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Enhancing handwashing frequency and technique of primary caregivers in Harare, Zimbabwe: A cluster-randomized controlled trial using behavioral and microbial outcomes

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ABSTRACT

Rationale: Consistent hand hygiene prevents diarrheal and respiratory diseases, but it is often not practiced. The disease burden is highest in low-income settings, which need effective interventions to promote domestic handwashing. To date, most handwashing campaigns have focused on promoting frequent handwashing at key times, whereas specifically promoting handwashing techniques proven to be effective in removing microbes has been confined to healthcare settings.
Methods: We used a cluster-randomized, factorial, controlled trial to test the effects of two handwashing interventions on the behavior of primary caregivers in Harare, Zimbabwe. One intervention targeted caregivers directly, and the other targeted them through their children. Outcome measures were surveyed at baseline and six weeks' follow-up and included observed handwashing frequency and technique and fecal hand contamination before and after handwashing.
Results: Combining the direct and indirect interventions resulted in observed handwashing with soap at 28% of critical handwashing times, while the corresponding figure for the non-intervention control was 5%. Observed handwashing technique, measured as the number of correctly performed handwashing steps, increased to an average of 4.2, while the control averaged 3.4 steps. Demonstrated handwashing technique increased to a mean of 6.8 steps; the control averaged 5.2 steps. No statistically significant group differences in fecal hand contamination before or after handwashing were detected.
Conclusions: The results provide strong evidence that the campaign successfully improved handwashing frequency and technique. It shows that the population-tailored design, based on social-cognitive theory, provides effective means for developing powerful interventions for handwashing behavior change. We did not find evidence that children acted as strong agents of handwashing behavior change. The fact that the microbial effectiveness of handwashing did not improve despite strong improvements in handwashing technique calls for critical evaluation of existing handwashing recommendations. The aim of future handwashing campaigns should be to promote both frequent and effective handwashing.

1. Introduction

Diarrhea is one of the leading causes of child death worldwide, with the highest mortality rates in low-income countries, particularly in sub-Saharan Africa (Fischer Walker et al., 2013; Rudan et al., 2007). Consistent hand hygiene can prevent morbidity and mortality from diarrheal and other infectious diseases (Borghi et al., 2002; Curtis and Cairncross, 2003; Feachem, 1984; Freeman et al., 2014). Despite its life-saving health impact, only a small proportion of people worldwide are estimated to wash their hands with soap after fecal contact (Curtis et al., 2009; Freeman et al., 2014), which calls for effective handwashing promotion, particularly in low-income countries, where the diarrheal disease burden is highest.

Social-cognitive theories have predominantly been used to explain health behaviors (Conner and Norman, 2005). Among these, the risks, attitudes, norms, abilities, and self-regulation (RANAS) approach (Mosler, 2012; Mosler and Contzen, 2016) has been successfully applied to gain a deeper understanding of the behavioral factors that steer frequent handwashing (Contzen and Mosler, 2015; Friedrich et al., 2017a; Seimetz et al., 2016a; Seimetz et al., 2016b) and to design and evaluate handwashing behavior change interventions (Contzen and Inauen, 2015; Contzen et al., 2015). However, an intervention that is

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effective in one context may fail in another, as the specific culture of the target population is relevant to an intervention's success (Asad and Kay, 2015). Accordingly, the RANAS approach provides a guideline on how to tailor an intervention to the specific mindset of a target population. In this study, we first identified the behavioral factors which steered handwashing behavior in the target population and, based on those findings, designed the campaign to target only the behavioral factors actually relevant in the target population.

With regard to the mode of delivery of interventions, an interesting but seldom used strategy to reach adults is to promote handwashing to children at schools and encourage them in turn to promote handwashing at home. This strategy has yielded mixed results in promoting safe drinking water consumption and frequent handwashing with soap among children and caregivers in Kenya (Blanton et al., 2010; Onyango-Ouma et al., 2005; Patel et al., 2012). The vast majority of handwashing campaigns, have targeted caregivers directly (e.g., Chase and Do (2012); Contzen et al. (2015); Huda et al. (2012); Luby et al. (2010); Scott et al. (2008)). Two studies implemented in rural India directly targeted caregivers and in addition their children (Biran et al., 2009, 2014); the more recent resulted in average handwashing frequencies across all household members of 37% at six-month follow-up. However, neither of these studies compared the relative effectiveness of (1) targeting adults through their children (2) targeting adults directly, and (3) a combination of both.

Until now, the target behavior and primary outcome measure of most handwashing campaigns has been the frequency of handwashing with soap at key times (e.g., Arnold et al. (2009); Biran et al. (2014, 2009); Contzen et al. (2015); Huda et al. (2012); Luby et al. (2010); Scott et al. (2008)). However, correct handwashing technique is crucial for the effective decontamination of hands (Centers for Disease Control and Prevention, 2002; Food and Drug Administration, 2013; World Health Organisation, 2009). This calls for interventions which, in addition to promoting frequent handwashing at key times, also promote effective handwashing technique. However, few campaign evaluations from non-healthcare settings have yet included handwashing technique as an outcome variable (Blanton et al., 2010; Luby et al., 2009; Patel et al., 2012). The measures of handwashing technique used in the literature of campaign evaluations were inconclusive and did not correspond to the handwashing technique recommended by the Centre for Disease Control, Food and Drug Administration of World Health Organization. Patel et al. (2012), for instance, defined correct handwashing technique as “using soap, lathering all hand surfaces, and air drying” (p. 595), while Blanton et al. (2010) considered “lathering hands thoroughly with soap, rubbing between fingers, and air drying” (p. 665). Luby et al. (2009) reported whether participants “rub[bed] their hands together at least three times” (p. 140). Further, none of the studies assessing campaign effects on handwashing technique also assessed microbial hand contamination. Consequently, it remains uncertain whether changes in handwashing technique also resulted in an improvement in handwashing effectiveness.

The aim of this study was to address these knowledge gaps and pilot an innovative approach to designing and evaluating a handwashing campaign in Harare, Zimbabwe. Our first goal was to determine how to best target caregivers' handwashing behavior in this context and to compare interventions which target adults indirectly through their children, target adults directly, and a combination of both. Our second goal was to test interventions which target both handwashing frequency and technique. Our third goal was to evaluate the interventions using both behavioral and microbial outcomes and to assess the interrelation of outcome measures.

2. Methods

2.1. Trial design

This study was a cluster-randomized, controlled trial. A 2 × 2 factorial design was used to quantify the individual effects of one intervention directly targeting caregivers and another targeting caregivers through their children and to determine the effect of combining the interventions. Accordingly, the four trial arms were (1) direct intervention in communities, (2) indirect intervention with children in schools, (3) combination of both, and (4) control with no intervention. A spatially clustered design was chosen to minimize spillover between participants of different intervention arms. Additional control households, not surveyed at baseline, were recruited at follow-up to uncover potentially confounding effects of the baseline data collection on outcome variables. This yielded an additional group, called follow-up-only control. Baseline data were collected in July and August 2014, interventions were implemented in October and November 2015, and follow-up data were collected six weeks after the campaign had ended in January and February 2016. This study is reported according to the CONSORT 2010 statement: Extension for cluster randomized trials (Campbell et al., 2012).

2.2. Participants

This study was done in 20 high population density areas in Harare, which formed the clusters of the trial. Participants were recruited one day prior to the baseline data collection by trained data collectors. Each area had to be in the neighborhood of a local primary school and, to minimize spill-over, each area had to be spatially separated from other areas that were part of this study. Participating households were selected using random route sampling. Starting from randomly selected crossroads within each area, data collectors selected every fifth house along their way. Within each household, the primary caregiver of a child attending the local primary school was identified and enrolled. Households with children attending other participating primary schools were excluded to minimize spill-over. In cases of ineligibility, the fifth next household was selected. Informed written consent was sought from all participants. Subsamples for microbial hand sampling were selected by appointing seven of the total 15 data collectors to collect microbial samples in the households which they visited, while the remaining eight data collectors did not take microbial samples. At follow-up, additional participants were enrolled from control areas. The same random route procedure was applied as during baseline enrollment. However, different crossroads than those selected during baseline were used as starting points for the random route selection at follow-up. Masking of participants was not possible, because the consent procedure required by the Medical Research Council of Zimbabwe included informing participants about the content of the study.

2.3. Sample size

We estimated that an effective sample size of 280 participants was required to detect medium effects in Cohen's $f^2 > 0.25$ in demonstrated handwashing technique at Type 1 error probability of 0.05 and statistical power of 0.95 assuming 3 experimental groups and one control group. Assuming as previous authors (Luby et al., 2010) a design effect of 1.5, and 30% drop-out, this would yield an actual sample size of 600 participants to be enrolled at baseline. For handwashing observations, two critical handwashing events per caregiver on average were anticipated during each observations, which led to 300 households to be enrolled in the observations. Due to logistical constraints, microbial samples were taken from only 235 households at baseline. Anticipating a design effect of 1.5 and 30% drop-out, this corresponds to an effective sample size of 110 participants, allowing detection of large effects in Cohen's $f^2 > 0.4$ at follow-up. Intra-cluster correlation coefficients are presented in Table A1 in the appendix. Sample size was estimated using G*Power 3.1.9.2. The sample sizes at both cluster and individual levels are displayed in the flowchart of the sample (Fig. 1).

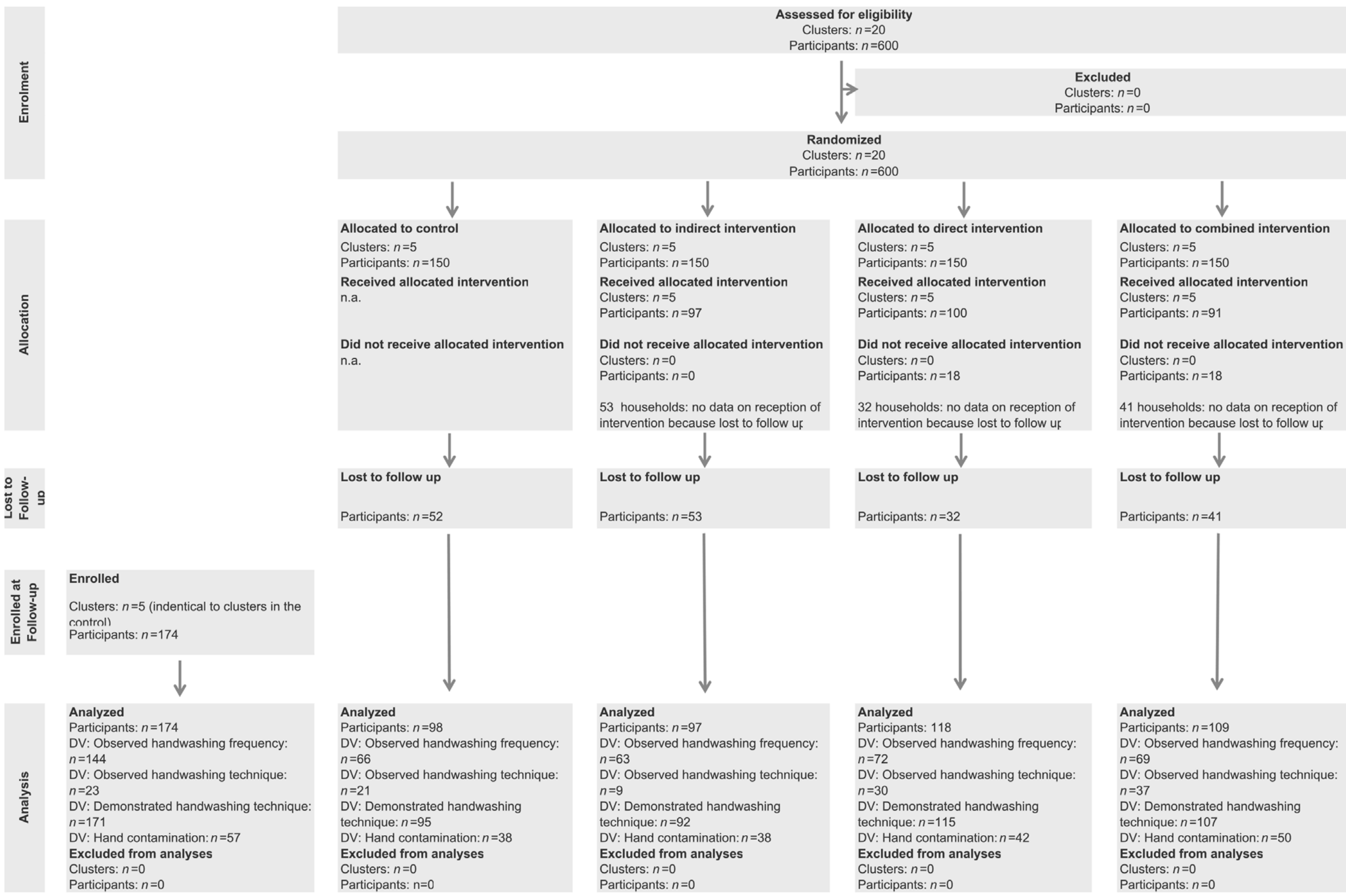


Fig. 1. Flow diagram of the sample. Note: DV = Dependent variable. No clusters were lost to follow-up.

2.4. Randomization

Clusters were allocated to intervention arms through simple randomization. Randomization was done directly before the beginning of the campaign using the random number generator in Microsoft Excel by a researcher not further involved in the study. Since clusters were spatially defined, allocation of participants to clusters was not required.

2.5. Interventions

We used the RANAS approach to systematic behavior change (Mosler, 2012) to tailor the interventions to the specific characteristics of the target population. The RANAS approach combines leading social-cognitive theories from health and environmental psychology and constitutes a guide to the design and evaluation of behavior change interventions. The factors steering handwashing behavior in the target population were identified through a quantitative survey of handwashing behavior and behavioral factors. To change these factors and, consequently, change handwashing behavior, specific behavior change techniques (BCTs) were selected to target each relevant factor. Thus, the intervention was tailored to the target population, as also proposed by Asad and Kay (2015). These BCTs were combined into intervention strategies, and each strategy was implemented in one campaign session. For each strategy, a slogan was created to summarize its key message. Details on the design of interventions are reported in Friedrich (2016). The draft campaign was discussed with the local grassroots stakeholders, including health promoters, local health center staff, school teachers, school heads, councilors, and members of the residence association, and the campaign was revised accordingly. The feedback focused predominantly on the design of activities and did not lead to changes in the selection of BCTs. The structure and content of the community and school level interventions are displayed in Tables 1 and 2. The protocols for the campaign implementation were written by a local NGO, which acted as the implementing partner. It coordinated the campaign implementation and trained the promoters in collaboration with the study manager. Campaign materials were designed by a local creative agency under the supervision of the implementing partner. The full intervention protocols are available from the authors on request. Due to time constraints, interventions could not be piloted in the target population before implementation.

The community-based direct interventions were implemented by the staff of the local health centers, and the school-based interventions were implemented by teachers at the local primary schools. Each intervention strategy was implemented in one week. The health center and school staff were trained on the Saturdays prior to the weeks of implementation of each strategy. Due to logistical constraints, the direct community interventions started two weeks before the school interventions. Further protocol deviations were noted during the implementation of the campaign. In BCT 8 of the direct intervention (Table 1), the discussion focused on the risk of not washing hands with soap rather than on disgust. In BCT 26, not all behavioral plans were documented correctly, and self-monitoring calendars (BCT 27) were distributed late to some communities. BCT 1 (Table 2) of the intervention with children was partly implemented without posters explaining the fecal-oral route.

2.6. Data collection & outcomes

Outcome variables were assessed at baseline and follow-up by trained local data collectors. The training included one week of

Table 1
Structure and content of the direct interventions with caregivers.

Strategy	Slogan	Communication channel	BCT	Activities	RANAS factor targeted
1	Handwashing? Of course! Because I like to be clean.	Interpersonal: Community meeting	BCT 8 Describe feelings about performing and about consequences of the behavior	Handwashing exercise visualizing dirt on hands and discussion to attach the feeling of disgust to not washing hands with soap and attach the feeling of cleanliness to washing hands with soap at key times.	Feelings: Disgust
			BCT 18 Prompt guided practice	Additional practice of handwashing with soap and effective scrubbing steps.	Confidence in performance
2	Handwashing? Of course! I can do it!	Interpersonal: Household visit	BCT 26 Prompt specific planning	Planning of when, where, and how to wash hands before contact with food and documentation of plans.	Action planning
			BCT 34 Use memory aids and environmental prompts	Plans are hung on the wall at the place of food preparation or eating.	Remembering
			BCT 27 Prompt self-monitoring of behavior	Distribution of a self-monitoring calendar, to record when hands were washed before contact with food. Placing self-monitoring calendar at handwashing location	Action control
3	Handwashing? Of course! We can do it!	Interpersonal: Household visit	BCT 26 Prompt specific planning	Planning of when, where, and how to wash hands after contact with stool and documentation of plans.	Action planning
			BCT 34 Use memory aids and environmental prompts	Plans are hung on the wall in the toilet	Remembering
			BCT 27 Prompt self-monitoring of behavior	Distribution of a self-monitoring calendar, to record when hands were washed after contact with stool. Placing self-monitoring calendar at handwashing location	Action control
			BCT 21 Organize social support	Initiate group discussion between household members how to support each other in washing hands with soap. Particular focus was put on how to cope	Confidence in performance + Others‘ (dis)approval
			BCT 30 Prompt coping with barriers	with the barriers of not washing hands with soap when in a hurry or not feeling like washing hands at the right moment.	Hindrance situation + Confidence in continuation
4	Handwashing? Of course! We all do it!	Interpersonal: Community meeting	BCT 21 Organize social support	Volunteers perform small dramas in which they present their social support strategies to the other participants of the community meeting.	Confidence in performance + Others‘ (dis)approval
			BCT 10 Prompt public commitment	Participants commit in groups of ten in front of other community members to always washing their hands with soap at key times. Participants are rewarded with a certificate for participating and filling the self-monitoring calendar.	Descriptive norm

Note: The numbering of BCTs refers to the BCT catalogue in Mosler and Contzen (2016).

Table 2
Structure and content of the indirect interventions targeting caregivers indirectly through their children.

Strategy	Slogan	Communication channel	BCT	Activities	RANAS factor targeted
1	Handwashing? Of course! It helps me stay healthy!	Interpersonal: Classroom activity	BCT 1 Present facts	The teacher asks the students what diarrhea is, how diarrhea is spread, and how it can be prevented. Discussion of fecal-oral route poster.	Health knowledge
			BCT 2 Present scenarios	Students reflect when the processes shown on the fecal-oral route poster happen during their daily life, draw one such situation and present it to the class.	
2	Handwashing? Of course! We have all we need!	Interpersonal: School event	BCT 16 Provide infrastructure BCT 34 Use memory aids and environmental prompts	Repair existing handwashing stations at the toilets and provide handwashing stations for classrooms in form of one 20 l bucket with a tap fitted in it and a second 20 l bucket to hold the dirty water. Children build dispensers for soapy water from plastic bottles by piercing a hole in the cap of the bottles. Plastic bottles are decorated with paints provided by the project. Colorful soap dispensers and handwashing stations serve as reminders. At a school event, the handwashing stations are inaugurated and awards are given for the most creatively decorated soap dispensers.	Confidence in performance Remembering
		Interpersonal: Classroom activity	BCT 3 Inform about and assess personal risk	Handwashing exercise visualizing dirt on hands and explanation that not washing hands at key times increases diarrhea risk.	Vulnerability
3	Handwashing? Of course! We can do it!	Interpersonal: Classroom activity	BCT 21 Organize social support	In each class, two students are responsible for refilling the water buckets and soap dispensers.	Confidence in performance
			BCT 27 Prompt self-monitoring of behavior	Self-monitoring calendar, to record when hands are washed at key handwashing times. Calendars are hung up in classrooms.	Action control
			BCT 28 Provide feedback on performance	The teacher regularly checks the self-monitoring calendars and gives feedback to children.	Action control + Others' (dis) approval
4	Handwashing? Of course! Everybody!	Interpersonal: Classroom activity	BCT 21 Organize social support	Teachers and students revise the system of how handwashing stations are refilled. Students discuss how they can further support each other in washing hands with soap at key handwashing times.	Confidence in performance
			BCT 10 Prompt public commitment	Classes commit to washing hands with soap at key times through posters which they design. Posters are hung up on the inside and outside of the classroom doors, so students from the same and other classes can see them.	Descriptive norm

Note: The numbering of BCTs refers to the BCT catalogue in Mosler and Contzen (2016).

theoretical and practical training on observation, interviewing, and sampling techniques. Behavioral observations and hand sampling were rehearsed in role plays. In the beginning of the survey, all data collectors performed at least two days of pre-testing before the start of the actual data collection. Outcome measures comprised observed handwashing frequency, observed handwashing technique, hand contamination before handwashing, demonstrated handwashing technique, hand contamination after handwashing, and the difference from pre-to post-wash, that is, the removal of bacteria.

Observed handwashing frequency was measured in a subsample through 3-h structured handwashing observations starting at 6 a.m. in the morning. For each critical handwashing situation, data collectors noted whether the caregiver had washed hands with soap or not. Eating and food preparation were categorized as critical food-related handwashing situations. Using or cleaning the toilet and changing the diapers of a baby were categorized as critical stool-related handwashing situations, which resulted in a dichotomous measure of handwashing with soap.

Observed handwashing technique, how respondents washed hands in critical handwashing situations, was assessed during the same 3-h structured observations. To minimize reactivity, handwashing technique was only observed if the data collectors could observe it without getting closer to the respondent than already needed to observe soap use. Handwashing technique was operationalized as the number of handwashing steps that were correctly performed during one handwashing episode out of eight steps that had been promoted during the campaign. The steps were based on recommendations by the Centers for Disease Control and Prevention (n.d.) and included (1) using running water for moistening and rinsing, (2) using soap, (3) scrubbing the palms of the hands (4) scrubbing the backs of the hands, (5) scrubbing between the fingers, (6) scrubbing the finger tips, (7) scrubbing under the finger nails, and (8) drying hands using a clean towel or air drying. For each handwashing episode, this resulted in a sum score of observed handwashing technique ranging from 0 (none of the recommended steps were performed) to 8 (all recommended steps were performed). Air-drying was defined as waving or shaking hands directly after handwashing. We operationalized handwashing technique as an index, similar to previous publications (Chudleigh et al., 2005; Gould, 1994). An unweighted index was used because, first, Centers for Disease Control and Prevention (n.d.) does not suggest any of the recommended steps to be more relevant for effective handwashing than others and, second, because no comprehensive evidence exists on the relative effectiveness of the steps which would justify such prioritization (Friedrich et al., 2017b).

Hand contamination before handwashing was measured as the number of *E.coli* colony forming units per hand (CFU/hand) in hand rinse samples, as previously reported (Pickering et al., 2010). Whether the right or left hand was sampled was decided randomly. In households which had participated in the structured observations, hand contamination was assessed after the observation period had ended. In households which had not been observed, hand contamination before handwashing was assessed at the beginning of the household visit. A detailed description of the sampling and processing protocol is reported in Friedrich et al. (2017b). Bacterial counts were log transformed for analyses, resulting in the measure 10 log CFU/hand.

After the first hand rinse sample had been taken, participants were requested to demonstrate how they would usually wash hands, either before handling food or after contact with stool. This demonstrated handwashing technique was operationalized in the same way as described for observed handwashing technique.

After the handwashing demonstration, the second hand sample was taken. Hand contamination after handwashing was measured exactly the same as was hand contamination before handwashing. The hand that was sampled was the hand from which the pre-wash sample had not been taken.

Bacteria removal was calculated by subtracting hand contamination after handwashing from the contamination before washing. All outcome measures pertained to the individual participant level. All participants were also subject to a 1-h structured interview on self-reported handwashing behavior and the social-cognitive factors of handwashing.

2.7. Analyses

The following group comparisons were tested. First, the intervention targeting caregivers indirectly through their children was compared to the control. Second, assuming stronger effects from targeting caregivers directly than indirectly, we compared the direct intervention to the indirect one. Third, we compared the combined intervention, in which caregivers had been both targeted through their children and directly to the solely direct intervention. Last, we compared control households newly recruited at follow-up with control households that had been already surveyed at baseline to test whether participation in the baseline date collection alone had an influence on the outcomes. We used generalized linear estimating equations with robust parameter estimates to compare the marginal means of outcome measures between intervention conditions. We modelled observed handwashing frequency with soap and with water only as binomial distribution with a logit link, observed and demonstrated handwashing technique as a normal distribution with an identity link, pre- and post-wash hand contamination as a negative binomial distribution with a log link, and bacteria removal as normal distribution with an identity link function. No covariates were included in the models. To account for the clustering of data at household and area levels, we used exchangeable correlation matrices. To control for false discovery rates due to multiple testing, we adjusted significance level of p-values as recommended by Benjamini and Hochberg (1995). To quantify the interrelation of outcomes, we used Spearman correlations, since some of the outcome variables were non-normally distributed.

To assess whether the intervention effects were area specific, descriptive statistics of socio-demographics and outcomes at baseline and follow-up were separately computed for each cluster. In addition to the aggregated measure for observed handwashing technique, absolute and relative frequencies were computed for the performance of individual handwashing steps at follow-up to quantify whether the interventions affected all handwashing steps equally or triggered increases only in particular steps. Further, descriptive statistics of socio-demographics and outcomes at baseline were separately computed for those participants who dropped out of the study over time and those who remained in the study. The statistical significance of these differences was not tested, as these additional analyses would require additional statistical power not considered during sample size calculation. All analyses were conducted using SPSS 22.

2.8. Ethics statement

This study was approved by the Research Council of Zimbabwe, the Medical Research Council of Zimbabwe, and the Institutional Review Board at the Faculty of Arts, University of Zurich.

3. Results

3.1. Baseline characteristics

At baseline, intervention and control households had very similar socio-demographic characteristics (Table 3). At cluster level, most socio-demographics were similarly distributed as well, with income being an exception (Table A1 and A2). In addition, the availability of functioning water taps differed greatly between clusters. With regard to the outcome variables, intervention groups were also similar at baseline, with the exception of handwashing frequency with soap, which was higher in the indirect and direct intervention groups than in the other two groups. Baseline values of observed handwashing technique

Table 3
Baseline characteristics of participants on individual and cluster levels.

Variables	Control ($n = 150$)		Indirect intervention ($n = 150$)		Direct intervention ($n = 150$)		Combined intervention ($n = 150$)	
Individual level	M/N	(*SD*/%)	M/N	(*SD*/%)	M/N	(*SD*/%)	M/N	(*SD*/%)
Number (%) of female participants	147	(98)	147	(98)	145	(97)	143	(96)
Mean (*SD*) Age (Years)	36.9	(11.1)	35.5	(10.8)	37.2	(11.2)	39.4	(12.5)
Mean (*SD*) Years of formal education	10.3	(2.4)	10.4	(2.3)	10.3	(2.3)	9.8	(2.5)
Mean (*SD*) Number of household members	5.5	(2.0)	5.9	(1.9)	5.8	(2.2)	5.4	(1.9)
Mean (*SD*) Monthly household income (USD)	282	(229)	334	(261)	298	(331)	294	(220)
Number of households having a water tap (%)	145	(97)	145	(97)	144	(96)	148	(99)
Number of households having a functioning water tap (%)	98	(66)	73	(49)	66	(44)	117	(78)
Handwashing with soap (%)	1.4		9.3		11.1		3.0	
Handwashing with water only (%)	27.0		27.9		30.1		34.3	
Mean (*SD*) Demonstrated handwashing technique	4.8	(1.6)	4.5	(1.7)	4.6	(1.7)	4.8	(1.8)
Mean (*SD*) Hand contamination with *E.coli* before washing (10 log CFU/hand)	1.5	(0.9)	1.5	(0.9)	1.3	(0.8)	1.4	(0.8)
Mean (*SD*) Hand contamination with *E.coli* after washing (10 log CFU/hand)	1.2	(0.8)	1.3	(0.9)	1.1	(0.6)	1.2	(0.8)
Mean (*SD*) Removal of *E.coli* through washing (10 log CFU/hand)	−0.3	(0.7)	−0.2	(0.9)	−0.2	(0.6)	−0.2	(0.7)
Cluster level	M	(*SD*)	M	(*SD*)	M	(*SD*)	M	(*SD*)
Mean (*SD*) Number of female participants	29.4	(0.5)	29.4	(0.9)	29	(0.7)	28.6	(1.1)
Mean (*SD*) Age (Years)	36.9	(2.9)	35.5	(1.5)	37.2	(1.5)	39.4	(3.8)
Mean (*SD*) Years of formal education	10.3	(0.6)	10.4	(0.3)	10.3	(0.5)	9.8	(0.9)
Mean (*SD*) Number of household members	5.5	(0.4)	5.9	(0.2)	5.8	(0.2)	5.4	(0.3)
Mean (*SD*) Monthly household income (USD)	281	(79)	334	(81)	299	(79)	294	(33)
Mean (*SD*) Number of households having a water tap	29	(1)	29	(1)	29	(2)	30	(1)
Mean (*SD*) Number of households having a functioning water tap	19	(11)	15	(13)	13	(12)	23	(5)
Mean (*SD*) Handwashing with soap (%)	1.4	(3.0)	9.3	(6.1)	11.1	(7.1)	3.0	(4.3)
Handwashing with water only (%)	27.0	(9.2)	27.9	(5.0)	30.1	(13.2)	34.3	(11.6)
Mean (*SD*) Demonstrated handwashing technique	4.8	(0.5)	4.5	(0.6)	4.6	(0.5)	4.8	(0.4)
Mean (*SD*) Hand contamination with *E.coli* before washing (10 log CFU/hand)	1.5	(0.2)	1.5	(0.2)	1.3	(0.2)	1.4	(0.2)
Mean (*SD*) Hand contamination with *E.coli* after washing (10 log CFU/hand)	1.2	(0.2)	1.3	(0.3)	1.1	(0.2)	1.2	(0.1)
Mean (*SD*) Removal of *E.coli* through washing (10 log CFU/hand)	−0.3	(0.2)	−0.2	(0.1)	−0.2	(0.1)	−0.2	(0.2)

Note: *SD* = Standard deviation.

are not reported, because they were not part of the baseline observation protocol. Intra-cluster correlation coefficients at baseline ranged from 0.04 to 0.12 and appear in Table A3 in the online appendix. Households that dropped out before the conclusion of the study showed similar socio-demographic characteristics and baseline values in outcomes to those households that remained in the study (Table A4).

3.2. Effects on observed handwashing frequency

Frequency of observed handwashing with soap was highest in the combined intervention group (28%) and the direct intervention group (19%), compared to 6% in the follow-up-only control, 5% in the control, and 2% in the indirect intervention group (Fig. 2, left). Handwashing frequency in the direct intervention group was significantly higher than in the indirect intervention group ($p < 0.001$). The comparisons of follow-up-only control vs. control, control vs. indirect intervention, and direct vs. combined intervention did not yield significant differences. Frequency of observed handwashing with water amounted to 21% in the direct intervention group, 22% in both the school intervention group and the follow-up-only control group, 30% in the control group, and 35% in the combined intervention group. No significant group differences were detected.

3.3. Effects on observed handwashing technique

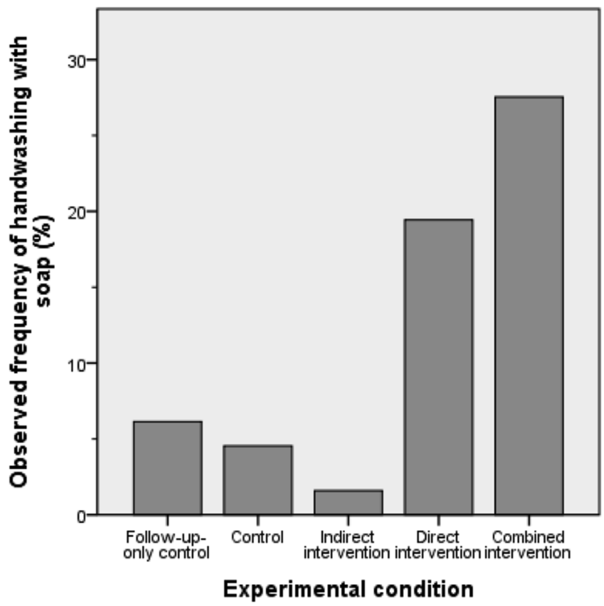
Observed handwashing technique (Fig. 2 right) was similar in the follow-up-only control (3.2 steps), control (3.4 steps), and indirect intervention groups (3.2 steps) and approximately one step higher in the direct (4.4 steps) and combined intervention groups (4.2 steps). The differences between the direct and the indirect intervention group was statistically significant ($p = 0.005$). Descriptive analyses of the performance of individual handwashing steps revealed that most handwashing steps were more frequently executed in the direct and combined intervention groups than in the other groups (Table A5 in the appendix). The largest differences were observed for soap use and scrubbing between fingers.

3.4. Effects on demonstrated handwashing technique

Fig. 3 shows the mean rates in demonstrated handwashing technique. It was significantly higher in the control group (5.2 steps) than in the follow-up-only control group (4.5 steps, $p < 0.001$) and significantly higher in the direct intervention group (6.2 steps) than in the indirect intervention group (5.0 steps, $p = 0.004$).

3.5. Effects on hand contamination and bacteria removal

Hand contamination measured before and after the handwashing demonstration (Fig. 3) did not differ significantly between intervention groups. The differences between the pre- and post-wash measurements (data not shown) did not differ significantly between groups either.



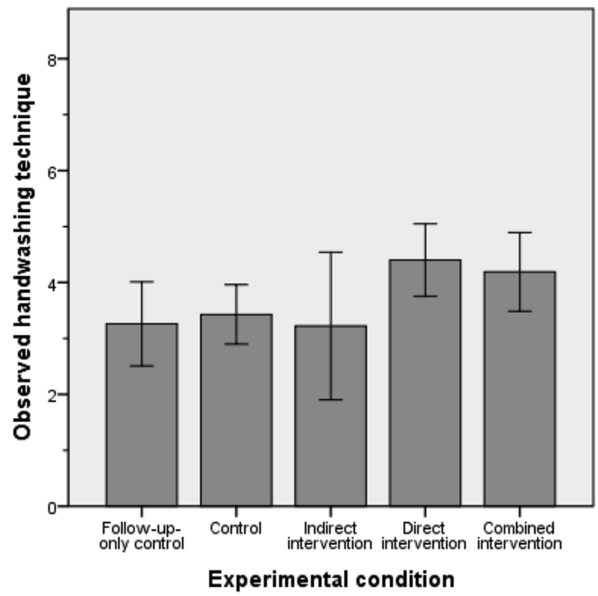


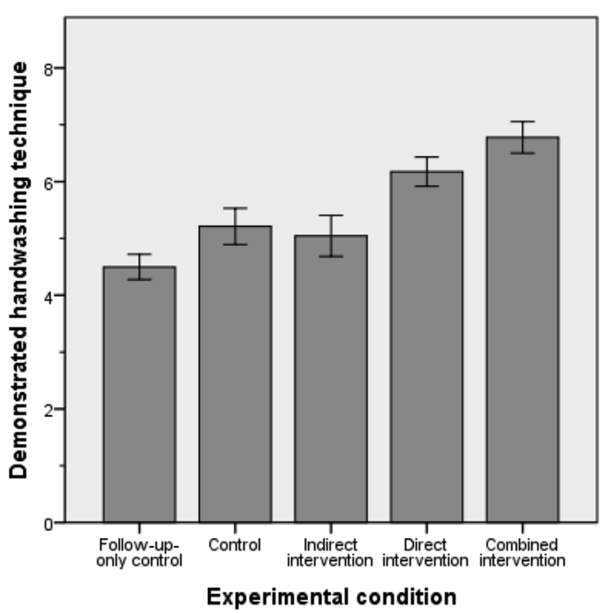
Fig. 2. Observed frequency of handwashing with soap (left) and observed handwashing technique (right) at six weeks follow-up after the interventions. Error bars show 95% confidence interval.

3.6. Effects on cluster levels

Descriptive analyses of effects on cluster level revealed that intervention effects strongly differed between the clusters (Table A1 and A2 in the appendix). In the direct and combined intervention groups, which were the groups with the highest intervention effects on behavioral outcomes, variation in cluster means of behavioral outcomes was also highest. The strongest variation of observed handwashing with soap and with water only was detected in the direct intervention group, which ranged from 6.7% handwashing with soap to 36.4% and from 0% handwashing with water only to 50%. The strongest variation in cluster means of demonstrated handwashing technique was detected in the combined intervention group, ranging from 4.8 to 7.3 steps. Variation in microbial outcomes was highest in the control and indirect intervention groups, in which changes in behavioral outcomes were minimal. The strongest variation in pre-wash hand contamination was observed in the indirect intervention group (0.8–2.2 10log CFU/hand), and the strongest variation in post-wash hand contamination was found in the control group (1.2–2.0 10log CFU/hand).

3.7. Correlation of outcome measures

The correlation of outcome measures is displayed in Table 4. All behavioral measures showed significant intercorrelation, with medium to strong correlations between observed handwashing technique and frequency and between observed handwashing technique and demonstrated handwashing technique. Microbial outcome measures were also intercorrelated, with strong correlations between hand contamination before and after washing and between the pre-wash contamination and the removal of bacteria. Surprisingly, the intercorrelation between demonstrated handwashing technique and contamination after washing was small, and demonstrated handwashing technique and removal of



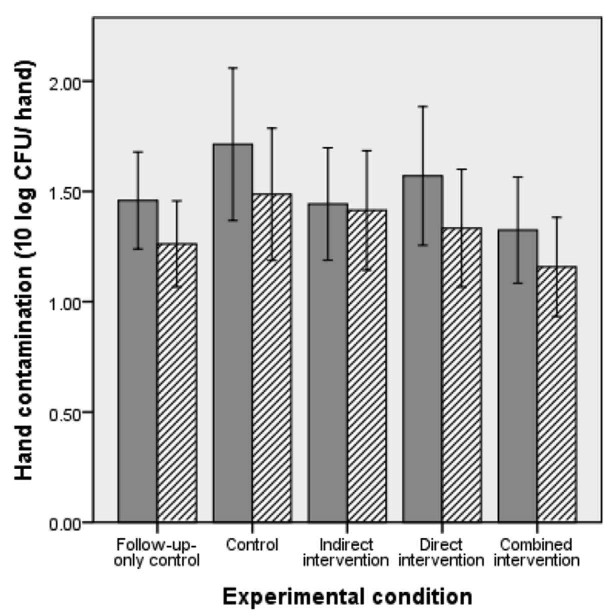


Fig. 3. Observed demonstrated handwashing technique (left) and *E.coli* hand contamination (right) before handwashing (solid bars) and after handwashing (hatched bars) at six weeks follow-up after interventions. Error bars show 95% confidence interval.

Table 4
Correlation of outcomes.

	Observed handwashing frequency		Observed handwashing technique		Demonstrated handwashing technique		Hand contamination before washing		Hand contamination after washing	
	n	*r*	*n*	*r*	*n*	*r*	*n*	*r*	*n*	*r*
Observed handwashing technique	42	0.484***								
Demonstrated handwashing technique	186	0.253***	51	0.494***						
Hand contamination before washing	79	0.000	26	0.117	222	-0.084				
Hand contamination after washing	79	-0.087	26	0.081	222	-0.177**	225	0.555***		
Removal of hand contamination	79	-0.020	26	-0.069	222	-0.095	225	-0.561***	225	0.298***

Note: r = Spearman's rho; *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

bacteria were not correlated significantly.

4. Discussion

The aims of this study were threefold: First, to evaluate a handwashing campaign aimed at improving both handwashing frequency and technique; second, to compare the relative effectiveness of handwashing promotions targeting caregivers directly with indirect promotions through their children; and, third, to determine whether changes in handwashing behavior lead to changes in hand contamination. In a cluster-randomized, factorial, controlled trial we evaluated direct and indirect interventions and assessed their impact on observed handwashing frequency, handwashing technique, and fecal hand contamination before and after handwashing.

The intervention targeting caregivers directly through community meetings and household visits and the combined intervention substantially increased caregivers' handwashing frequency and technique at key handwashing times. The population-tailored design, based on social-cognitive theory, provides effective means for developing powerful interventions for handwashing behavior change. This result also indicates that targeting handwashing, frequency, and technique at the same time is a promising strategy to trigger changes in both dimensions of handwashing behavior.

We did not find compelling evidence that children acted as powerful agents of change for handwashing promotion, although they might have added to the effect of the direct handwashing promotion. Implemented alone, the interventions targeting children did not have a significant effect on caregivers' handwashing behavior. As discussed by Onyango-Ouma et al. (2005) and Mwanga et al. (2008), children might not be considered family members from whom adults will take advice in the local culture. As a consequence, parents might have been unwilling to adopt a behavior upon request from their children.

Behavioral outcomes were interrelated. The strong correlation of observed handwashing frequency and observed handwashing technique suggest that both dimensions of handwashing behavior influence each other. This is in line with findings from the formative baseline of this campaign and suggests that targeting handwashing frequency and technique simultaneously is a better strategy than targeting each dimension separately.

The fact that demonstrated and observed handwashing technique were strongly correlated suggests that demonstrations may serve as a valid proxy of actual handwashing technique, for example when structured observations are not feasible because of financial or logistical constraints. The finding that demonstrated handwashing technique generally scored higher than observed handwashing technique suggests that participants were more reactive to the request to demonstrate handwashing than to being observed. Reactivity was particularly high among control participants who had already been enrolled at baseline, as shown by the higher scores for demonstrated handwashing technique in this group.

Despite strong effects on handwashing technique, the campaign did not significantly improve handwashing effectiveness as measured by the microbial outcomes. However, there is a tendency that post-wash hand contamination was lower in the groups where the technique of handwashing was better; for instance handwashing technique was best and post-wash contamination was lowest in the combined intervention group. The significant but low correlation between demonstrated handwashing technique and hand contamination after washing provides some evidence for this effect.

Several reasons may underlie this surprisingly low correlation between handwashing technique, contamination after handwashing, and the inability of the campaign to statistically significantly improve handwashing effectiveness despite improving technique. First, hands may have become recontaminated during handwashing. Contaminated faucet handles (Griffith et al., 2003), towels (Gil et al., 2014), and handwashing water itself (Palit et al., 2012) are potential sources of hand recontamination during handwashing. Second, handwashing technique could have improved those steps which were less relevant for microbial handwashing effectiveness. In the present trial, the major improvements detected in handwashing technique stemmed from soap use and scrubbing between the fingers (see supplementary information). However, quantification of the relative effectiveness of the handwashing steps at baseline did not show scrubbing between the fingers to be relevant at all (Friedrich et al., 2017b) but found scrubbing the finger tips and scrubbing under nails to be most strongly related to reduced post-wash hand contamination. However, those steps only partially improved in this trial. In summary, the improvements of handwashing technique probably did not lead to improvements in hand cleanliness because technique did not improve in the most relevant steps. In addition, hands were likely recontaminated during handwashing.

Despite strong effects on handwashing frequency, the campaign did not significantly impact pre-wash hand contamination. This contradicts findings from previous studies, which showed significant decreases of hand contamination along with increased handwashing frequency (Davis et al., 2011; Greene et al., 2012; Luby et al., 2010). Recontamination is likely to explain this finding. Recontamination of hands to pre-wash levels after 30 min has been reported by Devamani et al. (2014), and Ram et al. (2011) reported substantial recontamination within 2 h. Various household activities have been shown to contaminate hands (Pickering et al. (2011)).

Microbial outcomes were interrelated. The strongest correlations were detected between pre-wash contamination and bacteria removal and between pre-wash and post-wash contamination. On the one hand, this indicates that where hands were highly contaminated, removal through handwashing was also high. On the other hand, it shows that, despite washing, hands remained more contaminated if initial contamination had been high.

Within intervention groups, intervention effects varied between clusters. Contextual factors at community level can be crucial determinants of health-related behaviors and their uptake as the consequence of interventions (Kaufman et al., 2014) and provide a likely explanation for the detected inter-cluster variations in this study. The quality of intervention implementation, for example, likely varied between clusters as a consequence of variations in motivation and the skill of local promoters. Each cluster corresponded to one suburban area, so the interventions in each were implemented by different local health promoters and health center staff. Although all of them had received standardized training, implementation protocols, and supervision during the campaign implementation, differences in implementation quality are likely. Other potentially relevant contextual factors include the social networks of and communication between participants, poverty, and access to infrastructure (Kaufman et al., 2014). For example, access to water may be highly relevant for handwashing behavior. Further, general microbial contamination of the household environment or water may differ strongly from one cluster to another and, at the same time, be directly linked to hand (re)contamination.

4.1. Limitations

This study has important limitations. This campaign evaluation is based entirely on evidence from a single field study. The campaign was tailored to the target population, and the generalizability of its effects is limited to urban contexts in Zimbabwe. The time between completion of the baseline and follow-up data collection amounted to 18 months, over which a considerable number of participants dropped out, mostly because they had moved away. Although drop-outs were similar to households that remained in the study with regard to socio-demographics and baseline values in outcomes, this limits the generalizability of the study results to the residual population of the intervention areas. No covariates were included in the analyses due to limited statistical power. However, participants' socio-demographic characteristics were similar across groups as revealed by descriptive statistics of baseline values.

Protocol deviations were noted during the implementation of the campaign, as specified in the methods section. While promoting the campaign entirely through local health center staff and teachers provided challenges to intervention fidelity, it allowed a distinctly more valid projection of the effects of any upscaling of the campaign. Furthermore, the results of this study show that the campaign was effective in changing behavior, despite the protocol deviations.

Although structured observations are the preferred method of surveying handwashing behavior (Ram, 2013), they are likely to be subject to reactivity; participants modify their handwashing behavior when they know that they are being observed (Kohli et al., 2009). Values of observed handwashing behavior should consequently be considered an optimistic measure of actual behavior. However, we used conservative definitions of key handwashing times: Every resumption of food preparation, even after a short interruption, was counted as an independent critical food-related times and all toilet visits, most likely including both defecation and urination, were considered critical stool-related handwashing times.

This study reports considerable improvements in both handwashing frequency and technique as a result of a handwashing campaign using a sound operationalization of both dimensions of handwashing behavior. It provides strong evidence that the design approach based on social-cognitive theory and data from the target population provides effective means to develop powerful interventions for handwashing behavior change. The fact that the microbial effectiveness of handwashing did not improve despite strong improvements in handwashing technique calls for critical evaluation of existing handwashing recommendations. Clearly, more research is needed to understand and minimize hand recontamination. Future handwashing promotion should target both handwashing frequency and technique.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.socscimed.2017.10.025.

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