washing hands before food preparation tasks is associated with a reduction in the probability of reported foodborne illness. Propensity score matching can simulate random assignment to a condition so that pretreatment observable differences between a treatment group and a control group are homogenous on all the covariates except the treatment variable. Using the U.S. Food and Drug Administration's 2010 Food Safety Survey, we estimated the effect of self-reported hand washing behavior on the probability of self-reported foodborne illness. Our results indicate that reported washing of hands with soap always before food preparation leads to a reduction in the probability of reported foodborne illness.

Foodborne illness is a serious public health problem, and consumption of food contaminated with pathogenic microorganisms can cause serious illness or even death, especially among vulnerable populations such as infants, pregnant women, elderly individuals, and individuals with compromised immune systems *(29)*. Foodborne pathogens such as norovirus and *Salmonella* cause an estimated 47.8 million illnesses and 3,037 deaths per year in the United States *(21, 27, 28)*.

Hand washing has been recognized as a simple and effective method for reducing the risk of infection with certain viruses and other infectious agents *(1, 4, 7, 11, 18)*, particularly through reducing cross-contamination and the transmission of foodborne pathogens *(9, 10)*. Although many people claim to understand the importance of this simple strategy for avoiding illness, they often fail to consistently wash their hands effectively during food preparations *(13)* or do not know how to wash their hands effectively. The Centers for Disease Control and Prevention (CDC) recommends wetting the hands with clean water and soap and rubbing for 20 s *(5)*. A meta-analysis of studies on hand washing behaviors in the United Kingdom and United States revealed that about one in five consumers was not familiar with effective hand washing and drying procedures *(23)*.

Although most foodborne illness outbreaks are associated with food eaten in restaurants, data from the CDC Foodborne Outbreak Online Database (1998 to 2011) indicate that 13% of outbreaks can be attributed to food eaten in a private residence *(6)*. Laboratory testing of foods inoculated with foodborne pathogens has revealed that pathogens are easily transferred across kitchen surfaces *(24, 34)*. Even when foods are not contaminated before they enter a consumer's kitchen, improper handling can increase the likelihood of cross-contamination and lead to deadly illnesses. Many consumers use poor food storage practices (e.g., leaving cooked food out for too long before refrigeration) and do not wash cutting boards before slicing vegetables after cutting meat *(16, 19)*. Many consumers also fail to wash their hands after handling risky foods or risky food packaging *(13, 25)*. Those consumers who do wash after handling risky foods often do not perform the activity well enough to meet the recommended guidelines *(22)*.

The CDC recommends that hands be washed with soap and water before, during, and after food preparation and before eating *(5)* because hands have been identified as one of the major sources of pathogen transference *(32)*. In a study of microbial counts after consumer preparation of raw chicken and fresh salad, improper hand washing was included as one of the suspected routes of cross-contamination *(25)*. A study that combined observational, interview, and microbial sampling methods revealed that unsafe practices during meal preparation, including improper hand washing, was related to an increase in bacterial counts in inoculated chicken and produce *(13)*. Although no scientific evidence has directly linked hand washing and foodborne

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illness, one outbreak of *Escherichia coli* O157:H7 infection in which 1 person died and 12 persons became ill was attributed to improper hand washing *(14)*. Todd et al. *(31)* analyzed 816 foodborne illness outbreaks in which food workers were implicated and found that improperly washed bare hands played a large role in the outbreaks, but the direct effect of hand washing on incidences of foodborne illness is not yet known.

Some gaps remain in studies specifically focused on the role of hand washing in safe food handling by consumers *(23)*. The few studies are either qualitative and observational or had small sample sizes. The present study was conducted to estimate the association between self-reported consumer hand washing behaviors and self-reported foodborne illness using consumer survey data representative of the U.S. population. Using a propensity score matching technique, the survey data were rendered comparable to experimental data. This technique simulates random assignment of individuals into comparable groups, in this case those who reported that they washed their hands before preparing food and those who did not wash their hands before preparing food. The groups were compared in terms of the probability of self-reported foodborne illnesses. Based on the role that hygiene plays in maintaining public health *(1, 17)*, we hypothesized that regular hand washing practices lead to decreases in the probability of self-reported foodborne illnesses.

MATERIALS AND METHODS

Sample. Data for the analysis were obtained from the U.S. Food and Drug Administration (FDA) 2010 Food Safety Survey (FSS) *(33)*. This survey was a random-digit-dialing cross-sectional telephone (residential) survey of 4,568 individuals who were 18 years or older and lived in the 48 contiguous states. These individuals were selected from a nationally representative single-stage sample of telephone numbers generated from the GENESYS system *(20)*. The FSS has been conducted by the FDA since 1988 and is a cross-sectional tracking survey that estimates consumers' knowledge, perceptions, attitudes, and behaviors related to various food safety topics *(12)*.

For the present study, the analytical sample included individuals who prepared the main meal in the household all or almost all of the time with nonmissing information on hand washing behavior, foodborne illness, and other variables (n = 2,430). We restricted our sample to only those who reported that they prepared the main meal all or almost all of the time because the main focus was to investigate how hand washing before meal preparation is related to foodborne illnesses. Inclusion of respondents who were not involved with meal preparation in the home could have introduced a downward bias in our estimates. The response rate for the 2010 FSS was only 14%, mainly because of the overall decline in telephone survey response rates and the increase in the number of households with cell phones rather than landlines. For a detailed explanation of the response rate associated with GENESYS random-digit dialing and the FSS, see Fein et al. *(12)*. For other survey details, see the FDA 2010 FSS report *(33)*.

Variables. The dependent variable in our analysis was a self-reported, dichotomous indicator of foodborne illness incidence in the last year. This indicator was based on a series of questions posed to the respondents. Respondents were first asked whether they or someone else in the household had experienced any kind of sickness, other than an allergic reaction to food, that they thought was due to eating spoiled or contaminated food in either the past month or the past year. The response could be the ''respondent,'' ''someone else in the household,'' or ''both'' became sick or ''someone in the household died from foodborne illness.'' When the response was ''respondent'' or ''both,'' a follow-up question was asked specifically about how soon (minutes, hours, or days) after eating the suspect food did the respondent become sick. The dependent variable was coded as 1 when the response to the first question was either ''respondent'' or ''both'' and the respondent provided a valid answer to the second question.

The primary explanatory variable of interest was whether the respondents washed their hands with soap before beginning to prepare food (hand wash before cooking). Specifically, the respondents were asked, ''Before you begin preparing food, how often do you wash your hands with soap?'' The response to this question could be ''all of the time,'' ''most of the time,'' ''some of the time,'' or ''rarely.'' This variable was coded as 1 when the respondent indicated that they washed their hands ''all of the time.'' Other responses were coded as 0.

Other variables in our analysis used to estimate the propensity score were indicators of eating risky foods, four indicators of food safety perceptions and knowledge, health measures, and demographic characteristics. Each individual's perception and knowledge about food safety and food handling practices must be accounted for because these variables are likely to capture important differences in individual characteristics, which may be related to both hand washing behavior and foodborne illnesses.

Our risky food consumption variable (eats risky food) was created based on the work of Levy et al. *(19)* and indicates how many of the following items the respondent had eaten in the last 12 months: food products with raw eggs, raw shellfish, raw sprouts, raw milk, steak tartare, or other raw meat or chicken. The respondents also were asked whether hamburgers served at home were usually rare or medium done. The risky food consumption variable responses ranged from 0 (respondent did not eat any of the risky food items) to 7 (respondent ate all seven of the risky foods). Our food safety risk perception variable (food risk perception) is a composite measure of the respondent's perceived likelihood of getting sick from eating certain risky food items or performing certain risky food handling practices. The respondents were asked whether they would get sick if (i) they forget to wash their hands before they begin cooking, (ii) if vegetables they ate raw touched raw meat or chicken, (iii) if they ate meat or chicken that was not thoroughly cooked, (iv) if they ate a meat or chicken stew or a casserole that had been out of the refrigerator for 2 to 5 h after it had been cooked, or (v) if they ate a food that had been recalled. Responses to these questions ranged from 1 (not at all likely) to 5 (very likely). These responses were then summed to create the food risk perception score, which ranged from 5 to 25. Another food safety variable (germ risk perception) was measured based on whether the respondent thought that contamination of food by microorganisms was a ''serious food safety problem,'' ''somewhat of a problem,'' or ''not a food safety problem at all.'' These answers were coded as 1, 2, and 3, respectively. The third food safety variable (germ knowledge) measures how many of the following microbes whose presence in foods is a problem that the respondent had heard about: *Salmonella, E. coli, Campylobacter, Listeria, Vibrio,* and hepatitis A virus. The fourth food safety variable (food safety information) represents the number of food safety information sources from which the respondent received information on food safety or food recalls, such as a government

Web site, television and radio news, television cooking shows, Internet news sites, friends and family, doctors or other health care providers, and social network Web sites.

Our demographic measures were age, gender, race, education, and whether the respondent worked full time. We also included variables indicating whether the respondent shared a household with a child younger than 5 years of age, an adult 60 years or older, or a pregnant woman. Children, pregnant women, and older individuals are especially vulnerable to foodborne illnesses, and the presence of a person from one of these vulnerable groups in the home could mean that the respondent took special care in food preparation to avoid foodborne illness or was more vigilant in noticing symptoms of foodborne illness, thereby confounding the relationship between hand washing and foodborne illness.

Another set of variables were associated with health. We included whether or not the respondent reported having a food allergy or diabetes or was receiving chemotherapy or radiation therapy. We also included whether the respondent had any of the following health conditions: liver disease, human immunodeficiency virus infection, AIDS, organ transplant, or a weakened immune system.

Statistical analysis. Because hand washing is a nonrandom behavior, a simple regression about the effects of hand washing on foodborne illnesses may be ignoring potential selection biases. One potentially major source of selection bias is that individuals who wash their hands before food preparation may be less likely to attribute their illnesses to foodborne pathogens, whereas individuals who have had foodborne illness experience may be more likely to wash their hands. In other words, simple comparisons of incidence of foodborne illness and hand washing can be misleading when individuals who wash their hands are systematically different from those who do not. Propensity score matching is a method of correcting for selection bias *(26)*. This method is used to adjust for pretreatment observable differences between a treatment group and a control group, thus replicating random assignment in experimental design such that the treatment variable (in this case hand washing) can be treated as though it were assigned at random and such that the individuals included in the analysis are homogenous on all other covariates except the treatment variable *(15)*, i.e., one group receives the ''treatment'' and the control group (individuals who did not wash hands) does not.

Although this methodology addresses selection for observed variables, it does not extend to selection for unobserved variables. Thus, as in other studies, we relied on the richness of our data set to reduce such biases generated by unobservable variables. Although we are unable to account for many other characteristics that could predict hand washing behavior (e.g., the individual's propensity for risk aversion), variables such as food risk perception, food safety knowledge, and health conditions allowed us to account for unobservable variables indirectly. The variables selected for inclusion in the models were those considered necessary to improve the quality of the match between the treated and control groups based on prior research.

Empirical framework. Closely following the notations used by Ali and Ajilore *(2)*, an intuitive exposition of our estimation framework includes delineating the problem relying solely on the regression equation. An individual i reports experiencing a foodborne illness F_i. The interrelation of the foodborne illness and hand washing can be presented as:

$$F_i = \beta H_i + \alpha X_i + \varepsilon_i$$
$$H_i = \eta X_i + \nu_i$$

where H_i is 1 if the individual washes hands and 0 otherwise. Characteristics of the individual that influence the incidence of foodborne illness and washing hands are represented by X_i. Unobservable characteristics affecting F_i and H_i are captured by ε_i and ν_i, respectively. The effect of hand washing on foodborne illness is measured by β. $F_i(1)$ denotes the potential outcome for individual i under the treatment condition ($H_i = 1$), and $F_i(0)$ is the potential outcome if the same individual i receives no treatment ($H_i = 0$). Thus, $F_i = H_iF_i(1) + (1 - H_i)F_i(0)$ is the observed outcome for individual i. The individual treatment effect $\beta_i = F_i(1) - F_i(0)$ is unobserved because either $F_i(1)$ or $F_i(0)$ is missing. However, estimating F_i directly may yield a biased estimate of β if H_i and ε_i are statistically dependent. Two main sources can contribute to this dependency *(28, 31)*: X_i and ε_i may be correlated (the individuals' characteristics may be correlated with unmeasured propensities of experiencing foodborne illnesses), and ε_i and ν_i may be correlated (unobserved factors may affect both foodborne illness and hand washing). Selection bias may arise in the regression analysis because these estimators would utilize data from all observations to be combined into one estimate of the hand washing effect. In the presence of any factors that affect individuals' decisions to wash their hands and their incidence of foodborne illness, the estimate will reflect both the hand washing protection effect (the ''true'' hand washing effect we want to identify) and the hand washing selection effect (the effect that influences the individual's decision to wash, or report washing, hands).

In our analysis, the treatment is washing hands; thus, $H_i = 1$ denotes the treatment group, and $H_i = 0$ denotes the control group (individuals who do not wash their hands). Let $F_i(1)$ denote the potential outcome for individual i under the treatment condition ($H_i = 1$), and let $F_i(0)$ denote the potential outcome if the same individual i receives no treatment ($H_i = 0$). Thus, $F_i = H_iF_i(1) + (1 - H_i)F_i(0)$ is the observed outcome for individual i. Standard parametric models (e.g., probit) estimate the average treatment effect by taking the average outcome difference between the treatment groups: $\beta_{\mathrm{PROBIT}} = E[F_i(1)|H_i = 1] - E[F_i(0)|H_i = 0]$. If individuals who do not wash their hands before food preparation are unlikely to ever do so, the average treatment effect may not be particularly helpful for understanding how hand washing affects the incidence of foodborne illnesses. An alternative approach is to estimate the average treatment effect on the treated. To estimate this effect, the outcome difference between the two treatment groups conditional on X is determined and then averaged over the distribution of the observable variables in the treated population: $\beta_{H_{i=1}} = E[\beta_i|H_i = 1] = E[F_i(1)|H_i = 1] - E[F_i(0)|H_i = 1]$, which is the difference between the expected outcome for an individual who washes hands and the expected outcome for the same individual if he/she did not wash hands.

Although we can observe the outcomes for the individuals who wash their hands and thus are able to construct the first expectation $E[F_i(1)|H_i = 1]$, we cannot identify the counterfactual expectation $E[F_i(0)|H_i = 1]$ without invoking further assumptions. To overcome this problem, we must rely on the individuals who do not always wash their hands to obtain information on the counterfactual outcome. One way to construct a sample counterpart for the counterfactual outcomes for the treatment individuals if they had not received treatment is to use statistical matching. The matching estimators can be devised to reconstruct the condition of an experiment by stratifying the sample with respect to covariates X_i that influence selection into treatment. Selection bias is eliminated provided all variables in X_i are measured and balanced (comparable) between the two treatment groups within each stratum. In this case, each stratum represents a separate randomized experiment, and the simple outcome difference between the treatment group and the controls provides an unbiased estimate of the treatment effect *(2)*.

An identifying assumption in all matching methods is the conditional independence assumption, i.e., all relevant outcome differences between the matched treatment group and controls are captured in their observed characteristics. Hence, conditional on X the outcomes for those who do not wash their hands are the same as the outcomes for those who wash their hands would have been if they had not washed their hands. The conditional response of the treated individuals under the no-treatment condition could thus be estimated by the conditional mean response of the matched untreated individuals. Rosenbaum and Rubin *(26)* proposed using the conditional probability of selection into the treatment group (propensity score) to stratify the sample. These authors found that by definition the treated and the nontreated individuals with the same propensity score had the same distribution of X or balancing property of the propensity score. Matching treated and untreated individuals based on their estimated propensity score and placing them into one block means that selection into the treatment group within each block is random and the probability of receiving treatment within this block equals the propensity score. However, the probability of finding an exact match is theoretically zero. Thus, a certain distance between the treated and the untreated individuals must be accepted *(3)*. A variety of matching algorithms have been used in various studies, including Gaussian, Epanechinikov, and uniform (radius) kernel matching, and none are a priori superior to the others. Because there is no consensus in the existing literature on the appropriate or most efficient matching algorithm, we utilized all of these algorithms and compared our estimates. This use of all of the algorithms also provides a way to check the robustness of our results.

RESULTS

Table 1 includes the summary statistics for the outcome measure, our key explanatory variables, and all of the other variables used in our analysis. Of the 2,430 respondents, 10% self-reported experiencing foodborne illness in the last year, and 78% always washed hands with soap before food preparation.

To test whether hand washing practices lead to decreases in the probability of self-reported foodborne illnesses, we estimated the propensity score for selection into treatment groups using a probit model to decide which covariates to include. We relied on the proposition of Rosenbaum and Rubin *(26)* and Dehejia and Wahba *(8)*: for any given specification, group the observations into blocks defined by the estimated propensity score and verify whether the grouping succeeds in balancing the covariates between the treatment group and the control group within each block. When a particular structure that balances the covariates was not found (indicating that the specification does not capture the differences between the treated individuals and the controls), we included additional covariates until this condition was satisfied. We began by including the simplest set of controls (age, gender, and education) and succeeded in balancing the covariate when we included health indicators and controls to measure knowledge and perceptions of food safety. The extensive array of control variables contributed to satisfying the balancing property and producing quality matches (Fig. 1).

TABLE 1. *Descriptive statistics of the analytical sample (*n *= 2,430)*[a]

Variable	Mean[b]	SD	Minimum	Maximum
Reported foodborne illness	0.10		0	1
Hand wash before cooking	0.78		0	1
Practice specific hand wash	0.24		0	1
Male	0.28		0	1
Age (yr)	56.97	15.36	19	98
Education[c]				
Less than high school	0.08		0	1
High school	0.28		0	1
Some college	0.24		0	1
College plus	0.38		0	1
Race				
White	0.76		0	1
Black	0.07		0	1
Hispanic	0.13		0	1
Other	0.05		0	1
Employment	0.47		0	1
Presence of children younger than 5 yr	0.12		0	1
Presence of adults older than 60 yr	0.34		0	1
Pregnant	0.02		0	1
Eats risky food	1.28	1.16	0	6
Food risk perception	19.98	4.23	5	25
Germ risk perception	2.20	0.70	0	3
Germ knowledge	3.05	1.15	0	6
Food safety information	3.82	2.55	0	13
Food allergies	0.13		0	1
Diabetes	0.16		0	1
Health condition	0.04		0	1

[a] Data obtained from the 2010 FDA Food Safety Survey *(33)*.
[b] Means for the dummy variables can also be interpreted as percentages.
[c] Values for education do not sum to 1 because of rounding.

Table 2 includes results of the balancing test between the treatment and control groups for the variable of hand washing before cooking after stratifying the sample into blocks based on their estimated propensity score. The characteristics of the matched control within each block resemble those of the treated group (most t values were less than 1.96 at $\alpha = 0.05$ and thus insignificant), indicating that the balancing condition was satisfied within that block. Matching based on the full set of covariates result in a sample of 2,430 observations with propensity scores falling within the region of common support within each block. Figure 1 (the propensity score) also indicates that the treated group and control group were comparable, based on sufficient overlap in the propensity score within each block. Table 3 includes the probit estimates contributing to the propensity scores for the fully specified model. The values indicate the impact of the covariates on the estimated propensity score. Better food risk knowledge and perceptions were positively correlated with propensity scores for washing hands, whereas eating risky foods and having preexisting health conditions were negatively correlated with the propensity scores. Attitude toward germs and

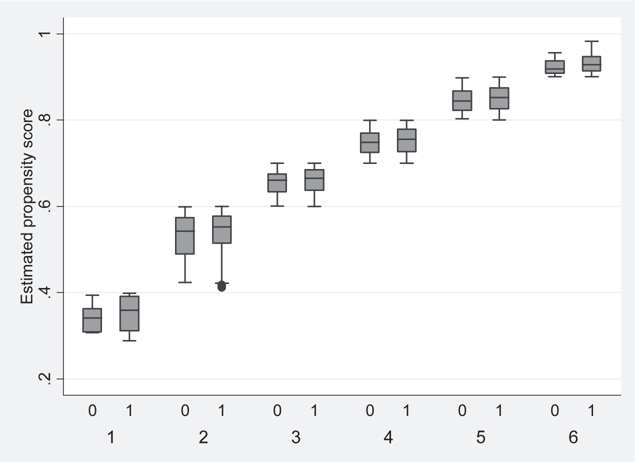

FIGURE 1. *Box plot of the estimated propensity score for treated individuals (1) and control individuals (0) within the common support region.*

greater access to more sources of food safety information were positively correlated with the propensity scores. Having some sort of food allergy was also positively correlated with the propensity score for hand washing. Although the pseudo R^2 is not large, it is similar to the values reported in studies in which the propensity score matching method has been utilized to provide causal evidence of certain treatments (e.g., Ali and Ajilore *(2)*).

Table 4 includes our results for foodborne illness under Gaussian, Epanechinikov, and uniform (radius) kernel matching estimates. To assess the sensitivity of the matching estimates to the choice of bandwidth (or radius), results are reported for different bandwidths for our main variable of interest only. Individuals who washed their hands were less likely to report incidences of foodborne illness. More precisely, the incidences of foodborne illness among those who washed hands were 3.1 to 4 percentage points lower than the incidence of foodborne illness would have been if the same individuals had not washed their hands. Under various matching specifications, the magnitude of the effect of hand washing did not vary significantly; it was largest under uniform matching (0.04) and smallest under Epanechnikov (0.031) matching, which indicates the robustness of our estimates.

DISCUSSION

We conducted this study to investigate whether washing hands with soap before food preparation at home can result in a reduction in the self-reported incidence of foodborne illness. After accounting for potential selection bias between the treatment group (individuals that always wash their hands before cooking) and control group (do not wash their hands before cooking), our results indicate that washing hands before food preparation may lead to a reduction in foodborne illness. These results suggest a protective effect of consistent hand washing before cooking. The relationship between washing hands before food preparation and a decrease in foodborne illness is consistent

TABLE 2. *Test of balance between the control and treatment groups within blocks for hand washing before cooking, including two-sample* t *test of means for covariates*[a]

Variable	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6
No. treated	4	105	218	532	715	320
No. of controls	6	80	135	170	117	28
Propensity score (range)	0.300, 0.400	0.400, 0.600	0.600, 0.700	0.700, 0.800	0.800, 0.900	0.900, 0.982
t value						
Male	1.26	0.82	0.28	0.73	0.80	0.48
Age	0.04	0.84	0.65	0.43	0.60	1.88
Less than high school	0.80	0.82	2.40	0.74	0.38	0.82
High school	0.25	0.20	0.91	0.60	0.58	0.34
Some college	1.26	1.28	0.51	0.79	1.28	0.61
College plus	0.37	2.11	2.20	0.22	0.46	1.52
White	0.80	0.17	1.98	0.20	0.41	0.29
Black	0.70	1.24	1.10	0.33	0.75	0.77
Hispanic	0.50	0.74	0.78	0.34	0.11	0.16
Employment	1.18	2.47	0.70	0.83	0.42	0.79
Children younger than 5 yr	0.04	0.02	0.95	0.37	1.25	1.40
Adults older than 60 yr	1.08	0.79	0.28	0.83	0.25	1.30
Pregnant	0.08	0.38	0.18	1.50	1.42	0.34
Eats risky food	1.18	1.05	0.94	1.08	1.30	1.75
Food risk perception	0.27	0.23	0.52	0.21	1.38	0.41
Germ risk perception	0.30	0.40	0.21	0.90	0.07	0.41
Germ knowledge	0.09	2.14	1.26	0.87	0.05	1.20
Food safety information	0.16	1.42	0.97	1.65	0.84	0.70
Food allergies	0.52	1.53	0.24	0.62	1.24	0.60
Diabetes	0.48	0.53	1.18	0.21	0.86	0.27
Health condition	1.27	0.43	0.26	0.83	0.15	0.01

[a] Data obtained from the 2010 FDA Food Safety Survey *(33)*.

TABLE 3. *Probit estimates predicting propensity scores (*n *= 2,430)*[a]

Variable	Coefficient	Standard error	*P* value
Male	−0.12	0.07	0.061
Age	−0.01	0.00	0.000
Less than high school	0.49	0.47	0.294
High school	0.28	0.46	0.537
Some college	0.40	0.46	0.377
College plus	0.39	0.46	0.389
White	0.14	0.14	0.294
Black	0.42	0.18	0.022
Hispanic	0.33	0.16	0.044
Employment	−0.08	0.01	0.270
Children younger than 5 yr	0.01	0.11	0.897
Adults older than 60 yr	0.21	0.07	0.003
Pregnant	0.13	0.25	0.597
Eats risky food	−0.08	0.03	0.005
Food risk perception	0.06	0.01	0.000
Germ risk perception	0.15	0.05	0.001
Germ knowledge	−0.02	0.03	0.471
Food safety information	0.02	0.01	0.128
Food allergies	0.19	0.10	0.047
Diabetes	−0.14	0.08	0.102
Health condition	−0.21	0.14	0.141
Log likelihood = −1187.033			
Pseudo R^2 = 0.075			

[a] Data obtained from the 2010 FDA Food Safety Survey *(33)*.

with previous reports that suggest that individual self-protective behaviors are an important element of food safety management *(13)*. Our study provides evidence that promoting simple preventive behaviors such as washing hands before meal preparation could be an effective strategy for reducing foodborne illness. Although over 70% of our respondents reported washing their hands before food preparation, the literature suggests that hand washing behavior is not at its optimal level *(35)*. A wide range of researchers have explored factors behind poor hand hygiene and how hand washing can reduce the risk of food contamination and cross-contamination; however, few studies have utilized a large nationally representative data set or focused directly on the causal relationship between hand washing behavior and foodborne illness. Based on the FSS, which is a large data set based on a nationally representative sampling design, our study addressed these limitations and has provided evidence of a significant relationship between hand washing before food preparation and reduced incidence of foodborne illness.

As with any empirical strategy, our approach has its limitations. The cross-sectional nature of our data does not allow conclusive establishment of a causal relationship between hand washing and foodborne illness. Because our foodborne illness variable was self-reported, it is subject to reporting bias. Although the sampling design of the 2010 FSS was nationally representative, the overall response rate was low. Thus, our data might not be representative of the U.S. population (e.g., the sampling design did not include households with only cell phones). Another limitation of our methodology (also applicable to all studies utilizing propensity score matching) is that the treatment and control groups were matched based on only observable characteristics; thus, the quality of the match was strictly a function of the quality of the data *(30)*. We attempted to address this limitation by controlling for an extensive array of covariates ranging from demographic characteristics to knowledge and perceptions about food safety and proper food handling practices. Selection bias is not totally eliminated with propensity score matching, and individuals who did not wash hands may also have been more likely to consume contaminated foods, and individuals who reported washing hands may not have reported foodborne illnesses because they might have attributed such illnesses to other causes. Eating in food service settings is a major risk for foodborne illness; however, the survey did not include questions about locations where food was consumed, so we were unable to use location as a covariate in the study. Our data set also did not include information about the length of time respondents spent washing hands (e.g., washing hands with water for 20 s is recommended by the CDC *(5)*) or whether respondents consistently washed their hands effectively during food preparations. These limitations could be addressed in future research in addition to exploring other hygienic practices that might have an impact on foodborne illness, such as the use of alcohol gels and other hand sanitizers to clean hands before cooking.

Our results support the importance of simple preventive practices such as hand washing for reducing foodborne illness. However, behavioral changes are hard to attain. Hand washing is primarily a behavior that is learned and

TABLE 4. *Estimated effect of hand washing before cooking and practice-specific hand washing on foodborne illness*

	Matching				
		Epanechnikov		Uniform	
Estimate	Gaussian	*h* = 0.01	*h* = 0.005	*r* = 0.01	*r* = 0.005
Hand washing before cooking[a]	−0.037**	−0.033**	−0.031**	−0.040***	−0.040***
Standard error[b]	0.018	0.016	0.017	0.018	0.019
No. treated	1,893	1,893	1,893	1,893	1,893
No. of controls	537	537	537	537	537

[a] Each cell represents a separate regression. Control group did not wash hands. ***$P < 0.001$; **$P < 0.05$.
[b] Standard errors for the matching estimators were obtained by bootstrapping methods with 500 replications.

reinforced in early childhood *(35)*. Awareness campaigns and promotions can thus be formulated that specifically target intervention messages to adolescents, young adults, or adults. Our results provide strong evidence of a causal link between hand washing and reduction of foodborne illness. Although randomized controlled clinical trials are still the ''gold standard'' for studying causal relationships, propensity score matching as used in our study can be used to simulate experimental study conditions by utilizing observational data, such as survey data, when it is impractical, impossible, or unethical to conduct an experimental study.

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