Handwashing, but how? Microbial effectiveness of existing handwashing practices in high-density suburbs of Harare, Zimbabwe

Max N.D. Friedrich MSc a,*, Timothy R. Julian PhD b, Andreas Kappler c, Tamuka Nhiwatiwa PhD d, Hans-Joachim Mosler a

a Department of Environmental Social Sciences, Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dübendorf, Switzerland
b Department of Environmental Microbiology, Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dübendorf, Switzerland
c Center for Applied Geoscience, University of Tübingen, Tübingen, Germany
d Department of Biology, University of Zimbabwe, Mount Pleasant, Harare, Zimbabwe

Key Words: Recommendation Efficacy Procedure Diarrhea Steps

Background: Consistent domestic hand hygiene can reduce diarrhea-related morbidity and mortality and the spread of other communicable diseases. However, it remains uncertain which technique of handwashing is most effective and practicable during everyday life. The goal of this study is to determine how the handwashing technique, as performed in the daily life by the participants of this case study in Harare, Zimbabwe, influences microbial handwashing effectiveness.

Methods: Handwashing technique of 173 primary caregivers was observed in their homes and hand rinse samples were collected before and after handwashing. Samples were analyzed for Escherichia coli and total coliform concentrations. Generalized linear models were used to predict fecal hand contamination after washing from observed handwashing technique.

Results: Cleaning under fingernails, scrubbing the fingertips, using soap, and drying hands through rubbing on clothes or a clean towel statistically significantly reduced E coli contamination of hands after washing. Tap use, scrubbing fingertips, and rubbing hands on clothes to dry them statistically significantly reduced total coliform contamination.

Conclusions: Recommendations for effective and practicable domestic handwashing in Harare, Zimbabwe, should include performing specific hand scrubbing steps (i.e., cleaning under the fingernails and rubbing the fingertips), and soap and tap use. This calls for further research to develop behavior change interventions that explicitly promote effective handwashing technique at critical times.

© 2017 Association for Professionals in Infection Control and Epidemiology, Inc. Published by Elsevier Inc. All rights reserved.

Consistent hand hygiene can reduce diarrhea-related morbidity and mortality. Diarrhea is among the leading causes of childhood mortality worldwide. Fischer Walker et al estimated that in 2011, 700,000 children died of diarrhea, with highest rates in South East Asia and Africa. According to estimations by Prüss-Ustün et al, 297,000 deaths were caused by inadequate hand hygiene worldwide during 2012. Handwashing at critical times, such as before eating, cooking, or other contact with food and after defecation and other contact with feces was shown to be among the most cost-effective methods to reduce diarrhea. Despite its importance, handwashing with soap is only practiced by a small proportion of people worldwide. This calls for effective handwashing promotion on a large scale.

Among others, the Centers for Disease Control and Prevention (CDC) and the World Health Organization provide recommendations on effective handwashing in health care settings. For domestic handwashing, the CDC recommends the following 5 steps:

1. Wet your hands with clean, running water (warm or cold), turn off the tap, and apply soap.
2. Lather your hands by rubbing them thoroughly, leaving the backs of your hands, between your fingers, and under your nails.
3. Scrub your hands for at least 20 seconds.
4. Rinse your hands well under clean, running water.
5. Dry your hands using a clean towel or air-dry them.

* Address correspondence to Max N.D. Friedrich, MSc, Department of Environmental Social Sciences, Swiss Federal Institute of Aquatic Science and Technology (Eawag), Überlandstrasse 133, 8600 Dübendorf, Switzerland.
E-mail address: max.friedrich@eawag.ch (M.N.D. Friedrich).

This work was funded by the Swiss Agency for Development and Cooperation (SDC). SDC has not officially endorsed this publication and the views expressed may not represent the views of SDC.

Conflicts of interest: None to report.
However, the microbial effectiveness of the recommended steps is only partly substantiated. Further, it remains uncertain whether performing the steps throughout the daily routine is acceptable for potential participants of handwashing-promotion activities. Comprehensive evidence to sustain the importance of the recommended steps is limited to soap use\textsuperscript{11-14} and does not corroborate the remaining steps. To our knowledge, there are no studies corroborating the first step’s suggestion for running water: No studies have compared the effectiveness of handwashing with running water versus, for example, stored water. With regard to characteristics of handwashing water, field experiments suggest that increased water volume and quality of handwashing water are associated with cleaner hands after washing.\textsuperscript{15} Further, the influence of thoroughness of handwashing, described by both length\textsuperscript{12,16-18} and scrubbing steps\textsuperscript{19} is uncertain. Evidence on which hand-drying technique is most effective are mixed\textsuperscript{20-22} and recontamination of hands from contaminated clothes is likely.\textsuperscript{23} None of the existing studies evaluate the relative importance of different handwashing steps. Further, most presented findings originate from laboratory or field experiments that compared prespecified handwashing regimens, in which singular handwashing steps were manipulated while the remaining handwashing technique remained constant.\textsuperscript{11,12,16-18} The studies therefore do not represent handwashing as performed by community members in their daily life, which some authors have suggested should be tested.\textsuperscript{12,24}

Handwashing campaigns should promote a technique of handwashing that is both effective in the local context and acceptable for the target population. Everyday life compliance with washing hands according to complex guidelines is assumed to be low.\textsuperscript{19,24} Particularly in developing countries, the CDC guidelines may be difficult to follow because running water from a tap and a clean towel, for instance, are often not available.\textsuperscript{25} In addition, local customs may suggest different handwashing procedures, such as in Zimbabwe where hands are traditionally moistened and rinsed in a bowl of water.\textsuperscript{26} As a consequence, investigating which handwashing steps are already in practice in the target population and determining their effectiveness in the context where they are usually performed is needed to decide which handwashing technique should be promoted. Taken together, there are substantial gaps in the understanding of which handwashing technique to promote to achieve microbial effective domestic handwashing in a specific target population. The goal of the present study is to determine how the handwashing technique, as performed in the daily life by the participants of this case study in Harare, Zimbabwe, influences handwashing effectiveness. Based on the findings, substantiated and parsimonious recommendations for effective handwashing in the target population are provided.

**Materials and Methods**

**Participants**

This study was implemented during June and July 2014 in 10 high-density and low-income suburbs of Harare, Zimbabwe. One working day before data collection, participants were recruited through random route sampling by selecting every fifth household starting from junctions in the study area. Because this study was part of a larger study, households needed to have at least 1 child attending the local primary school to be included in the sampling frame. Within each household, the primary caregiver was selected for the study and informed written consent was obtained. Nonresponding, ineligible, and refusing households were replaced by the fifth-next household on the sampling route. In total, 198 primary care givers were sampled.

**Enumerator training**

Before data collection, enumerators were enrolled in a 1-week training on sampling, observation, and interviewing techniques. To maximize standardization in the enumerators’ assessment of handwashing techniques, enumerators performed the different components of handwashing themselves and practiced observation of each other’s handwashing technique under supervision during the training. During a second training week, enumerators practiced data collection in the field and performed handwashing observations under supervision in at least 1 household before the actual data collection.

**Data collection**

Microbial contamination of hands was measured using hand rinse samples as previously reported.\textsuperscript{27} The data collector randomly selected the first hand to be sampled through the random function of OpenDataKit software (Department of Computer Science and Engineering, University of Washington, Seattle, WA) on a tablet computer.\textsuperscript{28} The selected hand of the participant was placed in a 2,040 mL sterile sampling bag (NASCO Corp, Fort Atkinson, WI) filled with 350 mL bottled water containing 17.5 mg/L sodium thiosulfate. Sodium thiosulfate had been added to inactivate residual chlorine potentially present in the water. The bag was fastened around the participant’s wrist with a flexible rubber strap. The participant’s hand was massaged in a standardized way. First, the palm of the hand, excluding fingers, was massaged for 10 seconds. Then, for each finger, the palm and back of the finger were simultaneously massaged for 5 seconds, both sides of the finger were simultaneously massaged for 5 seconds, the tip of the finger was massaged for 5 seconds, and the webbing to the subsequent finger for 5 seconds. Finally the back of the hand was massaged for 10 seconds. The participant’s hand was withdrawn from the bag and the bag was closed and immediately placed in a cooler box with ice. The participant’s hand was dried with a paper towel. Enumerators wore new nonsterile gloves for each hand sampling.

Subsequently, the participant was requested to wash hands in the way the participant would usually do either “before handling food” or “after contact with feces.” The prompt concerning which of the 2 critical moments the enumerator stated was determined through the OpenDataKit random function. The respondent was explicitly reminded to demonstrate the way he or she would usually wash hands in such occasions. Structured observation of the demonstrated handwashing technique was performed while the total time that the respondent washed hands was determined with the stopwatch function of the enumerator’s wristwatch. Handwashing steps observed included method of moistening hands, soap or other detergent use, performed scrubbing steps, method of rinsing hands, and way of drying hands (Table 1).

The second hand rinse sample was taken immediately after the handwashing demonstration from the hand that had not yet been sampled. The same procedure as described for the first sample was applied. After the second sampling, the enumerator recorded the handwashing observation data on the tablet computer. The sociodemographic characteristics of participants were subsequently collected in a standardized face-to-face interview. The questionnaire had been developed in English, translated into the local Shona language, and retranslated into English to reduce risk of potential translation mistakes. It was programmed with OpenDataKit and filled on tablet computers. Spot-check observations regarding the presence of separate handwashing facilities for food- and stool-related handwashing, presence of soap and water at these locations, and type of the device to dispense water were performed at the end of each household visit.
In addition, using log differences directly associated with diarrhea. Outcome variable because hand contamination has been shown to include these factors. In this study, hand contamination after washing was chosen as the outcome variable, representing 2/7ths and 2/70ths of the total sample size. Laboratories procedures

Samples were cooled with ice and transported to the laboratory of the Department of Biology, University of Zimbabwe. They were processed by 2 trained students within 6 hours after collection. Samples were processed in triplicate and were analyzed for numbers of E. coli and total coliform bacteria. Portions of 100 mL and 10 mL of each sample, representing 2/7ths and 2/70ths of the total sample collected, respectively, were passed through a 0.45-μm, 47-mm-diameter cellulose filter (Merck Millipore, Darmstadt, Germany) and placed on compact dry EC media plates (Nissui Pharmaceuticals, Tokyo, Japan). Before filtering a new sample, the filter unit was flamed with 80% ethanol, left for few minutes to cool down completely, and rinsed with bottled water containing 17.5 mg/L sodium thiosulfate. For the prewash sample, additional media plates were directly inoculated with 1 mL sampling solution because, compared with the postwash samples, higher contamination was expected. Plates were incubated for 24 ± 0.5 hours at 37°C ± 1°C. E. coli and total coliforms were counted per manufacturer’s instructions. At least 1 blank sample was run per day of data processing resulting in a total of 28 blank samples over the course of the study.

Data processing and statistical analyses

From the initial 198 participants who were sampled, 25 participants had to be excluded because of violations of the sampling and processing protocol, such as storage time of the samples exceeding 6 hours. The data of the remaining 173 participants were processed as follows. To obtain the value for each replicate, the sum of detected colony forming units across all plates of this replicate was divided by the total amount of sampling solution used for the respective replicate. Plates exceeding the maximum number of 250 CFU/plate were not countable and excluded. If no colonies were detected on any plate, the lower detection limit (3.2 CFU/hand) was inserted. The upper detection limits for the prewash and postwash samples were 87,500 CFU/hand and 8,750 CFU/hand, respectively. Of each sample, the mean of the 3 replicates was taken. For 17 of 331 total samples, only duplicates were available, due to processing mistakes.

Paired-samples t tests were performed to test significance of the change in log_{10} colony forming units per hand of E. coli and total coliform bacteria during handwashing. Fecal indicator bacteria per hand after handwashing were modeled as a function of the performed handwashing technique (eg, way of moistening hands and way of scrubbing hands), the prewash hand contamination and the order of hand sampling. A generalized linear model, with 10 log as a link function, a negative binomial distribution, and robust estimates of the parameters’ standard errors was used. Categorical predictors were entered as dummy variables as displayed in Table 1. Further, the initial hand contamination before washing was modeled as continuous predictors. To obtain unbiased parameter estimates, outliers with log colony forming units larger than 4× the standard deviation were removed from the models. For the model predicting E. coli counts after washing, the outliers included 6 participants (<4% of the total sample). For the model predicting total coliform counts after washing, 14 participants (8% of the total sample) were excluded. Therefore, the model results are restricted to individuals who achieved hand contamination < 3.2 log CFU E. coli per hand or 3.6 log CFU total coliforms per hand after handwashing.

Ethical approval

The study protocol was reviewed and approved by the Medical Research Council of Zimbabwe, the Research Council of Zimbabwe, and the Ethical Review Board of the University of Zürich.

RESULTS

Participants and study area

One hundred seventy-one participants (99%) were women and 2 participants (1%) were men. On average, the participants had attended 10 ± 2.7 years of formal education and were aged 37 ± 11.5 years. The average household size of participants amounted to 5.6 ± 1.8 household members and the average monthly household income was $341 ± $290.
Table 2
Generalized linear model of Escherichia coli and total coliform log_{10} colony forming units per hand after handwashing, modeled as a function of the performed handwashing technique

<table>
<thead>
<tr>
<th>Handwashing technique</th>
<th>E coli</th>
<th>Total coliforms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>95% Confidence interval</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>Upper</td>
</tr>
<tr>
<td>Intercept</td>
<td>1.45**</td>
<td>0.37</td>
</tr>
<tr>
<td>Moistening/rinsing</td>
<td>0.16</td>
<td>−0.38</td>
</tr>
<tr>
<td>Poured water on hands</td>
<td>0.82**</td>
<td>0.36</td>
</tr>
<tr>
<td>Dipped hands into water</td>
<td>−0.87**</td>
<td>−1.36</td>
</tr>
<tr>
<td>Soap use</td>
<td>−0.20</td>
<td>1.32</td>
</tr>
<tr>
<td>Handscrubbing</td>
<td>−0.84</td>
<td>2.17</td>
</tr>
<tr>
<td>Scrubbed back</td>
<td>−0.37</td>
<td>−5.46</td>
</tr>
<tr>
<td>Scrubbed under nails</td>
<td>−3.62***</td>
<td>−5.20</td>
</tr>
<tr>
<td>Interaction: Handscrubbing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scrubbed back × scrubbed between fingers</td>
<td>0.66</td>
<td>−0.43</td>
</tr>
<tr>
<td>Scrubbed back × scrubbed under nails</td>
<td>2.50***</td>
<td>1.29</td>
</tr>
<tr>
<td>Scrubbed back × scrubbed fingertips</td>
<td>3.05***</td>
<td>1.85</td>
</tr>
<tr>
<td>Scrubbed between fingers × scrubbed under nails</td>
<td>0.98</td>
<td>−0.21</td>
</tr>
<tr>
<td>Scrubbed between fingers × scrubbed fingertips</td>
<td>0.80</td>
<td>−0.30</td>
</tr>
<tr>
<td>Scrubbed under nails × scrubbed fingertips</td>
<td>0.02</td>
<td>−0.58</td>
</tr>
<tr>
<td>Scrubbing time &lt; 20 sec</td>
<td>0.54</td>
<td>−0.08</td>
</tr>
<tr>
<td>Drying</td>
<td>−0.85**</td>
<td>−1.39</td>
</tr>
<tr>
<td>Rubbed hands on clothes</td>
<td>−1.35**</td>
<td>−2.25</td>
</tr>
<tr>
<td>Used clean towel</td>
<td>−0.08</td>
<td>−0.89</td>
</tr>
<tr>
<td>Used dirty towel</td>
<td>0.00</td>
<td>−0.02</td>
</tr>
<tr>
<td>Hand contamination before washing</td>
<td>1.22***</td>
<td>0.94</td>
</tr>
<tr>
<td>Right hand sampled first</td>
<td>0.42</td>
<td>−0.04</td>
</tr>
</tbody>
</table>

NOTE: Model E coli likelihood ratio, \( \chi^2(20) = 242.89; P < .001 \), and model total coliforms likelihood ratio, \( \chi^2(19) = 147.44, P < .001 \).
† Wald confidence interval (B).
‡ No parameter estimate computed because not all combinations of rubbing back of hands × rubbing fingertips were observed.
** P < .05
*** P < .01
**** P < .001.

Observed handwashing infrastructure

One hundred fifty-six participants (90%) showed a specific place for handwashing. One hundred twenty-eight participants (74%) showed separate handwashing places for food- and stool-related handwashing. In 143 households (83%), water was present at 1 or more handwashing locations. One hundred three households (60%) had a place for handwashing with a water tap; most (86 households, or 83% of those with taps) had running tap water at the time of data collection. In 111 households (64%), soap was present at 1 or more handwashing locations.

Blanks

No E coli or total coliform colonies appeared on any of the blank samples.

Hand contamination before and after washing

In the prewash sample the average log_{10} CFU E coli per hand was 1.4 ± 0.9. The postwash samples yielded, on average, 1.2 ± 0.8 log_{10} CFU/hand. The reduction was statistically significant (\( t(172) = 4.28; P < .001 \)). The mean hand contamination with total coliform bacteria was reduced by 0.3 log_{10} CFU/hand from 2.5 ± 1.0 log_{10} CFU/hand in the prewash sample to 2.2 ± 0.9 log_{10} CFU/hand in the postwash sample (\( t(172) = 4.28; P < .001 \)).

Observed handwashing technique

Table 1 presents the observed handwashing technique of participants.

From 94 participants, the right hand was sampled first and from 79 participants the left hand was sampled first. The average time spent moistening, scrubbing, and rinsing hands amounted to 25.6 ± 14.9 seconds (median, 23.0 seconds) with an interquartile range of 16-32 seconds.

Effectiveness of handwashing technique

Results of a generalized linear model predicting the E coli and total coliform contamination of hands after washing based on the performed handwashing steps are presented in Table 2. For E coli, moistening and rinsing hands by dipping them into a vessel with water was statistically significantly associated with more contaminated hands after washing. Scrubbing the fingertips and under the fingernails led to significantly lower contamination of hands after washing. The positive and significant value of the interaction terms for scrubbing the back of the hands and under the nails and scrubbing the back of the hands and the fingertips indicate that the individual effect of each step is decreased when both are performed. Soap use improved the overall effectiveness of handwashing. The data further show that drying hands by rubbing them on the clothes or using a clean towel for hand drying was associated with cleaner hands after washing.

With regard to total coliform contamination after washing, moistening hands by pouring water from a vessel and dipping hands into a vessel led to higher hand contamination than moistening and rinsing hands under a tap. Soap use, in contrast to the results for E coli, was not statistically significantly related to total coliform contamination. Among the scrubbing steps, scrubbing the fingertips was associated with cleaner hands after washing. Like in the previous model for E coli, drying hands by rubbing them on clothes led to
lower contamination than air drying. However, using a clean towel was not associated with cleaner hands after washing.

Some trends consistent in both models were observed. For example, neither the total time spent for handwashing, nor scrubbing hands for more than 20 seconds, as it is recommended by CDC, was related to cleaner hands after washing. In addition, similar effects of moistening hands by dipping them into a vessel, scrubbing the fingertips, and drying hands on clothes were observed in both models. Also, the contamination before washing was a significant predictor of hand contamination after washing in both models.

**DISCUSSION**

The goal of the present study was to determine which steps of handwashing, as performed in the everyday life in suburbs of Harare, Zimbabwe, matter most to yield clean hands and to provide parsimonious recommendations for effective domestic handwashing in the study population. In a cross-sectional survey, the handwashing technique of primary caregivers in Harare was observed and its influence on hand contamination after washing was quantified. This study shows that recommendations for effective hand hygiene should include moistening hands under a tap; soap use; and performing specific scrubbing steps, including scrubbing under the fingernails and scrubbing the fingertips. Furthermore, the study suggests that inclusion of a minimum wash or scrubbing time may complicate recommendations without providing any additional bacterial removal. These findings from suburbs of Harare, Zimbabwe, demonstrate that handwashing technique influences microbial effectiveness. Future handwashing behavior change interventions should target both handwashing frequency and technique. The results further suggest a critical evaluation of existing handwashing recommendations in low- and middle-income countries.

Moistening hands under a tap led to cleaner hands than dipping hands into a vessel. For total coliforms, tap use was also more effective than manually pouring water on hands. Several mechanisms of action may lead to this effect. First, tap water was always from a fixed tap supplied by municipal water. This water might be less contaminated than stored water that was used when manually pouring water on hands or dipping hands into a vessel. As Hoque et al. suggested, using contaminated handwashing water may result in more fecal contamination on hands than using clean water. Different levels of water contamination for *E. coli* and total coliforms may explain the observed differences between the indicator organisms. Moistening hands by dipping them into the water, which is later used for rinsing, might more strongly contaminate the water with the more transient *E. coli* bacteria than with total coliforms. Second, using a tap allows hands scrubbing during hand moistening and rinsing, which may lead to additional removal of germs at this time. Third, tap water was available in larger quantity than stored water. This is likely to have prompted tap users to use more water, which may have further reduced hand contamination. Findings from a field experiment by Hoque et al. support this hypothesis showing that individuals who washed hands using 2 L water had lower loads of fecal indicator bacteria on hands after washing than individuals who used only 0.5 L.

Specific handscrubbing steps such as scrubbing under the fingernails and scrubbing the fingertips make handwashing more effective. We demonstrated reduced *E. coli* counts after handwashing when these steps were performed and reduced total coliform counts when the fingertips were scrubbed. Higher contamination of fingernails with *E. coli* than with total coliforms may account for the different effects of scrubbing under the nails. To our knowledge this is the first time that the effects of specific scrubbing steps were investigated. Because these steps do not require additional material, such as soap or a water tap, our findings highlight an opportunity for handwashing campaigns to increase handwashing effectiveness without providing additional hardware.

Neither scrubbing hands for at least 20 seconds or total handwashing time were associated with hand cleanliness after washing. This is in contrast with the CDC recommendation but corroborates previous experimental findings. This result is relevant for future handwashing promotion because it is doubtful whether people comply with complex recommendations that include minimum handwashing times. In contrast, recommending specific handwashing steps without a time limit might reduce complexity and increase compliance.

Using soap led to significantly less *E. coli* counts on hands than washing hands with water only. Controlling for other handwashing steps that were usually performed by this study’s participants, this corroborates the importance of soap, previously demonstrated in experimental trials. However, it is important to note that the effect of soap was less than one-third of that of rubbing under the nails and scrubbing the fingertips. This finding highlights the importance to perform specific hand scrubbing steps. Further, soap did not affect total coliform contamination. Being ubiquitous in the environment total coliforms may be part of the resident bacteria on hands and more difficult to remove than *E. coli*.

Drying hands on clothes led to less *E. coli* and total coliforms on hands. Using a clean towel led to less *E. coli* bacteria on hands than air drying. Rubbing hands on a towel or on clothes may have physically removed bacteria from hands as hypothesized by Huang et al. This questions the CDC recommendations that also promote air drying following handwashing.

**Limitations**

Individuals were not randomized to specific handwashing regimens, which limits the given recommendations to handwashing steps already in practice in the study community. However, this design allowed us to assess the importance of handwashing steps as performed in the usual way and give handwashing recommendations that are adapted to the real life of the study population. Furthermore, the results show that, except for hand drying with a clean and a dirty towel, all steps that we aimed to test were performed by a sufficient number of participants to evaluate them. More studies at other sites are required to generalize the given recommendations for effective handwashing.

Participants were directly observed by the enumerators during the handwashing demonstration that may have prompted participants to wash hands differently than they normally would. To minimize these effects, participants were explicitly reminded to wash hands in the usual way, that all information that was collected from them was handled confidentially, and that they would help their community most if they washed hands in the usual way. However, even if the handwashing demonstration had been biased, it would not have affected the relationship between the performed handwashing technique and its effectiveness.

*E. coli* and total coliform concentrations obtained from culture-based methods are imperfect indicators of hand contamination. We included in our results all observable bacterial colonies present on the compact dry plates that fit the manufacturer’s description. We may, therefore, have overestimated fecal bacterial contamination by including false positives with atypical morphology that nevertheless fit the manufacturer’s description. Although Julian et al. observed low false positive rates for *E. coli* on hands in Bangladesh as measured using the Colilert assay (which, like compact dry plates, relies on the presence of the β-galactosidase enzyme for *E. coli* identification), we did not attempt to confirm colonies isolated in this study.
Conclusions

This study shows that the handwashing technique is paramount for handwashing to effectively decontaminate hands. Worldwide, huge efforts are made to promote frequent handwashing with soap at critical times. Our findings raise the need to extend the focus of handwashing interventions to promoting effective techniques that include moistening hands with running water and performing specific hand-scrubbing steps. Field studies in other settings are needed to corroborate these results and further investigate the influence of hand drying methods. Handwashing steps as recommended by CDC are already in practice by some individuals of the survey population, which suggests that achieving uptake of the recommended technique by a larger share of the population can be a realistic aim of behavior change interventions. Additional research is needed to understand the behavioral determinants that drive people to apply effective handwashing techniques. This should support the design of interventions that make handwashing as effective as possible where the disease burden is high and resources are limited.

Acknowledgments

The authors thank Frederik Hammes for his advice on the laboratory procedures; Pablo Streich, Innocent Hove, Ellen Struve, and Karin Stögerer for their laboratory contributions; our field coordinators Belladonna Muzavazi and Eustace Sangoya; the enumerator team; and all study participants in Harare.

References