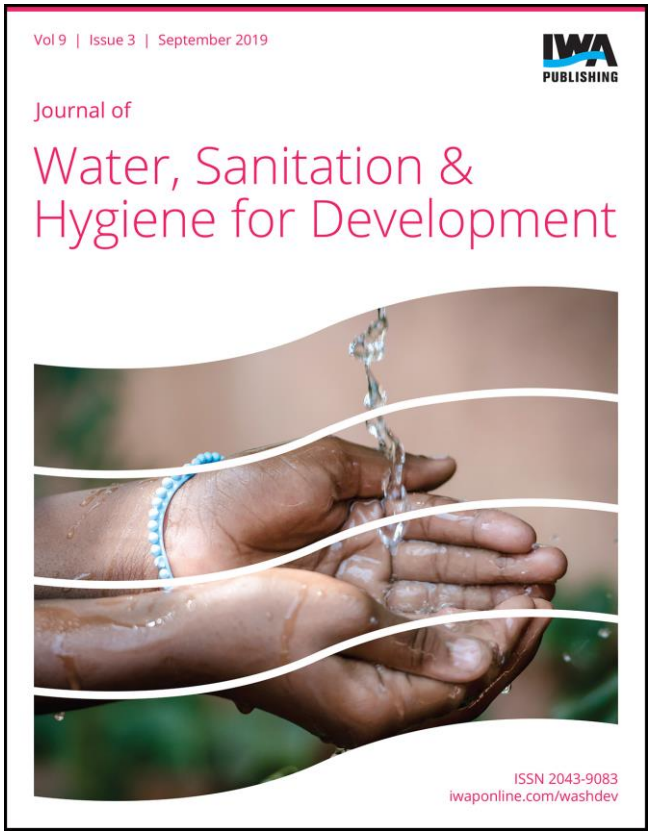

Research Paper

Effects of complexity of handwashing instructions on handwashing procedure replication in low-income urban slums in Bangladesh: a randomized non-inferiority field trial

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ABSTRACT

Handwashing instructions vary in complexity, with some recommending multiple steps. To assess whether complex handwashing instructions changed handwashing procedure replication, we conducted a randomized non-inferiority trial in a low-income area, Dhaka. We randomly assigned mothers and children aged 5–10 years to one of three handwashing instruction sets: simple ($N = 85$ mothers/134 children), moderate ($N = 75$ mothers/148 children), or complex (84 mothers/147 children). Simple instructions had three steps: wet, lather, and rinse hands, and moderate included the simple instructions plus steps to scrub palms, backs of hands, and dry hands in the air. Complex instructions included moderate instructions plus steps to scrub between fingers, under nails, and lather for 20 s. After baseline, cue cards were used to promote handwashing instructions, and adherence after 2 weeks of interventions was evaluated. Compliance with handwashing procedure replication to all instructions in simple, moderate, and complex increased after the intervention among mothers and children. Compliance to all instructions in the simple group was higher in the simple group (100%) compared to all instructions in moderate (47%) and complex instruction groups (38%). Simple handwashing steps are easier to remember for long time periods compared to complex steps.

Key words | adherence, Bangladesh, children, handwashing complexity, mothers, WASH, water and sanitation

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INTRODUCTION

In 2013, the World Health Organization estimated a total of 297,000 deaths attributed to inadequate handwashing, mostly from low-income countries (WHO 2014). Handwashing with soap has been considered one of the most effective ways of reducing infectious diseases (Fewtrell *et al.* 2005; Luby *et al.* 2005; Cairncross & Valdmanis 2006).

Handwashing has been promoted in Bangladesh and elsewhere (WHO 2014; UNICEF 2015) for the prevention

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of infections. But the practice is still infrequent among adults (Curtis *et al.* 2009; Halder *et al.* 2010; Luby *et al.* 2010) and children (Luby *et al.* 2005; Bowen *et al.* 2007; UNICEF 2012) around the globe (Curtis *et al.* 2009; Freeman *et al.* 2014). A UNICEF report showed that only 6% of children in Bangladesh schools observed washing their hands with soap after defecation and before eating (UNICEF 2012). Similar results were found in the Bangladesh National Hygiene Baseline Survey (icddr 2014), which showed that only 11% of school children reported handwashing with soap. The identification of potential barriers to handwashing behavior is important to improve adherence.

Handwashing is a complex behavior made up of several steps (Jumaa 2005; The Joint Commission Mission 2009; Friedrich *et al.* 2017). The Centers for Disease Control and Prevention (CDC) recommends five steps as part of the handwashing process (CDC 2014); WHO (WHO 2015) and UNICEF (UNICEF 2015) recommend 10–11 steps. Researchers evaluating the effects of handwashing interventions have also used various levels of complexity in the steps for the promotion of handwashing at the community level (Fuls *et al.* 2008; Luby *et al.* 2009; Pickering *et al.* 2010; Ram *et al.* 2011; Amin *et al.* 2014). The complexity of instructions can impact adherence to recommended health behaviors. For example, studies of patients using antiretroviral therapy for HIV/AIDS have shown that increased complexity in the medication regimen resulted in decreased patient adherence (Stone *et al.* 2001). A 17 country review on adherence to medication suggested that adherence to intake medication increased up to 10% when patients switched from the combination of multiple drugs to simpler single-dose therapy (Hutchins *et al.* 2011).

Several studies have investigated the effects of different regimens of handwashing complexity on microbial hand contamination. A recent community-based microbial handwashing effectiveness observational study in Zimbabwe found that a regimen of wetting hands by dipping into a vessel, using any soap, scrubbing the fingertips, and cleaning under the fingernails significantly lowers the contamination in post-wash hand rinse samples compared to pre-wash (Friedrich *et al.* 2017). The rest of the steps (scrubbing back of the hands, scrubbing between fingers, and scrubbing for >20 s) did not significantly remove *Escherichia coli*. The Zimbabwe study did not compare the bacterial load based on the different handwashing complexity steps. A recent hospital-based hand hygiene study in the United Kingdom found that the WHO-recommended complex six-step hand rubbing technique with alcohol-based handrub was more effective in removing the bacterial load from hands compared to the CDC-recommended simple three-step technique (Reilly *et al.* 2016). Results from the United Kingdom trial contrast with a number of recent trials in high-income countries (Tschudin-Sutter *et al.* 2015; Price *et al.* 2016), which found that the simplified three-step hand rubbing technique was more effective removing bacterial load from hands (median 4.45, IQR 4.04–5.15) compared to the WHO six-step (median 3.91, IQR 3.69–4.62, p 0.021) technique (Tschudin-Sutter *et al.* 2017). Although these studies provide some evidence on the effects of different regimens of handwashing complexity on microbial hand contamination, on different regimens of handwashing complexity, no data are available on how the complexity of regimens affects the handwashing procedures in a community setting.

Barriers to handwashing have been investigated in a number of studies in Bangladesh (Stanton & Clemens 1987; Scott *et al.* 2007; Nizame *et al.* 2013; Amin *et al.* 2014), but no study has been conducted to assess the impact of handwashing instruction complexity for handwashing procedure replication on the behavior at the community level. In a low-income urban area in Dhaka, Bangladesh, we conducted a randomized non-inferiority field trial among mothers of young children and children aged 5–10 years to evaluate whether increasingly complex handwashing instructions reduced handwashing procedure replication. We also assessed whether the complexity of handwashing instructions affected the ability of respondents to recall recommended times to wash hands.

METHODS

A non-inferiority trial aims to demonstrate that the test product is not worse than the comparator by more than a small pre-specified amount (Ricci 2010). For this study, we defined a non-inferiority trial to determine whether moderate and/or complex handwashing instructions (a new treatment) result in compliance with handwashing procedure replication that is not worse than simple handwashing

instructions (the reference treatment) by more than an acceptable amount (Piaggio *et al.* 2012). This amount is known as the non-inferiority margin or delta. There was no prior information on the specific topic of the complexity of handwashing instruction and handwashing behavior, and we assumed that moderate and/or complex handwashing instructions were 25% less adheres compared to simple handwashing instructions. For this study, we defined handwashing procedure replication as the demonstration of the full set of prescribed instructions provided to the respondents after baseline data collection.

Study site

We conducted this study from July to October 2010 in the Jafrabad area of Dhaka, a densely populated low-income area where people live in compounds containing multiple households (BBS 2001), and where the incidence of cholera is high (incidence rate of 1.64 per 1,000) (Chowdhury *et al.* 2011; Paul *et al.* 2016).

Enrolment of the study population

Fieldworkers surveyed all compounds in the Jafrabad area and prepared a line-list of 346 compounds. They then enrolled all compounds having more than four households ($N = 309$ compounds) to maximize the likelihood that at least one eligible respondent would be identified in each compound. Using a Microsoft Excel random number generator, one of the investigators (DS) assigned 103 compounds each (from the 309 selected compounds) to one of three handwashing complexity instruction sequences: simple (three steps: wet hands with water, apply soap and produce lather, and rinse both hands), moderate (six steps: wet hands with water, apply soap and produce lather, scrub palms of hands, scrub back of hands, rinsed both hands, and dry hands by waving in the air), or complex (nine steps: wet hands with water, apply soap and produce lather, scrub palms of hands, scrub back of hands, scrub between fingers, clean under fingernails, scrub for at least 20 s rinse both hands, and dry hands by waving in the air) (Figure 1).

Caregivers were considered eligible if they had a child <2 years old or a child 5–10 years old (Figure S1, available with the online version of this paper). Mothers of children <2 years old were selected because they are the group to which handwashing is most often promoted. We chose to interview mothers of older children because the primary school age (5–10 years old) is considered an optimal time to promote new behaviors and since children at this age are expected to take responsibility for their own handwashing. (Dutton *et al.* 2011; WSP 2015) (all data relevant to children 5–10 years old are shown in the online Supplementary Appendix). Fieldworkers performed systematic random sampling to identify every fourth household of the compound to determine mothers and children meeting the eligibility criteria. In brief, one fieldworker entered the assigned compound and began at the first household on the left of the main compound entrance. At the fourth household counting in a clockwise direction, the fieldworker attempted to recruit a study participant. If no eligible mother was available, the fieldworker continued in a clockwise direction one household at a time until an eligible mother was recruited. After recruiting one mother in that compound, the data collector proceeded to the next compound to recruit another mother in the same manner.

Data collection and intervention delivery

The fieldworkers used a survey questionnaire to collect baseline data on household demographics, current water and sanitation-related knowledge and reported practices, asked them to perform a demonstration of usual handwashing behavior after defecation including hand drying, then recorded knowledge of recommended times to wash hands.

Once baseline data were collected, the fieldworker used a pictorial cue card for all groups to promote recommended times to wash hands (before preparing food, before eating, after defecation, and after cleaning a child's anus) (Figure S2, available online). Using a second cue card (simple or moderate or complex handwashing instruction), the fieldworker thoroughly explained the instructions for how to wash hands based on the complexity level to which the household was assigned (Figure 1).

Handwashing demonstrations were conducted separately with children and their mothers during the intervention. Both of the instructions were provided once (during the initial visit), and no visual or verbal reminders were provided after the initial visit. Instructions ranged from 20 s to 3 min (simple to complex). For the complex group, to count the 20 s scrubbing

Figure 1 | Handwashing cue cards on three instruction sets during the intervention at Mohammadpur, Dhaka, Bangladesh, 2010.

time, a familiar song was selected by the research team to be sung while washing hands by the participants. The song was simply a widely known and popular song (like Happy Birthday to You … in the USA) that contains no content about handwashing, but only allowed a sense of timing.

Immediately after presenting the instructions, fieldworkers asked the participants to demonstrate handwashing behavior and then recorded which steps were demonstrated. The fieldworkers recorded all handwashing steps demonstrated prior to the intervention, immediately after the intervention, 'immediate visits', after 2 days, and after 2 weeks of intervention.

Recommended times to wash hands is a companion instruction to the handwashing set on how to wash hands: when to wash hands. Handwashing behavior at these key times is important to potentially prevent the transmission of pathogens to a new host (Luby *et al.* 2011; CDC 2016). We wanted to evaluate whether the increased number of steps in the complex group would alter recall of the information on when to wash hands. Thus, the respondent was asked to recall the recommended times at which hands should be washed with soap and demonstrate/show how to wash hands.

We evaluated whether the complexity of the recommended handwashing steps affected immediate handwashing procedure replication and recall of key times for handwashing immediately following the intervention, compared to baseline. Similar information was collected after 2 days and 2 weeks of intervention using the same methods in order to assess whether the time since intervention might affect the ability to reproduce the recommended handwashing steps and recall of key times to wash hands.

Recruitment took place from 25 July 2010 until 14 October 2010. Follow-up visits continued until 30 October 2010.

DATA ANALYSIS

To compare demonstrated handwashing practices of mothers between measurement at baseline and endline, we used the paired *t*-test. Since we measured the practices of one mother from each compound, we did not account for clustering. We also used the paired *t*-test to compare compliance to recommended handwashing times of mothers between measurement at baseline and endline. For children, we compared demonstrated handwashing practices between baseline and endline using a generalized linear model adjusting for pair matching. Since we measured the practices of more than one child from the same compound, we adjusted standard errors to account for clustering at the compound level.

ETHICS

Written informed consent was obtained from parents and assent was obtained from the children. Ethical approval was obtained by the Research and Ethical Review Committees of icddr,b and by the Social and Behavioral Sciences Institutional Review Board of the University at Buffalo.

RESULTS

Baseline characteristics of the participants

From the enrolled compounds, the fieldworkers re-enrolled 236 households in the simple group, 234 households in the moderate group and 241 households in the complex instruction group. Among the enrolled households, 92 mothers and 144 children were randomly assigned to the simple group, 80 mothers and 154 children in the moderate group; and 89 mothers and 152 children in the complex group (Figure S1). Mean ages of mothers and children were comparable across the groups (about 25 years for mothers and 7.5 years for children). The mean number of persons per household was 4.5 across groups. All intervention households (100%) had access to latrine facilities and among them, only 2–6% of households had access to a private latrine in their premises across the groups. Overall, more than 99% of households had access to municipal piped supplied water, and among them, only 7–15% sources were household private taps across the groups. Most of the household (95%) had access to water at the handwashing station but only 25–33% had soap across the groups. On average, only 13–17% of households had soap inside their latrine across the group, and the mean distances between handwashing station and latrines were between four and five paces. Almost all (99%) of the households had access to drinking water within the compound, and most of them were connected through piped water into a shared facility (Table 1).

Handwashing procedure replication by mothers

At baseline before the intervention, compliance to simple instructions was similar (wet hands with water = 100%, apply soap and produce lather 63–66%, and rinse hands thoroughly = 100%) across the intervention groups. Compliance to moderate and complex instructions was consistent across the intervention groups at baseline except for the step denoting air drying of hands (‘dried hands in the air’; the simple group 11%, the moderate group 15%, and in the complex group only 5%) (Table 2).

After the intervention, all mothers in simple, moderate, and complex instruction groups were able to reproduce all three handwashing steps provided in the simple instruction set. Out of six handwashing steps in the moderate instruction set, all (100%) mothers were able to reproduce four steps after the intervention (wet hands with water, apply soap and produce lather, scrub palms of hands, and rinse hands

Table 1 | Households characteristics at baseline among caregivers of young children and children between the age 5–10 years at Mohammadpur, Dhaka, Bangladesh, 2010

	Caregivers			Children		
Characteristics	**Simple** ***N*** **= 85**	**Moderate** ***N*** **= 75**	**Complex** ***N*** **= 84**	**Simple** ***N*** **= 134**	**Moderate** ***N*** **= 148**	**Complex** ***N*** **= 147**
Mean age (SD)	25 (6)	25 (6)	24 (6)	7 (1)	8 (2)	7 (2)
Gender (female) (%)	98	99	98	60	51	53
Years of education completed by the respondent (SD)	4 (3)	5 (4)	5 (3)	1 (1)	1 (1)	1 (1)
Years of education completed by the household head (SD)	5 (4)	5 (4)	5 (4)	5 (4)	4 (4)	5 (9)
Mean household size[a] (SD)	4 (1)	4 (2)	4 (1)	5 (1)	5 (2)	5 (2)
Main source of drinking water, *n* (%)						
Piped water connected through the shared handpump	62 (73)	46 (62)	55 (65)	102 (76)	84 (57)	104 (71)
Piped water into dwelling/private tap	7 (8)	6 (8)	8 (10)	12 (9)	22 (15)	10 (7)
Piped water into yard/compound	16 (19)	22 (29)	20 (24)	20 (15)	39 (26)	31 (21)
Other	0	1 (1)	1 (1)	0	3 (2)	2 (1)
Sanitation practice						
Access to any type of latrine facility	85 (100)	75 (100)	84 (100)	134 (100)	148 (100)	147 (100)
Types of latrine facilities used by the households						
Private	3 (4)	4 (5)	5 (6)	3 (2)	5 (3)	7 (5)
Shared	72 (96)	70 (94)	79 (94)	129 (96)	141 (96)	140 (95)
Public	0	1 (1)	0	2 (2)	2 (1)	0
Types of latrine facilities used by the households						
Flush or pour flush toilet to the piped sewer system	82 (96)	73 (97)	79 (94)	130 (97)	145 (98)	142 (100)
Flush or pour flush toilet to open drain/canal	2 (2)	2 (3)	5 (6)	4 (3)	3 (2)	5 (3)
Pit latrine with slab and no water seal	1 (1)	0	0	0	0	0
Mean number of households used one toilet (SD)	6 (1)	7 (1)	7 (1)	7 (6)	7 (6)	7 (5)
Presence of soap inside the toilet, *n* (%)	11 (13)	12 (16)	15 (18)	17 (13)	24 (16)	20 (14)
Mean distance between handwashing station and cooking area, paces (SD)	11 (9)	11 (8)	10 (7)	10 (9)	10 (8)	11 (8)
Mean distance between handwashing station and latrine, paces (SD)	5 (5)	5 (6)	5 (5)	5 (3)	4 (4)	4 (5)
Types of cleansing agent present at handwashing station, *n* (%)						
Only water	81 (95)	72 (96)	81(96)	128 (95)	141 (95)	139 (95)
Water and bar soap	23 (27)	23 (31)	28 (33)	37 (28)	37 (25)	40 (27)
Water and other cleansing agents[b]	4 (5)	3 (4)	4 (5)	9 (7)	8 (5)	8 (5)
Mean weight (g) of bar soap (SD)[c]	50 (33)	48 (44)	51 (34)	49 (32)	48 (36)	49 (34)
Mean time (s) to bring soap to station (SD)	14 (12)	11 (8)	12 (9)	13 (11)	12 (8)	12 (9)
Best materials reported to wash hands (water and soap) (%)	89	84	94	94	92	89

[a]Based on how many people eat from the same cooking pot.
[b]Detergent/liquid soap, ash or mud.
[c]Weight of regular bar soap used 75–125 g.

thoroughly) in all three intervention groups. Scrubbing the back of hands and air drying hands also increased after the intervention [the proportional difference between baseline and endline for scrubbing back of the hand = 21 ($p < 0.001$) and for hands dried in the air = 32 ($p \leq 0.001$)]. Among the nine complex handwashing instruction steps, all (100%) mothers able to reproduce five steps after the intervention (wet hands with water, apply soap and produce lather, scrub palms and back of the hands, and rinse hands thoroughly). Scrubbing the back of hands, scrubbing between

Table 2 | Evaluation of demonstrated handwashing practice of mothers assigned to simple, moderate, and complex handwashing instructions at Mohammadpur, Dhaka, Bangladesh, 2010

	Instruction groups								
	Simple			Moderate			Complex		
Handwashing steps	Baseline N=85 n (%)	Endline N=84 n (%)	Differences‡ %	Baseline N=75 n (%)	Endline N=75 n (%)	Differences‡ %	Baseline N=84 n (%)	Endline N=83 n (%)	Differences‡ %
Simple Instructions									
Wet hands with water	85 (100)	84 (100)	0	75 (100)	75 (100)	0	84 (100)	83 (100)	0
Apply soap and produce lather	56 (66)	84 (100)	34*	51 (68)	75 (100)	32*	53 (63)	83 (100)	37*
Rinse hands thoroughly	85 (100)	84 (100)	0	75 (100)	75 (100)	0	84 (100)	83 (100)	0
Moderate Instructions									
Wet hands with water	85 (100)	84 (100)	0	75 (100)	75 (100)	0	84 (100)	83 (100)	0
Apply soap and produce lather	56 (66)	84 (100)	34*	51 (68)	75 (100)	32*	53 (63)	83 (100)	37*
Rinse hands thoroughly	85 (100)	84 (100)	0	75 (100)	75 (100)	0	84 (100)	83 (100)	0
Scrub palms of hands	85 (100)	84 (100)	0	75 (100)	75 (100)	0	84 (100)	83 (100)	0
Scrub back of hands	46 (54)	78 (93)	38*	50 (67)	66 (88)	21*	55 (65)	83 (100)	34*
Dried hands in the air	9 (11)	22 (26)	17†	11 (15)	35 (47)	32*	4 (5)	32 (38)	34*
Complex instructions									
Wet hands with water	85 (100)	84 (100)	0	75 (100)	75 (100)	0	84 (100)	83 (100)	0
Apply soap and produce lather	56 (66)	84 (100)	34*	51 (68)	75 (100)	32*	53 (63)	83 (100)	37*
Rinse hands thoroughly	85 (100)	84 (100)	0	75 (100)	75 (100)	0	84 (100)	83 (100)	0
Scrub palms of hands	85 (100)		0	75 (100)	75 (100)	0	84 (100)	83 (100)	0
Scrub back of hands	46 (54)	84 (100)	38*	50 (67)	66 (88)	21*	55 (65)	83 (100)	34*
Dried hands in the air	9 (11)	22 (26)	17†	11 (15)	35 (47)	32*	4 (5)	32 (38)	34*
Scrub between fingers	12 (18)	45 (53)	36*	16 (21)	47 (63)	41*	19 (23)	80 (96)	73*
Clean under finger nails	2 (2)	16 (19)	18*	5 (7)	17 (23)	16*	7 (8)	66 (79)	71*
Scrub for at least 20 sec	14 (16)	50 (59)	43*	23 (31)	50 (67)	36*	25 (30)	74 (89)	60*

* Proportion differences are statistically significant with P-value <0.001

† Proportion differences are statistically significant with P-value <0.005‡ Differences between handwashing procedure replication measured at baseline and after two weeks of intervention (endline)

Actual intervention received

fingers, scrubbing for 20 s, cleaning under the finger nails and drying hands in the air also increased after the intervention [proportional difference for scrubbing back of the hand = 34 ($p < 0.001$), scrubbing between fingers = 73 ($p < 0.001$), scrubbing for 20 s = 60 ($p < 0.001$), cleaning under the fingernails = 71 ($p < 0.001$), and for drying hands in the air = 34 ($p \leq 0.001$)] (Table 2).

Overall, air drying of hands was least memorized to across all intervention groups after the intervention compared to other steps (in the simple group 26%, in the moderate group 47%, and in the complex group 38%). Cleaning under fingernails was more frequently memorized to in the complex group (79%) compared to the simple (19%) and moderate groups (23%) after the intervention (Table 2).

The mean duration of mothers scrubbing hands was 18 s at baseline. The mean duration increased in all the groups after the intervention: 22 s in simple, 26 s in moderate and 31 s in complex groups. On average, 80% of mothers dried hands at baseline and among them, 11% dried hands by waving in the air, 48% used their own clothing, and 16.5% used cloths other than clothing for drying. After the intervention, an average 92% of mothers dried hands and among them, 47% dried hands in the air, 24% used their own clothing, and 23% used cloths other than clothing (Table S1, available with the online version of this paper).

When we evaluated handwashing procedure replication to the moderate and complex instruction sets without inclusion of the air drying step, 88–98% of mothers in the

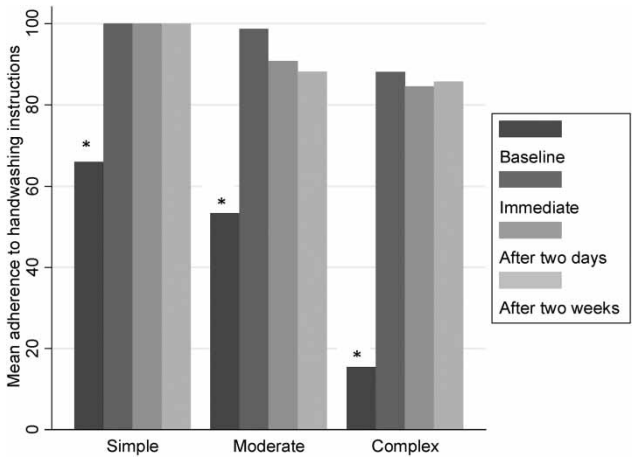

Figure 2 | Compliance with handwashing procedure replication (Handwashing procedure replication was defined as the ability to reproduce the full set of prescribed instructions provided to the respondents after the baseline data collection.) to handwashing instructions in different instruction sets and in different time periods without air drying among the mothers at Mohammadpur, Dhaka, Bangladesh, 2010. *There was a significant increase in handwashing adherences after the intervention in all follow-up visits compared to the baseline.

moderate group recalled all instructions included in the moderate sets; 84–88% of mothers in the complex group recalled all instructions included in the complex set during three follow-up assessments (Figure 2).

Recall of recommended times to wash hands with increased instruction complexity

At baseline, about 75% of mothers in all three instruction sets identified 'before eating' and 'after defecation' as times at which they should wash hands with soap. About 30% recalled 'before preparing food' and less than 30% noted 'after cleaning a child's anus' as times to wash hands. Among four recommended handwashing key times, recall of three handwashing key times (before preparing food, before eating, and after cleaning child's anus) were significantly increased in simple and moderate groups after the intervention compared to baseline. Recall of all four handwashing key times was increased among the mothers from the complex group [proportional differences: before preparing food = 57 ($p < 0.001$), before eating = 25 ($p \leq 0.001$), after cleaning child's anus = 50 ($p < 0.001$) and after defecatio $n = 16$ ($p < 0.005$)] (Table 3).

Effects of instruction complexity on recall to handwashing complexity and recall of recommended times to wash hands were similar among children as among mothers (Supplementary Information, available online).

DISCUSSION

Increasingly complex handwashing instructions did not reduce the ability of mothers of young children or children aged 5–10 years to reproduce the full set of instructions prescribed to them, or the recall of recommended times for handwashing. Our study evaluated the recall of prescribed handwashing instructions for 2-week time periods. Although most of the respondents reproduced complex instructions (except hand drying (38%)) during handwashing

Table 3 | Compliance with handwashing procedure replication to four recommended handwashing times among the mothers in different intervention groups at Mohammadpur, Dhaka, Bangladesh, 2010

	Instruction groups								
	Simple			Moderate			Complex		
Handwashing steps	Baseline $N = 85$ n (%)	Endline $N = 84$ n (%)	Differences[a] %	Baseline $N = 75$ n (%)	Endline $N = 75$ n (%)	Differences[a] %	Baseline $N = 84$ n (%)	Endline $N = 83$ n (%)	Differences[a] %
Before preparing food	29 (34)	79 (93)	59[b]	21 (28)	72 (96)	68[b]	28 (33)	76 (90)	57[b]
Before eating	63 (74)	81 (95)	21[b]	58 (77)	74 (99)	22[b]	61 (73)	82 (98)	25[b]
After cleaning child's anus	24 (28)	74 (87)	59[b]	16 (21)	62 (83)	62[b]	21 (25)	65 (77)	52[b]
After defecation	66 (78)	79 (93)	15 (0.006)	57 (76)	66 (88)	12 (0.056)	65 (77)	78 (93)	16[c]

[a]Differences between handwashing procedure replication measured at baseline and after 2 weeks of intervention (endline).
[b]Proportion differences are statistically significant with P-value <0.001.
[c]Proportion differences are statistically significant with P-value <0.005.

demonstrations after 2 weeks of intervention, this short-term recall may or may not be maintained or translated into improved handwashing practice. Memorizing multiple items for a short duration engages working memory (Baddeley & Hitch 1974), and such information may only be held temporarily in the brain (Miyake & Shah 1999). Working memory does not store larger amounts of information (i.e., six or nine handwashing steps) as effectively and may not translate this information into long-term memory (Baddeley 2003). Studies have also suggested that it is easy to hold fewer than seven items in the brain, but once it reaches seven and beyond, it becomes difficult for the respondents to recall (Miller 1956; Saaty & Ozdemir 2003). In our study, we used three handwashing regimens based on those used in public health communications: a simple (three-item) list is easy to remember; a moderate (six-item) list, and a complex (nine-item) list. The simple three-item list may have been more easily retained in short-term memory and with repetition this memory may translate into routine handwashing practice. But when presented with the nine-item list, participants might have difficulty retaining the nine items in their short-term memory. There is sparse literature on the effects of different levels of regimen complexity on hand contamination. A recent hospital-based randomized hand hygiene study in the United Kingdom found that the WHO-recommended complex six-step hand rubbing technique with alcohol-based handrub was more effective in removing the bacterial load from hands compared to the CDC-recommended simple three-step technique (Reilly *et al.* 2016).

One approach to overcome the complexity associated with increasingly complex six- or nine-step regimens might be 'chunking' or grouping multiple items (Neath & Surprenant 2003). For example, the complex set of handwashing instructions we used in this study (nine-item) could be chunked into three groups of steps: Group 1: lathering; Group 2: scrubbing; and Group 3: rinsing and drying. The chunking strategy may facilitate retention in short-term memory and transfer to working memory (Curtis *et al.* 2017). These chunk groups are repeated over and over through long-term interventions until all the relevant neural systems work together to automatically produce these handwashing steps and to transfer the information into long-term memory (Butler 2010; Karpicke 2016).

Much of the low compliance to moderate and complex instructions is due to the low recall to a single step, air drying of hands (46% in both groups). This result is consistent with a community-based handwashing evaluation in rural Bangladesh, which found that, during observation, only 22% of the women dried their hands in the air (Hoque 2003). A qualitative study in Kenya also suggested that most of the women either do not dry their hands or if they do, generally dry them on their own clothing (Person *et al.* 2013).

Since hand drying in the air is infrequently practiced in Bangladesh and elsewhere, we should consider how important it is to retain this instruction in order to ensure that hands are microbiologically clean. A hand-drying comparison study conducted in the United States evaluated the ability of four different drying methods (cloth towels, paper towels, warm forced air from hand dryer, and spontaneous room air evaporation) to prevent recontamination during the drying process from washed hands, but did not find significant differences between the four hand-drying methods (Gustafson *et al.* 2000). A recent hospital-based handwashing study in the United Kingdom suggested that hand drying with a paper towel more effectively prevents microbial recontamination compared to using an electric air-dryer (Best Parnell & Wilcox 2014). A further study suggested that air drying might facilitate microbial cross-contamination (Huang *et al.* 2012). In addition, hand drying with air takes more time than using a paper towel and may lead to increased contact time between the micro-organism and wet hands (Patrick *et al.* 1997; Merry *et al.* 2001). Mothers in urban communities in Bangladesh already spend substantial time carrying out household tasks (Hanchett *et al.* 2003; Person *et al.* 2013) and might be unwilling to spend the additional time for drying hands by waving in the air. Our data suggested that the respondents practiced hand drying using their own clothing, as found previously (Hoque 2003). Hand drying with cloths increased during follow-up visits (12% at baseline and 20% at follow-up visits) even though this step was not promoted by the field-workers. A recent community-based study in Zimbabwe found that drying hands by rubbing on clothes or a clean towel significantly reduced *E. coli* contamination of hands after washing (Friedrich *et al.* 2017). Thus, there may be minimal benefits realized by promoting a specific air-drying step

for handwashing. Future community-based handwashing interventions should evaluate the effect of using clean clothing for hand drying for better handwashing compliances and improved hand hygiene.

There are important limitations to this study. First, we used supervised handwashing regimens with pre-specified handwashing techniques (Hoque *et al.* 1995) and measured the ability to recall prescribed handwashing instructions. The community members may not practice all nine complex handwashing steps in practice, when not observed directly, even though they demonstrate the handwashing steps to the fieldworkers. Observation and self-reported data generally exaggerate socially desirable behaviors, which may bias the results (Danquah 2010; Ram 2013). Secondly, our study was conducted in an urban slum of Dhaka, and results from this study may not take into account contexts in other settings; we have not explored locations with different water and soap availability found to impact handwashing behavior (Halder *et al.* 2010). Our study did not explore the association between individual household facilities and handwashing behavior that other studies in Bangladesh have evaluated (Luby & Halder 2008; Rabbi & Dey 2013). We found that handwashing facilities (presence of handwashing station = 95–96%, any soap and water together = 30–44%) (Table 1) in our study area were similar to the nationally represented data (presence of handwashing station = 82%, any soap and water together = 40%). The study area we selected represents other low-income communities of Dhaka only, and our results may not be applicable to other settings. Field studies in other settings could validate these results. Third, our study did not evaluate overall handwashing behaviors but a demonstration of different handwashing steps and recall of key times to wash hands among a low-income urban neighborhood of Dhaka city. Our result provides insight on the degree of the complexity of handwashing instructions that can feasibly be included in interventions. There are numerous physical and psychosocial drivers of behavior; knowledge of how to wash hands is only one of them (globalhandwashing.org 2018). This may ultimately help us to understand the ability of community members to adhere to hand hygiene when provided with different instruction sets, but does not address other important behavioral, contextual, or psychological aspects of handwashing (WaterAid 2016). Finally, the study was conducted nearly a decade ago, but we believe that the results of this study are still relevant. Our results point to potential limitations of complex handwashing instructions in community settings, and which step(s) of complex and moderately complex handwashing instructions should be accentuated more during the handwashing promotions for better adherence. Even though there has been some work on microbiological effectiveness of different handwashing regimens in low-income settings (Amin *et al.* 2014; Friedrich *et al.* 2017; Tschudin-Sutter *et al.* 2017), there are no data available during the period between the data collection and this publication that address the relationship between the handwashing instruction complexity and the handwashing procedure replication or recall of key times.

Changing handwashing behavior is complex and depends on many factors including the availability and affordability of handwashing products, shame and disgust feelings of an individual, motivation, emotion and habit in the light of emerging developments in psychology, anthropology, and marketing (Curtis *et al.* 2009). Our study concluded that simple handwashing steps are easier to remember for long time periods compared to complex steps. Complex handwashing instructions, such as those suggested by UNICEF (2015), may not be achieved (Reilly *et al.* 2016). It is important to continue to improve our understanding of the drivers of handwashing behavior (Biran *et al.* 2014) to achieve better handwashing compliances and improved hand hygiene.

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