Combining Environmental Microbiology and Health Psychology to Promote Effective Handwashing

Dissertation
der Mathematisch-Naturwissenschaftlichen Fakultät
der Eberhard Karls Universität Tübingen
zur Erlangung des Grades eines
Doktors der Naturwissenschaften
(Dr. rer. nat.)

vorgelegt von
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aus Frankfurt am Main

Tübingen
2016

Gedruckt mit Genehmigung der Mathematisch-Naturwissenschaftlichen Fakultät der Eberhard Karls Universität Tübingen.

Tag der mündlichen Qualifikation:	14.12.2016
Dekan:	Prof. Dr. Wolfgang Rosenstiel
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Zusammenfassung

Händewaschen mit Seife beugt Durchfallerkrankungen vor. Händewaschkampagnen gehören daher zu den häufigsten Maßnahmen zur Durchfallprävention in Entwicklungsländern. Ein Defizit bisheriger Kampagnen besteht in deren unzureichender Evaluierung: Es ist bisher unklar, ob Veränderungen im Verhalten tatsächlich zu Veränderungen der Handkontamination führen. Des Weiteren verfolgten bisherige Kampagnen nicht das Ziel, neben der Häufigkeit auch die Technik des Händewaschens, das heißt die ausgeführten Händewaschschritte, zu verbessern. Wir wissen nicht, welche Händewaschtechnik besonders effektiv ist, um Keime zu entfernen und wie Menschen motiviert und in die Lage versetzt werden können, eine solche Händewaschtechnik in ihrem Alltag tatsächlich anzuwenden. Ziel dieser Dissertation ist es, diese offenen Fragen an Hand einer Fallstudie in Harare, Simbabwe zu untersuchen.

Die Resultate zeigen, dass die Technik des Händewaschens dessen Effektivität beeinflusste. Jedoch waren nur einige der allgemein empfohlenen Händewaschschritte tatsächlich relevant. Die alltägliche Anwendung der empfohlenen Händewaschtechnik wurde von kontextuellen und sozial-kognitiven Verhaltensfaktoren bestimmt. Die durchgeführte Kampagne, die auf die Veränderung dieser Verhaltensfaktoren der Technik und die der Händewaschhäufigkeit zielte, verbesserte beide Dimensionen des Händewaschverhaltens. Jedoch hatte die Kampagne keinen messbaren Einfluss auf die Handkontamination der Teilnehmerinnen.

Die Resultate und Literaturrecherche werden im „Integrated framework for changing handwashing behaviour and hand contamination“ zusammengeführt. Das Framework unterscheidet zwei Dimensionen des Händewaschverhaltens: Technik und Häufigkeit. Es besagt, dass Händewaschkampagnen das Verhalten verändern, indem sie die relevanten Verhaltensfaktoren beeinflussen. Rekontamination aus dem Haushaltsumfeld wird als wichtigster Faktor benannt, welcher der Verringerung der Handkontamination durch Händewaschen entgegen wirkt. Zukünftige Händewaschkampagnen sollten auf Grundlage sozialkognitiver Modelle entwickelt werden und zum Ziel haben, sowohl Händewaschhäufigkeit als auch Händewaschtechnik zu verbessern und Rekontamination zu verringern.

Abstract

Handwashing with soap prevents diarrhoea. Promoting domestic handwashing with soap has been a priority, particularly in developing countries where the disease burden is highest. However, a major shortcoming of existing campaigns is that they have not been evaluated for their effects on both handwashing behaviour and hand contamination. Consequently, it remains unknown whether changing handwashing behaviour actually leads to reductions in hand contamination. Further, most campaigns did not target handwashing technique, how hands are washed. It remains uncertain whether handwashing technique influences handwashing effectiveness in this context. It is also unknown what motivates and enables people to perform effective handwashing technique. To address these knowledge gaps, this thesis reports findings from a case study in Harare, Zimbabwe on the design and evaluation of a theory-based handwashing campaign.

Results show that handwashing technique influences handwashing effectiveness. However, only some of the commonly recommended steps of handwashing technique were found to be relevant. Further, contextual and social-cognitive behavioural factors explain why people perform effective handwashing technique. A campaign targeting these factors and those steering handwashing frequency substantially enhanced both dimensions of handwashing. However, despite effects on behaviour, the campaign did not significantly affect hand contamination.

These findings and the available literature are combined in an *integrated framework for changing handwashing behaviour and hand contamination*. The framework considers two dimensions of handwashing behaviour: technique and frequency. It proposes a causal link from handwashing promotion to hand contamination through changing handwashing behaviour and its behavioural factors. Hand recontamination from the household environment is introduced as an important factor which disrupts the link from handwashing behaviour to hand contamination. Future hand hygiene campaigns should be designed based on social-cognitive theory, promote handwashing frequency and handwashing technique, and reduce hand recontamination.

Acknowledgements

Foremost, I would like to thank Prof Dr Hans-Joachim Mosler and Prof Dr Andreas Kappler. I am most grateful for their open minds in supporting this interdisciplinary project and their constant support and encouragement, which enabled me to complete this thesis. I am grateful to the entire Group of Environmental and Health Psychology at Eawag for their cheerful companionship and frequent discussions and advice during this project. I am particularly grateful to Dr Robert Tobias for his invaluable advice on the survey design and to Dr Elisabeth Seimetz for her close collaboration. I am very grateful to Ina Sonego for her feedback on the draft of this thesis and to Dr Simon Milligan for proofreading it. I would like to cordially thank Drs Frederik Hammes, Philippe Perisset, Ellen Struve, and Karin Stögerer for their support in developing the sampling and laboratory protocols and building the field incubator. I am very grateful to Dr Timothy Julian for his invaluable advice from the beginning of this project.

I am most grateful to Dr Tamuka Nhiwatiwa and his team at the University of Zimbabwe for their fruitful collaboration and support throughout the project. I would like to thank Belladonnah Muzavazi and Eustace Sangoya for their invaluable contributions as field coordinators during the data collection and campaign implementation. I am grateful to Innocent Hove, Friederike Neiske, and Pablo Streich for their dedicated laboratory work and to Marc Binkert, Marcel Lauber, Nadine Romann, and Jurgita Slekiene for their valuable contributions to the data collection. I am most grateful to the dedicated data collection team and all the study participants in Harare who made this data collection possible. I would like to thank the Swiss Agency for Development and Cooperation (SDC) and Eawag for funding this project. I am grateful to Health Services at the City of Harare, Ministry of Primary and Secondary Education of Zimbabwe, health centre staff, and teachers for their collaboration and implementing the campaign. I would like to thank ActionAid Zimbabwe, the Farm Community Trust of Zimbabwe, and the Combined Harare Residence Association for coordinating the campaign implementation and the Swiss Embassy in Harare and ActionAid Zimbabwe for their logistical support.

List of publications

Accepted

Friedrich, M., Julian, T. R., Kappler, A., Nhiwatiwa, T., & Mosler, H.-J. (in press). Handwashing, but how? Microbial effectiveness of existing handwashing practices in high-density suburbs of Harare. *American Journal of Infection Control*.

Friedrich, M., Binkert, M., & Mosler, H.-J. (in press). Contextual and psychosocial determinants of effective handwashing technique: Recommendations for interventions from a case study in Harare, Zimbabwe. *American Journal of Tropical Medicine and Hygiene*.

Submitted

Friedrich, M., Kappler, A., & Mosler, H.-J. (submitted). Enhancing handwashing frequency and technique of primary caregivers in Harare, Zimbabwe: A cluster-randomized controlled trial using behavioural and microbiological outcomes.

Seimetz, E., Slekiene, J., **Friedrich, M.**, & Mosler, H.-J. (submitted). Identifying behavioural determinants for interventions to increase handwashing practices among primary school children in rural Burundi and urban Zimbabwe.

In preparation

Navab-Daneshmand, T., **Friedrich, M.**, Mosler, H.-J., & Julian, T. R. (in preparation). Impact of environmental faecal contamination on hand hygiene in urban Harare.

Personal contribution

The work described in this thesis was mainly financed by the Swiss Agency for Development and Cooperation (SDC). Additional time and material for the campaign evaluation using microbial outcomes was financed by Eawag. The conceptual background of the SDC funded project was designed by Prof Dr Hans-Joachim Mosler, Dr Elisabeth Seimetz, and me. The conceptual background of the Eawag funded project was designed by Prof Dr Hans-Joachim Mosler, Dr Timothy Julian, and me. The concept of this dissertation was designed by Prof Dr Hans-Joachim Mosler, Prof Dr Andreas Kappler, and me.

Chapter 3

Prof Dr Hans-Joachim Mosler, Dr Timothy Julian, Prof Dr Andreas Kappler, and me designed the concept of this paper. Pablo Streich and Innocent Hove, the laboratory assistants during the baseline survey, and I developed the sampling and laboratory protocols. I performed the analyses with frequent feedback from Dr Timothy Julian. I had the lead in writing the paper. Dr Timothy Julian and all co-authors contributed to interpretation of results and writing the paper.

Chapter 4

Prof Dr Hans-Joachim Mosler and I designed the concept of this paper. I, Dr Robert Tobias, and Prof Dr Hans-Joachim Mosler developed the data collection procedure. I supervised the data collection. Marc Binkert performed preliminary analyses on overall handwashing technique. I performed the remaining analyses. I had the lead in writing the paper. All co-authors contributed to interpretation of results and writing the paper.

Chapter 5

All co-authors designed the concept of this paper. I and Prof Dr Hans-Joachim Mosler developed the data collection procedure. I supervised the data collection. I performed the analyses. I had the lead in writing the paper. All co-authors contributed to the interpretation of results and writing the paper.

1 General introduction

Organizations worldwide have promoted handwashing with soap to decrease the global burden of diarrhoeal and respiratory diseases. Large-scale promotion programmes, particularly in low-income countries, have attracted huge funding from private and public sources, but many have failed to change handwashing behaviour. Furthermore, the vast majority of programmes at smaller scale lack comprehensive evaluation. This calls for a new approach to both handwashing promotion and its evaluation.

In recent years, researchers and practitioners have started to apply existing theories of health behaviour change to the promotion of handwashing. The underlying paradigm postulates that protective behaviours such as handwashing as well as harmful behaviours are driven by behavioural factors. In order to change health behaviour, interventions have to change the factors which underlie the behaviour.

The bulk of domestic handwashing campaigns have aimed at increasing the frequency with which people wash hands with soap in key handwashing situations. Even through it has long been acknowledged, for example in healthcare and the food industry, that handwashing technique is a fundamental dimension of hand hygiene, this dimension has so far not been considered in domestic handwashing campaigns. Handwashing technique, that is how people wash their hands, is likely to strongly influence the effectiveness of handwashing in removing germs and pathogens. Improving handwashing technique thus constitutes a promising lever with which to increase the impact of handwashing promotion.

The aims of this thesis are therefore to define effective handwashing technique in low-income settings in developing countries, to apply social-cognitive theory to promote this technique, and to provide evidence of the behaviour change thus triggered and its impact on hand contamination. It is based on theory from both environmental microbiology and health psychology and strives to combine both disciplines so as to inform the future practice and research of handwashing promotion.

This chapter provides a short introduction on why handwashing and its promotion is relevant for public health, reports findings on how handwashing behaviour is related to hand contamination, reviews the available evidence on the behavioural factors steering handwashing, and summarizes previous efforts to promote handwashing in low-income settings in developing countries.

1.1 Handwashing and health

Preventing diarrhoeal diseases has been high on the agendas of both governmental and non-governmental organizations, particularly since the adoption of the Millennium Development Goals (MDGs) in 2000. Despite being both easily preventable and treatable, diarrhoea is among the main reasons globally for the death of children aged less than five years, second only to pneumonia. It is estimated that 1.7 billion episodes of diarrhoea occurred in children under five in 2010, of which 700,000 led to death (Fischer Walker et al., 2013). Diarrhoea is responsible for 17% of child deaths worldwide, which is about double the global number of child deaths from malaria and almost six times the number of child deaths from HIV/AIDS (Rudan, El Arifeen, Black, & Campbell, 2007). Although the incidence of diarrhoea is similar across the world, mortality due to diarrhoeal diseases is highest in low-income countries (Fischer Walker et al., 2013).

The effort to fight diarrhoea and reduce global child mortality depends substantially on prevention (United Nations Children’s Fund & World Health Organisation, 2009). In addition to rotavirus and measles vaccinations, exclusive breast feeding, and vitamin A supplementation, key strategies for diarrhoea prevention include the promotion of handwashing with soap, improved water supply, and sanitation promotion (United Nations Children’s Fund & World Health Organisation, 2009). Particular emphasis has been put on promoting handwashing among caregivers, the individuals who take care of children. The evidence base for the effectiveness of handwashing with soap in preventing diarrhoea is relatively strong. The results of a meta-analysis by Curtis and Cairncross (2003) indicate that promotion of handwashing with soap reduces diarrhoea risk by approximately 43%. More recent evidence provides similar results, although the reduction declines to 23% when adjusting for unblinded studies (Freeman et al., 2014).

Despite its positive impact on health, handwashing with soap is rarely practised. Freeman et al. (2014) estimated that just 19% of the world population wash hands with soap and water after possible contact with faeces. According to estimates by Prüss-Ustün et al. (2014), 297,000 diarrhoea deaths could be prevented yearly by adequate handwashing. The enormous potential of handwashing to prevent diarrhoeal diseases, particularly in developing countries, together with low handwashing rates call for effective handwashing promotion at large scale.

Little is known about the key situations in which domestic handwashing in developing countries is needed, as few studies have linked handwashing with soap in specific situations to health impacts. Luby, Halder, Huda, Unicomb, and Johnston (2011a) found the frequency of handwashing with soap before feeding a child, as self-reported by caregivers, to be related to lower rates of child diarrhoea, while self-reported handwashing at other times, such as after toilet use or before cooking, was not associated with child diarrhoea rates. Another study by Luby, Halder, Huda, Unicomb, and Johnston (2011b) showed a negative relation between frequent handwashing before food preparation and after defecation, as reported by observers, and diarrhoea in children. However, no significant impact was found of frequent observed handwashing before feeding a child on diarrhoea. The limited number of studies and mixed results reveal high uncertainty on exactly when hands should be washed.

In summary, diarrhoea claims hundreds of thousands of lives each year. Promoting handwashing before contact with food and after contact with faeces reduces diarrhoea. However, few people wash hands with soap in those key situations. This calls for effective handwashing promotion at large scale.

1.2 Handwashing and hand contamination

This section summarizes the available evidence regarding the effects of handwashing behaviour on microbial hand contamination. The focus lies on low-income settings in developing countries. Two dimensions of handwashing behaviour are distinguished: handwashing frequency and handwashing technique. The term *handwashing frequency* describes the relative frequency with which people wash hands with soap in key handwashing situations. Key handwashing situations refer to all situations which involve contact with faeces and contact with food. The term *handwashing technique* denotes the number of steps that people take when handwashing. It describes how people wash their hands and is one of the core constructs of this thesis. Two constructs are used to describe microbial hand contamination. *General hand contamination* denotes the contamination of hands with faecal indicator bacteria at random times. *Effectiveness of handwashing* denotes the impact of handwashing on hand contamination directly after washing. Hand contamination is commonly quantified as the decadic logarithm (log_{10}) of the number of detectable colony-forming units of indicator organisms per hand (CFU/hand). Last, the research questions derived from this section are presented.

1.2.1 Handwashing frequency and general hand contamination

Many studies have shown that handwashing with soap decontaminates hands. Overviews of studies conducted in industrialized countries are available in Sickbert-Bennett, Weber, Gergen-Teague, and Rutala (2004) and Kampf and Kramer (2004). Evidence from field studies in developing countries is less abundant. Amin et al. (2014) reported experimental findings from Bangladesh that washing hands with bar soap reduced hand contamination with thermotolerant coliforms by 0.6 log_{10} CFU/hand on average. In contrast, washing hands with water alone achieved mean log reductions of only 0.3 log_{10} CFU/hand. Pickering, Boehm, Mwanjali, and Davis (2010) found handwashing with soap to reduce hand contamination of *Escherichia coli* (*E. coli)* and faecal streptococci by 0.7 log_{10} CFU/hand and 0.6 log_{10} CFU /hand respectively.

It seems intuitive that the more frequently hands are washed in key handwashing situations, the less contaminated they are throughout daily life. However, the effects of frequent handwashing on general hand contamination are limited. Recontamination of hands to pre-wash levels after only 1 hour has been reported by Devamani, Norman, and Schmidt (2014). Results from a field experiment conducted by Ram et al. (2011) reported recontamination of all study participants' hands after 2 hours and did not find any correlation between general hand contamination and observed frequency of handwashing of the participants. This contrasts with longitudinal findings which are discussed in Section 1.4.3.

In summary, frequent handwashing with soap in key handwashing situations reduces hand contamination. However, frequent handwashing has not been found to be related to general hand contamination measured at random times. Recontamination of hands from the environment is likely to counter the effects of handwashing quickly.

1.2.2 Handwashing technique and handwashing effectiveness

The previous sections have argued that handwashing with soap decontaminates hands and that less contaminated hands lead to lower diarrhoea rates. However, handwashing technique may also be of great relevance for effective hand decontamination.

The Centers for Disease Control (CDC) and the World Health Organization (WHO) provide recommendations for effective handwashing technique in healthcare settings (Centers for Disease Control and Prevention, 2002; World Health Organisation, 2009). For domestic handwashing, the CDC (Centers for Disease Control and Prevention, n.d.) recommends five 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 together with the soap. Be sure to lather 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.

The following paragraphs review the evidence base for the effectiveness of each of these steps. In addition, the practicability of the steps in low-income settings in developing countries is discussed. The effectiveness of soap use has already been discussed in the previous section.

Use of clean running water

The available literature provides no evidence that use of running water from a tap per se results in more effective handwashing than manually rinsing and moistening hands with stored water. However, there is some evidence that the volume and quality of handwashing water influences handwashing effectiveness. Hoque, Mahalanabis, Alam, and Islam (1995) reported that women who washed hands with more water (2 l as compared to 0.5 l) had significantly fewer faecal coliform bacteria on hands after washing. Similarly, Mattioli et al. (2014) found that increased water volume used for handwashing was associated with lower likelihood of enteric virus markers on hands. In addition to water volume, water quality may influence subsequent microbial contamination on hands. A study in Bangladesh showed that washing hands with highly contaminated pond water led to higher faecal coliform contamination on hands after washing than using less contaminated tube-well water (Hoque, Mahalanabis, Alam, et al., 1995).

Handscrubbing

The effectiveness of specific scrubbing steps has not been investigated, to the best of my knowledge. On the effect of scrubbing time, Amin et al. (2014) found no statistically significant differences between study participants who scrubbed hands for 15 seconds or 30 seconds with either soapy water or bar soap. This is supported by laboratory studies that found no statistically significant differences between scrubbing hands with plain soap for 10 or 15 seconds compared to 30 seconds (Fuls et al., 2008; Lucet et al., 2002).

Hand-drying

There is evidence that how hands are dried affects subsequent contamination. Findings from Bangladesh showed that drying hands on the clothes being worn led to significantly more contamination than not drying hands. In contrast, drying hands on a clean piece of cloth did not lead to higher contamination (Hoque, Mahalanabis, Alam, et al., 1995). Gil et al. (2014) found kitchen cloths to be the most contaminated item in the kitchens of rural households in Peru. In consequence, the risk of contamination through cloths may be high. Luby et al. (2011a) found that children living in households where hand-drying with a clean towel or air was observed had lower rates of diarrhoea, although the effect was not statistically significant.

Practicability

Recommended handwashing technique must also be practicable if it is actually to be performed. Various authors have raised doubts about whether complex handwashing recommendations, in particular those including a minimum scrubbing time, are practicable during daily routines (Bloomfield, Aiello, Cookson, O'Boyle, & Larson, 2007; Conover & Gibson, 2016). The preconditions for washing hands as recommended by the CDC, such as availability of water from a tap, soap, and a clean towel, are often not met in developing countries (Sandhu & Goodnight, 2014). In addition, local customs may suggest different handwashing procedures. In Zimbabwe, for instance, hands are traditionally moistened and rinsed in a bowl of water (Kaltenthaler, Waterman, & Cross, 1991).

1.2.3 Interrelation of handwashing frequency and technique

Handwashing frequency and handwashing technique constitute two dimensions of the same behaviour, and their impact is likely to be interdependent. Without the right technique, even frequent handwashing would not effectively decontaminate hands. Conversely, effective handwashing technique is unlikely to have a strong impact if infrequently practised. A study conducted in rural India looked at the interrelation of handwashing technique and handwashing frequency in adolescents and found that they were correlated (Dobe et al., 2013). Participants who washed hands more frequently also washed them with better technique. However, this is the only study available on this topic.

1.2.4 Research questions

In summary, recommendations for effective handwashing technique are only partly substantiated in the context of domestic handwashing in developing countries. There are considerable gaps in our understanding of both the effectiveness and the practicability of recommended handwashing technique. This leads to the first research question of this thesis: Which handwashing technique is (a) effective in decontaminating hands and (b) practicable in low-income settings in developing countries?

In addition, it remains uncertain how handwashing technique and handwashing frequency are interrelated. This leads to the second research question of this thesis: Are handwashing frequency and handwashing technique interrelated?

Similarly, the interrelation of handwashing effectiveness (the hand contamination directly after washing) and general hand contamination (the hand contamination at random times) remains uncertain, as this was not assessed in any of the literature reviewed. This leads to a third research question: Are general hand contamination and handwashing effectiveness interrelated?

1.3 Behavioural factors steering handwashing

The sections above have discussed different dimensions of handwashing behaviour and their impact on hand contamination. Building on that, this section reviews the existing evidence on what motivates and drives individuals to perform those behaviours and which processes could prompt new engagement in them. First, a selection of theories is introduced; these constitute the theoretical foundation of the risks, attitudes norms, abilities, and self-regulation (RANAS) approach (Mosler, 2012; Mosler & Contzen, 2016) applied in this thesis. Second, a summary is made of the available evidence on the behavioural factors which steer frequent handwashing with soap. The term *behavioural factors* is used as an umbrella term which includes both social-cognitive factors and contextual factors. Third, the available, though very limited, literature on the behavioural factors steering handwashing technique is reviewed. Last, the research question derived from this section is presented.

1.3.1 Social-cognitive theories of health behaviours and behaviour change

A leading paradigm for explaining and changing health behaviours is the social cognition approach. It postulates that the behaviour of an individual is driven rather by the individual's subjective view of reality than by an objective perspective on the actual reality (Conner & Norman, 2005). Consequently, researchers have developed social cognition models which postulate that behaviour is driven by specific social-cognitive factors. In health psychology, such factors comprise, for example, the health threat that is perceived to be associated with a behaviour, such as the perceived likelihood of contracting diarrhoea. In contrast to contextual factors such as gender, age, laws and regulations, and personality, which are likely determinants of behaviour too, social-cognitive factors are assumed to be more open to change (Conner & Norman, 2005). In addition, social-cognitive factors are assumed to mediate the effect of other more behaviour-distal factors (Conner & Norman, 2005). This makes the social cognition approach highly relevant for behaviour change. As Michie, Johnston, Francis, Hardeman, and Eccles (2008) proposed, behaviour change interventions are likely to be more effective if they target the causal determinants of behaviour. This means that the behaviour-steering social-cognitive factors have to be changed to change behaviour.

The social cognition approach has been criticized for neglecting other relevant factors, such as personality of individuals or emotional reactions (Conner & Norman, 2005). Further, most models are restricted to explaining how intentions are formed and few (e.g. Prochaska & DiClemente, 1983; Schwarzer, 2008) consider the volitional processes that transform intentions into goals and actions. However, volitional processes such as planning are highly relevant for behaviour change (Gollwitzer, 1999). Last, many models do not specify how social-cognitive factors can be manipulated to achieve behaviour changes.

Nevertheless, the social cognition approach has been widely applied to explain and change health behaviours. The health belief model (Rosenstock, 1974) describes the likelihood of a person's engagement in a health-enhancing behaviour as a function of the perceived vulnerability to a health threat and its perceived severity. The more vulnerable the person feels and the more severe a health threat is considered to be, the likelier the person is to take action against it. The actual choice of health-enhancing behaviour depends on the benefits expected from the behaviour and the costs it entails.

The protection motivation theory (Rogers, 1975) postulates that threat appraisal and coping appraisal together determine an individual's intention to engage in a health-protective behaviour and assumes actual behaviour to be a function of intention. Threat appraisal is conceptualized, similarly as in the health belief model, as a function of perceived vulnerability to and severity of a health threat. Action-outcome efficacy, the belief that the particular action removes the health threat, and in a revised version of the model (Maddux & Rogers, 1983), self-efficacy are postulated to form coping appraisal.

Social cognition theory (Bandura, 1977) originally introduced the concept of self-efficacy. Self-efficacy can be described as a person's confidence in being able to perform a specific behaviour. Self-efficacy is assumed to predict behavioural performance directly and indirectly through its influence on intention.

The theory of planned behaviour (Ajzen, 1991), an extension of the theory of reasoned action (Ajzen & Fishbein, 1980), describes the execution of a behaviour as dependent on a person's intention to execute that behaviour and his or her perceived behavioural control. Perceived behavioural control is a construct similar to self-efficacy and can be described as a person's perception that executing the behaviour is within that person's control. Intention is determined by (1) attitudes, the evaluation of perceived consequences of a behaviour, (2) subjective norms, the individual's perception of whether significant others approve the individual engaging in the behaviour or not, and (3) perceived behavioural control.

The theory of normative conduct, (Cialdini, Reno, & Kallgren, 1990) disentangles the construct of norms into two components: a descriptive norm, the individual's perception of the extent to which others perform a behaviour, and a set of injunctive norms, which is similar to the construct of subjective norms proposed in the theory of planned behaviour.

In contrast to the models described so far, the transtheoretical model of behaviour change (Prochaska & DiClemente, 1983) postulates that behaviour change towards a health-enhancing behaviour or away from a health-threatening one occurs in six stages: pre-contemplation, contemplation, action, and termination. For most stages, the authors postulate strict time criteria. The model also includes social-cognitive variables such as self-efficacy and action-outcome expectancy, which denotes the anticipation whether the behaviour will lead to the expected outcomes.

The health action process approach (Schwarzer, 2008), a stage model too, puts particular emphasis on how behavioural intentions are transformed into actions. It breaks down the process of adopting a health-enhancing behaviour into two phases, namely a motivational phase, which is completed when intention towards behaviour change has been built, and a volitional, post-intentional, phase. Three elements that are crucial to achieving the aim of the motivational phase and forming a behavioural intention are risk perception, positive outcome expectancies towards the new behaviour, and action self-efficacy. Factors crucial to transforming intention into practice and maintaining the behaviour include maintenance and recovery self-efficacy, planning of the new behaviour, and action control. Maintenance self-efficacy denotes a person's confidence in the ability to maintain the behaviour despite difficulties. Recovery self-efficacy refers to a person's confidence in the ability to re-initiate the behaviour after relapse. Action planning denotes the extent to which an individual has concrete ideas of when, where, and how to initiate the behaviour. Action control refers to the extent to which individuals consciously compare their actual behaviour to their behavioural intentions. Coping planning denotes whether a person is able to anticipate barriers that might hamper the target behaviour and has strategies to overcome them.

The RANAS model (Mosler, 2012) is a conceptual model to explain change in hygiene and sanitation behaviour and a guideline to design and evaluate behaviour change campaigns. As shown in Figure 1, the RANAS model groups behavioural factors from the theories described above in five factor blocks. According to the RANAS model, behaviour is altered by changing the specific factors that steer that behaviour. In explaining how to identify such factors in a specific population and suggesting interventions to change them, the RANAS model provides a guideline to designing behaviour change campaigns.

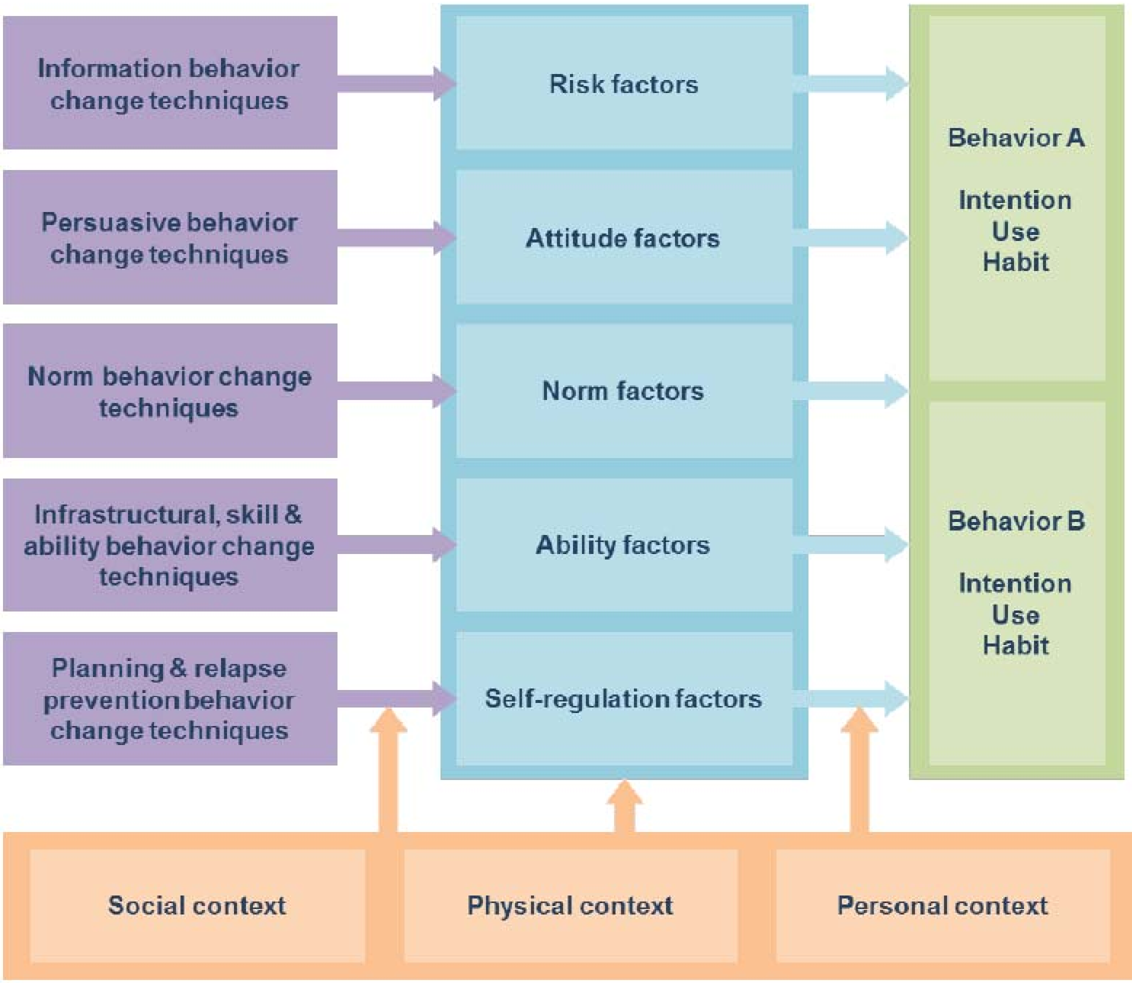

Figure 1: Overview of the extended RANAS model (Mosler & Contzen, 2016).

The first factor block, risk factors, comprises perceived vulnerability and severity of a health threat (Rosenstock, 1974). In addition, it includes factual knowledge, for example of the symptoms of, reasons for, and strategies against a health threat. Instrumental beliefs and affective appraisal are aggregated under attitudinal factors and constitute the second factor block. Instrumental beliefs are defined as beliefs about the costs, such as efforts and monetary costs, and benefits of the target behaviour (Rosenstock, 1974). Affective appraisal describes the feelings induced by the target behaviour itself or by thinking of the behaviour (Trafimow & Sheeran, 1998). The third factor block, normative factors, comprises descriptive, injunctive, and personal norms (Cialdini et al., 1990). Personal norms reflect what a person expects him- or herself to do (Schwartz, 1977). In this thesis, the personal norm will be considered part of commitment (see description below). Ability factors constitute the fourth factor block and include several forms of self-efficacy, namely action self-efficacy (Bandura, 1977), maintenance self-efficacy, and recovery self-efficacy (Schwarzer, 2008). The actual ability and knowledge to perform the behaviour is seen as precondition (Frick et al., 2004). Action planning (Gollwitzer et al., 2006), action control, coping planning (Schwarzer, 2008), remembering, and commitment constitute self-regulation factors and constitute the fifth factor block. Remembering describes the ease with which performing the behaviour is remembered. Commitment has been defined by Tobias (2009, p. 411) as the "strength of any form of internal pressure felt by a person to perform a behaviour".

In addition to social-cognitive factors, an extended version of the RANAS model (Mosler & Contzen, 2016) postulates that context influences behaviour via the social-cognitive factors through mediation and moderation. Contextual factors are broadly classified into the social context, such as existing regulations and customs, the physical context, such as availability of infrastructure, and personal context, such as age and gender.

To determine the factors to be changed, the occurrence of each factor in the target population should be measured (Mosler, 2012). For the social-cognitive factors, this is done by interviewing a randomly selected sample of the target population using a standardized questionnaire. Contextual factors are measured through spot checks and questionnaires. Finally, the behaviour-steering factors should be identified using statistical analysis. The RANAS approach suggests specific interventions to change each factor and consequently change behaviour (Mosler & Contzen, 2016).

Several studies provide empirical evidence for the RANAS model. It explained 57% of variance in the use of a community water filter in Ethiopia (Huber & Mosler, 2013) and 59% of the variance of deep tube-well use in Bangladesh (Mosler, Blöchliger, & Inauen, 2010). It has been used to investigate the behavioural factors steering drinking water chlorination in Chad (Lilje, Kessely, & Mosler, 2015). It explained 63% of the variance of habitual cleaning of water storage containers in rural Benin (Stocker & Mosler, 2015) and 68% of the variance in habitual latrine cleaning behaviour in Burundi (Sonego & Mosler, 2014).

In several studies, the RANAS model has been applied to determine the behavioural factors steering handwashing frequency. These are reviewed in the following section. More extensive literature reviews on the behavioural factors steering frequent handwashing with soap can be found elsewhere (Contzen, 2014; Seimetz, 2015).

1.3.2 Behavioural factors steering handwashing frequency

Thus far, five studies using the RANAS model have been published to identify the behavioural factors steering frequent handwashing with soap in key situations. Contzen and Mosler (2015) performed two cross-sectional studies, one in displacement camps and low-income neighbourhoods in Port-au-Prince, Haiti, and one in rural southern Ethiopia. Linear regression models of the factors steering handwashing frequency yielded 36% to 56% of explained variance in self-reported handwashing frequency. Seimetz, Slekiene, Friedrich, and Mosler (submitted) investigated the behavioural factors steering frequent handwashing with soap in primary schools in low-income suburbs of Harare, Zimbabwe, and in primary schools in rural Burundi, where the RANAS model explained 24% and 45% respectively of the variance in behaviour. Seimetz, Boyayo, and Mosler (2016) reported findings from another cross-sectional study in rural Burundi that quantified the effects of contextual and social-cognitive factors on caregivers' handwashing frequency. While contextual factors accounted for 13% in the variance in handwashing, adding social-cognitive factors explained 54% of the variance. Two studies provide longitudinal evidence on the behavioural factors steering frequent handwashing. Contzen and Inauen (2015) investigated changes in social-cognitive factors as mediators of the effect of commitment, infrastructure, and education intervention on handwashing behaviour. Seimetz, Kumar, and Mosler (2016) quantified the effect of an awareness-raising campaign in India for handwashing with soap in key situations on changes in social-cognitive factors and intention. The next paragraph discusses the relevance of the factors postulated in the RANAS model for explaining frequent handwashing with soap in the light of evidence from these studies.

The studies suggest that, among the risk factors, perceived vulnerability to contracting diarrhoea is not a relevant predictor of handwashing frequency. In contrast, the perceived severity of the consequences of diarrhoea was associated with handwashing frequency in Ethiopia (Contzen & Mosler, 2015) and Burundi

(Seimetz, Boyayo, et al., 2016; Seimetz, Kumar, et al., 2016). No substantial association was detected between health knowledge and handwashing frequency.

In most studies, instrumental beliefs (within the attitude factor block and mostly surveyed as health benefits of handwashing) either were not significantly related to frequent handwashing with soap or predictivity was relatively small (Seimetz, Boyayo, et al., 2016; Seimetz et al., submitted). Nurture, the motivation to keep children healthy, constitutes an exception and was found to be among the strongest predictors of handwashing in Ethiopia (Contzen & Mosler, 2015), corroborating the findings of Aunger et al. (2010). However, nurture was not considered in the remaining studies. Affective beliefs, surveyed in most studies as the extent to which people like washing hands with soap, was mostly irrelevant, except for caregivers in rural Burundi, where it was the second strongest predictor (Seimetz, Boyayo, et al., 2016). Feeling disgusted when not washing hands in key handwashing situations has been postulated to be among the most important drivers of frequent handwashing (Aunger et al., 2010; Porzig-Drummond, Stevenson, Case, & Oaten, 2009). It was found to be a predictor of handwashing in Ethiopia and Haiti (Contzen & Mosler, 2015), although effect sizes were relatively small.

Norm factors were consistently related to the frequency of caregivers' handwashing with soap (Contzen & Mosler, 2015; Seimetz, Boyayo, et al., 2016). In particular, descriptive norms strongly predicted the handwashing behaviour of school children in Zimbabwe and Burundi (Seimetz et al., submitted). The importance of norm factors is supported by longitudinal evidence reported both by Seimetz, Kumar, et al. (2016), who found increases in injunctive norms to be related to an increased intention to wash hands with soap frequently and by Contzen and Inauen (2015), who found increases in descriptive norms to be related to more frequent handwashing with soap as a consequence of a handwashing campaign.

Within the ability factors, action self-efficacy was positively related to more frequent handwashing with soap and was a consistent predictor in all studies. Increases in action self-efficacy resulted in higher intentions to wash hands with soap (Seimetz, Kumar, et al., 2016). In contrast, maintenance self-efficacy was not found to be related to handwashing frequency in any of the studies. An additional factor introduced by Contzen and Mosler (2015), impediments, describes the perceived barriers preventing individuals from washing hands and was consistently negatively associated with handwashing in Haiti and Ethiopia.

Among self-regulation factors, commitment, coping planning, and remembering were found to predict handwashing behaviour, although findings are less consistent between studies than they are for norm and ability factors. Coping planning was associated with handwashing behaviour in Haiti and Ethiopia (Contzen & Mosler, 2015). However, this cannot be corroborated from the remaining studies, since the effects of coping planning were not reported. Evidence for the ease of remembering to wash hands in key handwashing situations being a significant predictor of handwashing is mixed, with significant association reported from Burundi (Seimetz, Boyayo, et al., 2016) and Haiti (Contzen & Mosler, 2015), but negligible effects found in most of the remaining studies. Increases in remembering, as a consequence of the campaign in Ethiopia, led to increases in handwashing behaviour, but no cross-sectional association was found. Commitment was found to be relevant in Haiti (Contzen & Mosler, 2015), and changes in commitment in India (Seimetz, Kumar, et al., 2016) and Ethiopia (Contzen & Inauen, 2015) were associated with increased intention to wash hands frequently with soap and increased behaviour. Action planning/control was surveyed in a few of these studies and yielded mixed results (Seimetz, Boyayo, et al., 2016; Seimetz, Kumar, et al., 2016; Seimetz et al., submitted).

Considering contextual factors, several studies have shown household wealth to be associated with handwashing frequency (Luby & Halder, 2008; Pickering & Davis, 2012; Scott, Lawson, & Curtis, 2007). It has been shown that access to running water correlated with higher handwashing frequency (Pickering & Davis, 2012). In addition, there is evidence that having a designated place for handwashing is related to more frequent handwashing with soap (Devine, Karver, Coombes, Chase, & Hernandez, 2012; Scott et al., 2007). Evidence on the influence of contextual factors on handwashing frequency has been extensively reviewed by Seimetz (2015) and Seimetz, Boyayo, et al. (2016). In addition, Seimetz, Boyayo, et al. (2016) assessed the relative effects of contextual factors on handwashing behaviour. The study identified a designated place for handwashing, availability of more than 7.5 litres of water per person per day, and household wealth to predict handwashing frequency. However, when including social-cognitive factors in the model, only availability of more than 7.5 litres of water per person per day remained a significant predictor.

A major shortcoming of the literature available on determinants of frequent handwashing is that all studies rely on self-reported measures of handwashing behaviour. Thus far, no comprehensive study incorporating observed measures of handwashing frequency has quantified its behaviour-steering factors.

In summary, the factors in the RANAS model explain the variance in self-reported frequency of handwashing well. Norm factors comprising the perception of others' behaviour and the approval or disapproval of significant others were the strongest drivers consistently associated with frequent handwashing. In addition, a person's perceived ability to always wash hands with soap (action self-efficacy) was consistently among the most relevant factors. For most of the remaining factors in the RANAS model, the results are not as consistent, which suggests that the relevance of most factors depends largely on the target population. Since most evidence originates from cross-sectional studies, no conclusions about causality can be drawn. All studies relied on self-reports of behaviour, and no evidence is available from direct observation. The next section discusses the behavioural factors steering handwashing technique.

1.3.3 Behavioural factors steering handwashing technique

Evidence on the behavioural factors steering handwashing technique is limited, and no studies thus far have applied the RANAS model to investigate them. In one study conducted among healthcare workers at an intensive care unit in China, participants showed better overall handwashing technique after an intervention (Lam, Lee, & Lau, 2004). The intervention included information about correct handwashing steps and their importance for the spread of healthcare-associated diseases, prompts for correct handwashing at handwashing basins, and advice on how to overcome barriers to applying proper handwashing technique (Lam et al., 2004) suggesting that action knowledge, remembering, and coping planning may be relevant behavioural factors steering handwashing technique in this context. Examining domestic handwashing, Hoque, Mahalanabis, Alam, et al. (1995) found perceived health benefits of handwashing to be associated with handwashing technique, as measured by washing both hands, the use of washing agents, the scrubbing of hands, and the total amount of water used, although statistical significance was not tested. In Lima, another study addressing domestic handwashing by Huttly et al. (1994) found that individuals scrubbed hands particularly thoroughly when preparing to go out and before eating.

There is some evidence on the association of contextual factors with handwashing technique. Hoque, Mahalanabis, Alam, et al. (1995) found an association of education and economic indicators with handwashing technique. Song, Kim, and Park (2013) found that family factors, such as the amount of time spent with parents, influenced children's handwashing technique.

In summary, there are substantial gaps in our understanding of what steers individuals to perform effective handwashing technique. First, there is little published evidence on the social-cognitive and contextual factors of handwashing technique. Second, the selection of behavioural factors surveyed in the few studies reported so far was not informed by theory, suggesting that potentially important factors have been neglected. Third, none of the reported studies used an official definition of handwashing technique such as those published by the World Health Organisation (2009), the United States Food and Drug Administration (2013) or the Centers for Disease Control and Prevention (n.d.).

Effective handwashing technique can also be seen as a sequence of different behaviours: moistening hands, using soap, scrubbing, rinsing, and drying. The behavioural factors underlying each of those steps may thus be different. However, the studies which have so far investigated the behavioural factors of handwashing technique used aggregated measures of handwashing technique that did not disentangle which behavioural factors steered which specific steps.

1.3.4 Research question

Overall, the social cognition approach has been widely used to explain and change health behaviours. Building on this, the RANAS approach to systematic behaviour change provides a framework to identify the behavioural factors steering hygiene behaviours in developing countries and to design behaviour change interventions. While substantial evidence exists on which behavioural factors steer handwashing frequency in different contexts and should thus be targeted by interventions, our current understanding of the behavioural factors steering handwashing technique is limited and unsystematic. This leads to the fourth research question of this thesis: Which behavioural factors steer handwashing technique?

1.4 Changing handwashing behaviour

This section reviews the literature on changing handwashing behaviour through handwashing campaigns. First, the behaviour change approaches of past campaigns are reviewed. Second, past research on the success of different modes of delivery is summarized. Third, the target behaviours and outcome measures of past handwashing campaigns are discussed. Finally, the knowledge gaps identified are summarized and the research questions derived.

1.4.1 Behaviour change approaches of past handwashing campaigns

The majority of handwashing campaigns reported in the literature have consisted of health and hygiene education, the provision of handwashing devices or support in constructing them, and soap supply. (Arnold, Arana, Mäusezahl, Hubbard, & Colford, 2009; Greene et al., 2012; Huda et al., 2012; Luby et al., 2001; Luby et al., 2009; Onyango-Ouma, Aagaard-Hansen, & Jensen, 2005; Saboori et al., 2013). Although the exact content of the interventions is often not described in detail, the studies suggest that interventions mainly targeted risk factors, such as enhancing knowledge on how washing hands prevents diarrhoea or increasing the perceived risk of contracting diarrhoea when not washing hands in key handwashing situations. This is critical because, as outlined in the previous chapter, various factors beyond risk factors drive handwashing frequency.

Handwashing campaigns targeting behavioural factors beyond risk factors are relatively rare, but their number has increased in recent years. They can be classified by their intended mechanisms of action. One type of campaign has been designed to particularly target emotional drivers (Biran et al., 2014; Biran et al., 2009; Scott, Schmidt, Aunger, Garbrah-Aidoo, & Animashaun, 2008). The most successful example is the Super Amma campaign (Biran et al., 2014), which focused on nurture, disgust, and the status associated with handwashing and affiliation to social groups. It yielded 37% observed handwashing with soap at six-month follow-up compared to 6% in the control. A second group of campaigns has targeted the social-cognitive factors proposed by the theories reviewed in the previous sections. Luby et al. (2010) reported the effects of handwashing promotion using the transtheoretical model of behaviour change (Prochaska & DiClemente, 1983). The intervention was very successful in increasing observed handwashing with soap after defecation, from 26% to 85%, and handwashing before eating and preparing food, from less than 1% to 26%. However, the intervention consisted of intensive, twice-weekly household visits and soap supply over a period of four months, and it is open to question whether abundant soap and operability can be provided at larger scales. Contzen, Meili, and Mosler (2015) reported the effects of a handwashing campaign in Ethiopia designed using the RANAS model. A combination of education, infrastructure promotion, and public commitment resulted in more than 30% observed stool-related handwashing with soap at follow-up compared to 10% to 15% in the control. However no group differences were detected for food-related handwashing.

In summary, relatively few handwashing campaigns reported in the literature have been designed based on social-cognitive theory, but the results of those that have are promising.

1.4.2 Modes of delivery of past handwashing campaigns

Little evidence exists on which mode of delivering handwashing campaigns is most effective. The vast majority of handwashing campaigns have targeted caregivers through direct communication in household visits or at group meetings (e.g. Chase & Do, 2012; Contzen, Meili, et al., 2015; Huda et al., 2012; Luby et al., 2010; Scott et al., 2008). In addition, mass media campaigns have yielded considerable success in increasing handwashing frequency, although the studies examining these relied entirely on self-reports of handwashing behaviour (Contzen & Mosler, 2013; Scott et al., 2008).

Enrolling children in a hygiene campaign to indirectly target their parents has been discussed as a promising mode of delivery (Mwanga, Jensen, Magnussen, & Aagaard-Hansen, 2008; Onyango-Ouma, Aagaard-Hansen, & Jensen, 2004). The 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).

A combination of directly targeting both caregivers and their children was tested in two handwashing campaigns in rural India (Biran et al., 2014; Biran et al., 2009). As mentioned above, the Super Amma study (Biran et al., 2014) achieved considerable improvements in observed handwashing frequency. However, it remains unknown whether this success is primarily attributable to the direct campaign, the indirect campaign, or both, as only the combination was compared to a non-intervention control. Until now, no study has compared the relative effects of targeting caregivers directly, indirectly through their children, and combining both approaches.

In summary, indirectly targeting caregivers through promoting handwashing with soap to their children might be a promising strategy to change caregivers' behaviour, but until now, this approach has not been rigorously evaluated.

1.4.3 Target behaviours and outcome measure of past handwashing campaigns

Handwashing frequency

Thus far, the target behaviour and evaluated outcome of most domestic handwashing campaigns has been the frequency of handwashing with soap in key situations (e.g. Arnold et al., 2009; Biran et al., 2014; Biran et al., 2009; Contzen, Meili, et al., 2015; Huda et al., 2012; Luby et al., 2010; Scott et al., 2008). Self-reports have frequently been used in evaluations of handwashing campaigns (Arnold et al., 2009; Chase & Do, 2012; Contzen, Meili, et al., 2015; Scott et al., 2008). However, they have been shown to be subject to strong biases (Contzen, De Pasquale, & Mosler, 2015; Ram, 2013). Although structured observations are more resource intensive, they have been acknowledged to yield more valid measures of actual handwashing behaviour (Ram, 2013; Ram, Luby, Halder, Islam, & Granger, 2010). Structured observations require that a data collector is placed in one household for a defined period of time. In each key handwashing situation, the data collector notes whether hands were washed with soap or not. Structured observations have been used to quantify campaign effects on handwashing frequency in a growing body of literature (Biran et al., 2014; Biran et al., 2009; Huda et al., 2012; Luby et al., 2010).

Handwashing technique

Few domestic handwashing campaigns have included handwashing technique as a specific target behaviour and outcome variable (Blanton et al., 2010; Luby et al., 2009; Patel et al., 2012). None of them was designed to target behavioural factors beyond risk factors. Further, in those few published studies, the measures of handwashing technique did not match the definitions of effective handwashing technique published by the World Health Organisation (2009), the Food and Drug Administration (2013), or the Centers for Disease Control and Prevention (n.d.). Patel et al. (2012), for instance, defined correct handwashing technique as “using soap, lathering all hand surfaces, and air drying” (p. 595). At one-year follow-up after an intervention indirectly targeting caregivers through their children, these researchers did not identify significant improvements in handwashing technique. Blanton et al. (2010) considered “lathering hands thoroughly with soap, rubbing between fingers, and air drying” (p. 665) to be effective handwashing. The share of caregivers who demonstrated proper handwashing according to this definition increased from 25% at baseline to 41% at three-month follow-up. Luby et al. (2009) reported whether participants “rub[bed] their hands together at least three times” (p. 140). Fifty per cent of mothers in intervention households complied with this handwashing technique, while only 23% of mothers in control households did.

General hand contamination

Whether enhanced handwashing frequency actually translates into reduced general hand contamination constitutes a major gap in our current understanding of handwashing campaigns. General hand contamination, measured at random time points, was only used as an outcome indicator in two studies. Luby et al. (2001) reported that participants in households that had received soap and an education intervention had 65% fewer thermotolerant coliforms on hands than the non-intervention control. Pinfold and Horan (1996) reported an average reduction of faecal streptococci at follow-up of 65% in the intervention group compared to a reduction of 34% in the control. Considering the quick recontamination of hands reported by Devamani et al. (2014) and Ram et al. (2011) which has been discussed in Section 1.2.1, the finding that handwashing campaigns substantially reduced general hand contamination is surprising. However, since the studies only assessed hand contamination but not handwashing frequency, the exact relation of handwashing behaviour change to changes in general hand contamination remains uncertain.

Handwashing effectiveness

Handwashing effectiveness was not assessed in any of the campaign evaluations reviewed here, including those campaigns targeting handwashing technique. Consequently, it remains uncertain whether improvements in handwashing technique actually resulted in improvements in handwashing effectiveness. In addition, the interrelation of handwashing effectiveness and general hand contamination has not been assessed. For example, it may be possible that improvements in handwashing effectiveness correlate with reductions in hand contamination.

In summary, few domestic handwashing campaigns have striven to improve handwashing technique, and those that did used inconclusive measures. Further, it remains unclear whether improvements in technique actually resulted in improvements in microbial handwashing effectiveness. Similarly, it remains unclear whether increasing handwashing frequency through a campaign can reduce general hand contamination.

1.4.4 Research questions

Overall, few handwashing campaigns have been designed based on social-cognitive theory. However, the results of those that have are promising. A shortcoming of previous handwashing campaigns is that none of them explicitly targeted handwashing technique, which is likely to be very relevant to effectively decontaminating hands. As a consequence, the fifth research question of this thesis is this: Can theory-based interventions enhance both (a) handwashing technique and (b) frequency?

The majority of handwashing campaigns have directly targeted caregivers, while others have targeted caregivers through promoting handwashing to their children, and some have used a combined approach. However, the relative effects of direct handwashing promotion, indirect promotion through children, and a combination of both has never been tested. To investigate this research gap, Research Question 6 reads as follows: Which mode of delivery, (1) targeting caregivers directly, (2) targeting caregivers indirectly through their children, or (3) a combination of both, is most effective in changing handwashing behaviour?

Most previous handwashing campaigns have been evaluated by their effect on handwashing behaviour. Few campaign evaluations have used hand contamination as an outcome, and no study has yet quantified campaign effects on both behavioural and microbial outcomes. Whether enhancements in handwashing technique induced by a handwashing campaign actually translate into improvements in handwashing effectiveness thus remains uncertain. This leads to Research Question 7: Does enhancing handwashing technique increase microbial handwashing effectiveness?

Correspondingly, it remains unknown whether enhancements in handwashing frequency induced by a handwashing campaign actually translate into changes in general hand contamination. This leads to Research Question 8: Does enhancing handwashing frequency reduce general hand contamination?

2 Objectives, research questions, and expected output of the thesis

The overall aim of this thesis is to combine environmental microbiology and health psychology to promote effective handwashing. The objectives of this thesis are threefold: First, to quantify whether handwashing technique influences microbial handwashing effectiveness, second, to determine the behavioural factors which steer handwashing technique, and third, to quantify the effects of a theory-based handwashing campaign on handwashing frequency, technique, and faecal hand contamination. This leads to eight research questions (RQs):

RQ1: Which handwashing technique is (a) effective in decontaminating hands and (b) practicable in low-income settings in developing countries?

As outlined in the literature review presented in Section 1.2.2, recommendations for handwashing technique issued in various contexts in industrialized countries have not been corroborated in low-income settings in developing countries. However, effective handwashing seems to be of particular importance in these settings, since this is where environmental pathogen contamination and the disease burden are highest. Further, the practicability of existing handwashing recommendations in developing countries is debatable. These knowledge gaps lead to Research Question 1.

RQ2: Are handwashing frequency and handwashing technique interrelated?

The impacts of handwashing frequency and handwashing technique seem interdependent. Effective handwashing technique is assumed to be required to remove germs effectively. However, effective handwashing can only reduce hand contamination when hands are washed. This leads to Research Question 2.

RQ3: Are general hand contamination and handwashing effectiveness interrelated?

The interrelation of handwashing effectiveness and general hand contamination has not been quantified in any of the studies reviewed above. However, both variables may be strongly interrelated; for example, washing hands more effectively could result in hands being detectably cleaner for a longer time. This leads to the third research question.

RQ4: Which behavioural factors steer handwashing technique?

The literature review of behavioural factors which steer handwashing technique (Section 1.3.3) yielded inconclusive and unsystematic evidence. However, according to the RANAS model of systematic behaviour change (Mosler, 2012), identifying these behavioural factors constitutes the precondition to designing effective behaviour change interventions. This leads to Research Question 4.

RQ5: Can theory-based interventions enhance both (a) handwashing technique and (b) frequency?

Most handwashing campaigns, reviewed in Section 1.4, aimed solely at enhancing handwashing frequency, not technique. However, if the assumption holds that handwashing technique is paramount to effectively removing pathogens, interventions are needed that improve both frequency and technique of handwashing. Designing interventions based on theory and data from the target population constitutes a promising approach to enhancing handwashing technique as it has yielded considerable changes in handwashing frequency (Contzen, Meili, et al., 2015), safe water consumption, and sanitation behaviours (compare Section 1.4.1).

RQ6. Which mode of delivery, (1) targeting caregivers directly, (2) targeting caregivers indirectly through their children, or (3) a combination of both, is most effective in changing handwashing behaviour?

Changing the behaviour of caregivers by enrolling their children in hygiene campaigns has been discussed as a promising approach (Mwanga et al., 2008; Onyango-Ouma et al., 2004). However, the effectiveness of this approach has not been quantified relative to targeting caregivers directly or targeting caregivers both directly and indirectly through their children.

RQ7: Does enhancing handwashing technique increase microbial handwashing effectiveness?

Assuming that the causal relationship between handwashing technique and handwashing effectiveness examined by Research Question 1 is established, an intervention which improves handwashing technique should also improve handwashing effectiveness. However, none of the campaigns reviewed in Section 1.4.3 reported effects on both technique and effectiveness.

RQ8: Does enhancing handwashing frequency reduce general hand contamination?

Evidence on whether promoting frequent handwashing reduces general hand contamination is controversial. Recontamination of hands to pre-wash levels has been reported to occur within a short time (Devamani et al., 2014; Ram et al., 2011). However, intervention trials have shown strong effects of promotion of frequent handwashing with soap on general hand contamination (Luby et al., 2001; Pinfold & Horan, 1996).

These research questions were investigated through a case study implemented in Harare, Zimbabwe from November 2013 to February 2016. The case study comprised the design, implementation, and evaluation of a handwashing campaign in low-income suburbs of the city. Chapter 3 of this thesis reports cross-sectional evidence on the relation of handwashing technique, handwashing effectiveness, and general hand contamination and aims to answer Research Questions 1 and 3. To respond to Research Question 4, a second cross-sectional study aiming to identify the contextual and social-cognitive factors steering handwashing technique is reported in Chapter 4. The interrelation of handwashing frequency and technique, the subject of Research Question 3, is also reported in Chapter 4. Chapter 5 addresses Research Questions 5 to 8 with longitudinal evidence on the effects of the behaviour change campaign on handwashing frequency, technique, general hand contamination, and handwashing effectiveness. Chapter 5 also reports the interrelation of behavioural and microbial measures in additional response to Research Questions 1, 2, and 3. The empirical chapters are complemented with supplementary descriptive statistics (Annex I), photos of the data collection and campaign (Annex II) and a practical overview of the entire project (Annex III).

The expected output of this thesis is twofold: (1) to provide empirical evidence in response to the research questions, and (2) to combine this evidence and the available literature into an integrated framework for changing handwashing behaviour and hand contamination.

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

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A similar version of this chapter is accepted for publication at American Journal of Infection Control.

3.1 Abstract

Background. Consistent domestic hand hygiene can reduce diarrhoea-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 every-day 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 analysed for *Escherichia coli (E.coli)* and total coliform concentrations. Generalized linear models were used to predict faecal 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 the fingertips, and rubbing the 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 handscrubbing steps (i.e., cleaning under the fingernails, rubbing the fingertips), and soap and tap use. This calls for further research to develop behaviour change interventions that explicitly promote effective handwashing technique at critical times.

3.2 Introduction

Consistent hand hygiene can reduce diarrhoea-related morbidity and mortality. Diarrhoea is one of the leading causes of childhood mortality worldwide (Rudan et al., 2007). Fischer Walker et al. (2013) estimated that in 2011, 700.000 children died of diarrhoea, with highest rates in South-East Asia and Africa. According to estimations by Prüss-Ustün et al. (2014) 297.000 deaths were caused by inadequate hand hygiene worldwide in 2012. Handwashing at critical times, such as before eating, cooking, or other contact with food and after defecation and other contact with faeces was shown to be among the most cost effective methods to reduce diarrhoea (Borghi, Guinness, Ouedraogo, & Curtis, 2002; Curtis & Cairncross, 2003; Feachem, 1984; Freeman et al., 2014). Despite its importance, handwashing with soap is only practiced by a small proportion of people worldwide (Freeman et al., 2014). This calls for effective handwashing promotion at large scale.

Among others, the Centers for Disease Control (CDC) and the World Health Organization (WHO) provide recommendations on effective handwashing in healthcare settings (Centers for Disease Control and Prevention, 2002; World Health Organisation, 2009). For domestic handwashing, the CDC (Centers for Disease Control and Prevention, n.d.) recommends the following five 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 together with the soap. Be sure to lather 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.*

However, the microbiological 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 (Amin et al., 2014; Burton et al., 2011; Luby et al., 2001; Sickbert-Bennett et al., 2004) 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 (Hoque, Mahalanabis, Alam, et al., 1995). Further, the impact of thoroughness of handwashing, described by both length (Amin et al., 2014; Conover & Gibson, 2016; Fuls et al., 2008; Lucet et al., 2002) and scrubbing steps (Lin et al., 2003) is uncertain. Evidence on which hand-drying technique is most effective are mixed (Gustafson et al., 2000; Hoque, Mahalanabis, Pelto, & Alam, 1995; Huang, Ma, & Stack, 2012) and recontamination of hands from contaminated clothes is likely (Gil et al., 2014). 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 pre-specified handwashing regimens, in which singular hand washing steps were manipulated while the remaining hand washing technique remained constant (Amin et al., 2014; Burton et al., 2011; Lin et al., 2003; Lucet et al., 2002). The studies therefore do not represent handwashing as performed by community members in their daily life, which some authors have suggested should be tested (Amin et al., 2014; Bloomfield et al., 2007).

Handwashing campaigns should promote a technique of handwashing which 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 (Bloomfield et al., 2007; Conover & Gibson, 2016). Particularly in developing countries, the CDC guidelines may be difficult to follow as running water from a tap and a clean towel, for instance, are often not available (Sandhu & Goodnight, 2014). In addition, local customs may suggest different hand washing procedures, such as in Zimbabwe where hands are traditionally moistened and rinsed in a bowl of water (Kaltenthaler et al., 1991). 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 microbiological 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.

3.3 Methods

Participants

This study was implemented in June and July 2014 in 10 high-density and low-income suburbs of Harare, Zimbabwe. One working day prior to data collection, participants were recruited through random route sampling by selecting every 5th household starting from junctions in the study area. Since this study was part of a larger study, households needed to have at least one 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. Non-responding, ineligible, and refusing households were replaced by the 5th next household on the sampling route. In total, 198 primary care givers were sampled.

Enumerator training

Prior to data collection, enumerators were enrolled in a one-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. In a second training week, enumerators practiced data collection in the field and performed handwashing observations under supervision in at least one household prior to the actual data collection.

Data collection

Microbial contamination of hands was measured using hand rinse samples as previously reported (Pickering, Boehm, et al., 2010). The data collector randomly selected the first hand to be sampled through the random function of OpenDataKit software on a tablet computer (Hartung et al., 2010). The selected hand of the participant was placed in a 2040 ml sterile sampling bag (NASCO Corp., United States of America) filled with 350 ml of 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 five seconds, both sides of the finger were simultaneously massaged for five 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 participants hand was dried with a paper towel. Enumerators wore new non-sterile 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 faeces". The prompt concerning which of the two 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 hand washing observation data on the tablet computer.

The socio-demographic characteristics of participants were subsequently collected in a standardized face-to-face interview. The questionnaire had been developed in English, translated into the local language Shona, 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 devise to dispense water were performed at the end of each household visit.

A subset of the study participants had been surveyed in a 3-hour structured handwashing observation on the same day prior to hand sampling.

Indicator organisms

Faecal indicator bacteria (total coliforms and *E. coli)* were used as objective measures of handwashing effectiveness. Total coliforms are bacteria defined by their ability to be cultured in selective media for Gram-negative microorganisms containing lactose when incubated at 35-37°C. Total coliforms are ubiquitous in the environment and are not necessarily associated with sanitary risks. However, total coliforms are used as an indicator of process effectiveness comparing concentrations before and after treatment (e.g., before and after handwashing). *E. coli* are a species of bacteria found in the gut of warm blooded animals and are a subset of total coliform. Although many strains of *E. coli* are pathogenic, most are harmless. Hand hygiene studies conducted in the field rely on faecal indicator bacteria concentrations on hands to quantify faecal hand contamination and handwashing effectiveness (Amin et al., 2014; Hoque, Mahalanabis, Pelto, et al., 1995; Pickering, Davis, et al., 2010; Pickering, Julian, Mamuya, Boehm, & Davis, 2011).

To evaluate handwashing effectiveness, both the log difference of hand contamination before and after washing (Amin et al., 2014; Pickering, Boehm, et al., 2010) and the log hand contamination after washing (Burton et al., 2011; Hoque, Mahalanabis, Alam, et al., 1995) have been used in previous studies. In this study, hand contamination after washing was chosen as outcome variable because hand contamination has been shown to be directly associated with diarrhoea (Pickering, Davis, et al., 2010; Pinfold & Horan, 1996). In addition, using log differences would not differentiate between reductions of different magnitudes (e.g. reduction from 3 to 2 log CFU/hand amounting to 900 CFU/hand would be modelled in the same way as a reduction from 2 to 1 log CFU/hand amounting to 90 CFU/hand).

Laboratory procedures

Samples were cooled with ice and transported to the laboratory of the Department of Biology at University of Zimbabwe. They were processed by two trained students within 6 hours after collection. Samples were processed in triplicates and were analysed for numbers of *E. coli* and total coliform bacteria. Portions of 100 ml and 10 ml of each sample, representing $2/7^{ths}$ and $2/70^{ths}$ of the total sample collected, respectively, were passed through a 0.45-µm, 47-mm-diametre cellulose filter (Merck Millipore, Germany) and placed on compact dry EC media plates (Nissui pharmaceuticals, 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 pre-wash sample, additional media plates were directly inoculated with 1 ml of sampling solution because, compared to the post-wash samples, higher contamination was expected. Plates were incubated for 24 +/- 0.5 hours at 37 +/- 1 °C. *E. coli* and total coliforms were counted per manufacturer's instructions. At least one 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 that 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 pre-wash and post-wash samples were 87,500 CFU / hand and 8,750 CFU / hand, respectively. Of each sample, the mean of the three replicates was taken. For 17 of the 331 total samples, only duplicates were available, due to processing mistakes.

Paired-samples t-tests were performed to test significance of the change in $\log_{10}$ CFU / hand of *E.coli* and total coliform bacteria during hand washing. Faecal indicator bacteria per hand after handwashing were modelled as a function of the performed hand washing technique (e.g. way of moistening hands, way of scrubbing hands), the pre-wash 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 modelled as continuous predictors. To obtain unbiased parameter estimates, outliers with log CFU larger than 4 time the standard deviation were removed from the models. For the model predicting *E. coli* counts after washing, the outliers included 6 participants (less than 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 of less than 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.

3.4 Results

Participants and study area

171 participants (99%) were female and 2 participants (1%) were male. On average, the participants had attended 10 years of formal education (SD = 2.7) and were 37 years old (SD = 11.5). The average household size of participants amounted to 5.6 household members (SD = 1.8) and the average monthly household income was 341 USD (SD = 290).

Observed handwashing infrastructure

156 participants (90%) showed a specific place for hand washing. 128 participants (74%) showed separate handwashing places for food and stool related hand washing. In 143 households (83%), water was present at one or more handwashing locations. 103 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 one 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 pre-wash sample the average $\log_{10}$ CFU *E. coli* per hand was 1.4 (SD = 0.9). The post-wash samples yielded, on average, 1.2 (SD = 0.8) $\log_{10}$ CFU/hand. The reduction was statistically significant, $t(172) = 4.28$, $p < 0.001$. The mean hand contamination with total coliform bacteria was reduced by 0.3 $\log_{10}$ CFU/hand from 2.5 (SD = 1.0) $\log_{10}$ CFU/hand in the pre-wash sample to 2.2 (SD = 0.9) $\log_{10}$ CFU/hand in the post-wash sample, $t(172) = 4.28$, $p<0.001$.

Observed handwashing technique

Table 1 presents the observed handwashing technique of participants.

Table 1. Observed handwashing technique, categorical characteristics.

Handwashing technique	n	%
Moistening / Rinsing		
Used tap*	72	42
Poured water on hands	29	17
Dipped hands into water	72	42
Soap use		
Did not use soap*	91	53
Used soap	82	47
Handscrubbing		
Scrubbed the palm	173	100
Scrubbed back	160	92
Scrubbed between fingers	102	59
Scrubbed under nails	46	27
Scrubbed fingertips	50	29
Scrubbing time > 20 sec	107	62
Drying		
Air dried*	134	77
Rubbed hands on clothes	23	13
Used clean towel	7	4
Used dirty towel	9	5

Note: N = 173. * Used as reference category for multivariate models.

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 seconds (SD = 14.9, Mdn = 23.0) with an interquartile range of 16 to 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. Generalized linear model of *E. coli* and total coliform log10 CFU/hand after handwashing, modelled as a function of the performed hand washing technique. 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. *S*crubbing 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 hand washing. 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 significant 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 spend 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.

Table 2. Generalized linear model of *E. coli* and total coliform log10 CFU/hand after handwashing, modelled as a function of the performed hand washing technique.

	E.coli				**Total coliforms**			
			95% CI †				95% CI †	
Handwashing technique	B		Lower	Upper	B		Lower	Upper
(Intercept)	**1.45**	**	**0.37**	**2.53**	**2.16**	**	**0.91**	**3.40**
Moistening / Rinsing								
Poured water on hands	0.16		-0.38	0.70	**0.77**	**	**0.23**	**1.32**
Dipped hands into water	**0.82**	***	**0.36**	**1.28**	**0.76**	**	**0.20**	**1.32**
Soap use	**-0.87**	**	**-1.36**	**-0.37**	0.06		-0.48	0.60
Handscrubbing								
Scrubbed back	-0.11		-0.89	0.66	0.88		-0.14	1.90
Scrubbed between fingers	-0.77		-1.77	0.22	1.26		-0.04	2.56
Scrubbed under nails	**-3.87**	***	**-5.46**	**-2.28**	-0.98		-2.57	0.61
Scrubbed fingertips	**-3.62**	***	**-5.20**	**-2.04**	**-1.41**	**	**-2.21**	**-0.60**
Interaction: Handscrubbing								
Scrubbed back * Scrubbed between fingers	0.66		-0.43	1.75	-1.22		-2.61	0.17
Scrubbed back * Scrubbed under nails	**2.50**	***	**1.29**	**3.71**	0.82		-0.47	2.11
Scrubbed back * Scrubbed fingertips	**3.05**	***	**1.85**	**4.25**	‡		‡	‡
Scrubbed between fingers * Scrubbed under nails	0.98		-0.21	2.17	-0.84		-1.93	0.25
Scrubbed between fingers * Scrubbed fingertips	0.80		-0.30	1.90	0.98		0.00	1.97
Scrubbed under nails * Scrubbed finger-tips	0.02		-0.98	1.02	**1.26**	*	**0.20**	**2.32**
Scrubbing time > 20 sec.	0.54		-0.08	1.15	0.58		-0.13	1.29
Drying								
Rubbed hands on clothes	**-0.85**	**	**-1.39**	**-0.31**	**-0.61**	*	**-1.13**	**-0.09**
Used clean towel	**-1.35**	**	**-2.25**	**-0.44**	-0.37		-1.33	0.59
Used dirty towel	-0.08		-0.89	0.73	0.83		-0.53	2.18
Total wash time (seconds)	0.00		-0.02	0.02	0.00		-0.03	0.02
Hand contamination before washing	**1.22**	***	**0.94**	**1.50**	**0.85**	***	**0.64**	**1.06**
Right hand sampled first	0.42		-0.04	0.88	0.05		-0.41	0.51

Notes: Model *E.coli* likelihood ration $\chi^2(20) = 242.89$, $p < 0.001$. * p < .05, ** p<.01, *** p<.001. Model total coliforms likelihood ratio $\chi^2(19) = 147.44$, $p < 0.001$. * p < .05, ** p<.01, *** p<.001. † Wald Confidence Interval (B). ‡ No parameter estimate computed because not all combinations of rubbing back * rubbing fingertips were observed.

3.5 Discussion

The goal of the present study was to determine which steps of handwashing, as performed in the every-day life in suburbs of Harare, 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 impact on hand contamination after washing quantified. This study shows that recommendations for effective hand hygiene should include: 1) moistening hands under a tap, 2) soap use, and 3) 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 microbiological effectiveness. Future handwashing behaviour 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 which was used when manually pouring water on hands or dipping hands into a vessel (Genthe et al., 1997; Levy, Nelson, Hubbard, & Eisenberg, 2008; Palit, Batabyal, Kanungo, & Sur, 2012; Pickering, Davis, et al., 2010). As Hoque, Mahalanabis, Alam, et al. (1995) suggested, using contaminated handwashing water may result in more faecal 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 handscrubbing 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, Mahalanabis, Alam, et al. (1995) support this hypothesis showing that individuals who washed hands using 2 liters of water had lower loads of faecal indicator bacteria on hands after washing than individuals who used only 0.5 liters (Hoque, Mahalanabis, Alam, et al., 1995).

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. As 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 (Amin et al., 2014; Fuls et al., 2008; Lucet et al., 2002). This result is relevant for future handwashing promotion because it is doubtful whether people comply with complex recommendations that include minimum handwashing times (Bloomfield et al., 2007). 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 which were usually performed by this study's participants, this corroborates the importance of soap, previously demonstrated in experimental trials (Amin et al., 2014; Burton et al., 2011). 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 handscrubbing 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. (2012). This questions the CDC recommendations which also promote air drying following handwashing.

Limitations

Individuals were not randomized to specific handwashing regimes which limits the given recommendations to handwashing steps already in practice in the study community. However, this design allowed to assess the importance of handwashing steps as performed in the usual way and give handwashing recommendations which 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 which we aimed to test were performed by a sufficient number of participants to evaluate them. More studies at other sides are required to generalize the given recommendations for effective handwashing.

Participants were directly observed by the enumerators during the handwashing demonstration which may have prompted participants to wash hands differently than they normally would (Kohli et al., 2009). To minimize these effects, participants were explicitly reminded to wash hands in the usual way, that all information that were 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 relation 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 manufacturer's description. We may, therefore, have overestimated faecal bacterial contamination by including false positives with atypical morphology that nevertheless fit the manufacturer's description. Though Julian et al. (2015) 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.

Conclusion

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 impact of hand-drying methods. Handwashing steps as recommended by CDC are already in practice by some individuals of the survey population, which suggest that achieving uptake of the recommended technique by a larger share of the population can be a realistic aim of behaviour change interventions. Additional research is needed to understand the behavioural determinants which 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.

3.6 Acknowledgements

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. We 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 Belladonnah Muzavazi and Eustace Sangoya; the enumerator team and all study participants in Harare.

4 Contextual and psychosocial determinants of effective handwashing technique: Recommendations for interventions from a case study in Harare, Zimbabwe

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A similar version of this chapter is accepted for publication at American Journal of Tropical Medicine and Hygiene.

4.1 Abstract

Handwashing has been shown to considerably reduce diarrhoea morbidity and mortality. To decontaminate hands effectively, the use of running water, soap, and various scrubbing steps are recommended. This study aims to identify the behavioural determinants of effective handwashing.

Everyday handwashing technique of 434 primary caregivers in high-density suburbs of Harare, Zimbabwe was observed and measured as 8-point sum score of effective handwashing technique. Multiple linear and logistic regression analyses were performed to predict observed handwashing technique from potential contextual and psychosocial determinants.

Knowledge of how to wash hands effectively, availability of a handwashing station with functioning water tap, self-reported frequency of handwashing, perceived vulnerability, and action planning were the main determinants of effective handwashing technique. The models were able to explain 39% and 36% of the variance in overall handwashing technique and thoroughness of handscrubbing.

Memory aids and guided practice are proposed to consolidate action knowledge, and personalized risk messages should increase the perceived vulnerability of contracting diarrhoea. Planning where, when, and how to maintain a designated place for handwashing with sufficient soap and water are propose to increase action planning. Since frequent self-reported handwashing was associated with performing more effective handwashing technique, behaviour change interventions should target both handwashing frequency and technique concurrently.

4.2 Introduction

Hand hygiene is key to reducing the global burden of diarrhoea and respiratory diseases (Borghi et al., 2002; Curtis & Cairncross, 2003; Feachem, 1984; Freeman et al., 2014; Prüss-Ustün et al., 2014). By acquiring pathogens from surfaces in the environment and transferring them to the mouth or nose, hands constitute a key route for the transmission of infectious diseases (Bloomfield et al., 2007). Handwashing with soap has been shown to decontaminate hands (Kampf

& Kramer, 2004; Pickering, Davis, et al., 2010; Pinfold & Horan, 1996) and reduce the risk of ingesting pathogens and acquiring diarrhoea.

Performing the handwashing technique correctly is crucial for handwashing to effectively decontaminate hands in healthcare (Centers for Disease Control and Prevention, 2002; World Health Organisation, 2009), the food industry (Food and Drug Administration, 2013) and household settings (Centers for Disease Control and Prevention, n.d.). For domestic handwashing, the CDC recommends tap and clean water use, soap use, specific scrubbing steps and drying hands with a clean towel or air drying. These recommendations have been corroborated by microbiological analyses of handwashing effectiveness in the population of this case study in Harare, Zimbabwe(Friedrich, Julian, Kappler, Nhiwatiwa, & Mosler, in press). To our knowledge, there are, however, no studies which investigated the relationship between handwashing technique and health outcomes. Those studies reporting health benefits of handwashing found these benefits in the absence of particular attention to handwashing technique.

How individuals can be motivated to actually perform effective handwashing technique remains unclear as few studies have investigated the psychosocial and contextual determinants that drive individuals to perform effective handwashing technique. An intervention that included information on how to wash hands effectively and how effective handwashing prevents disease, prompts, and advice on how to cope with barriers was found to improve handwashing technique in health care settings (Lam et al., 2004). In two studies of domestic handwashing, the perceived health benefits of effective handwashing (Hoque, Mahalanabis, Alam, et al., 1995) and attitudinal factors such as the value of personal appearance (Huttly et al., 1994) have been found to be related to more effective handwashing. Contextual factors such as higher education level, higher frequency of handwashing after defecation and before eating and, for children, the amount of time spent with parents have been found to be associated with performing effective handwashing technique (Dobe, Mandal, & Jha, 2013; Hoque, Mahalanabis, Alam, et al., 1995; Song et al., 2013). While these studies provide valuable insights on potential behavioural determinants of effective handwashing, none of them were based on a theoretical framework. To our knowledge, no study yet has systematically investigated the behavioural determinants of effective handwashing. As a consequence, evidence on which behavioural factors steer handwashing technique are fragmentary. The roles of many potential determinants, such as self-efficacy or self-regulation, which have been postulated in theory, remain unknown. Furthermore, the steps that constitute effective handwashing technique, specifically moistening and rinsing hands with running water, applying soap, scrubbing hands with certain steps, and drying hands using a clean towel or air-drying, can be seen as discrete behaviours that are each steered by distinct behavioural determinants. As a consequence, analyses are required to individually identify the behavioural determinants of each handwashing step.

To identify the determinants of water and sanitation behaviours in developing countries, the Risk, Attitudes Norms, Abilities, and Self-regulation (RANAS) model has been applied in various contexts (Lilje et al., 2015; Mosler, 2012; Sonego & Mosler, 2014; Stocker & Mosler, 2015). It comprises a broad array of potential behavioural determinants derived from major theories of social and health psychology and provides a guideline for selecting behaviour change interventions based on behavioural determinants identified in the target populations. The RANAS model has been successfully applied to predict and change the frequency of handwashing at key handwashing situations in several countries (Contzen & Inauen, 2015; Contzen, Meili, et al., 2015; Contzen & Mosler, 2012, 2015).

Taken together, washing hands with an effective technique is recommended by various institutions. However, what drives individuals to do so or prevents them from actually applying effective handwashing techniques remains largely unknown. The first goal of this study is to identify the contextual and psychosocial determinants of performing effective handwashing technique through a case study in high-density suburbs of Harare, Zimbabwe. The second goal is to select behaviour change techniques that target the determinants identified and that thus are suitable for improving handwashing technique in the target population.

4.3 Methods

Study design

A cross-sectional survey was performed in high-density suburbs of Harare in June and July 2014. The study was approved by the Medical Research Council of Zimbabwe, the Research Council of Zimbabwe, and the Ethical Review Board of the University of Zurich.

Sampling

Participants were recruited from high-density suburbs of Harare, Zimbabwe, through random route sampling, by selecting every fifth household starting from randomly selected junctions in the study area. Informed, written consent was obtained from all participants one day prior to data collection. To be included in the sampling frame, households needed to have at least one child attending the local primary school. The primary caregiver in each household was the target participant. With 56 respondents refusing participation in the survey, the refusal rate was 12%. Non-responding, ineligible and refusing households were replaced by the fifth next household on the sampling route. In total, 450 primary caregivers were sampled. Eliminating cases with missing values yielded a final sample size of 434 cases. Estimation of the detectable effect sizes using G*power specified that small to medium effects (f^2 = 0.07) were detected with a Type 1 error probability of α = 0.05 and a statistical power of 0.95.

Data collection

Data were collected through structured observations of handwashing technique, structured quantitative interviews, and spot-check observations using OpenDataKit software on tablet computers (Hartung et al., 2010). Prior to data collection, enumerators were enrolled in one week of theoretical and practical training, which was followed by one week's training in data collection in the field.

For measuring handwashing technique, it was randomly decided whether participants were asked to demonstrate handwashing before eating or after defecation using the random function of OpenDataKit software. The respondent was requested to wash hands in the usual way and reminded that all data were handled confidentially, and that his/her community would benefit most from the survey if the usual handwashing procedure was demonstrated. Enumerators observed the handwashing technique and subsequently recorded the procedure they had observed. The steps recorded included all handwashing steps recommended by CDC for domestic handwashing (Centers for Disease Control and Prevention, n.d.): how hands were moistened and rinsed, whether soap was used, whether specific scrubbing steps were performed, and how hands were dried after washing (See Table 1).

The subsequent structured quantitative interview surveyed potential determinants of performing effective handwashing technique. It was conducted in the local language, Shona, and lasted approximately one hour. The questionnaire had been developed in English, translated to Shona and retranslated to English to minimize the risk of translation mistakes. The interview was divided into two parts. The first part surveyed general constructs that did not require respondents to have a uniform definition of effective handwashing technique. These comprised general knowledge of diarrhoea and its transmission, diarrhoea incidence in the household, the perceived severity of diarrhoea, the perceived frequency of handwashing with soap at key times, action knowledge, action planning, and additional items on the determinants of handwashing frequency. The first part of the interview was followed by a handwashing instruction in which the enumerator demonstrated to the respondent how to wash hands “in a new way”. This new way included all steps considered to constitute effective handwashing (see definition below). This was necessary to ensure that all respondents had the same understanding of effective handwashing technique and to survey their beliefs about effective handwashing technique in a standard way across participants. Perceived vulnerability, attitudes, norms, self-efficacy, action control, and commitment were surveyed in the second part of the interview, followed by the expenditure of time for water collection and socio-demographic characteristics. At the end of each household visit, spot-check observations on the types and condition of handwashing facilities and general hygiene indicators (reported elsewhere) were conducted.

Approximately half of the participants were subject to 3 hours of structured observation of handwashing frequency and microbiological hand sampling before and after the handwashing demonstration.

Measures

General handwashing technique was operationalized through a sum score similar to previous research by Gould (1994) and Chudleigh, Fletcher, and Gould (2005). The number of components of effective handwashing technique that were performed by the respondents was summed on an 8-point index. Based on the recommendations from the Centers for Disease Control and Prevention (n.d.), running water use, soap use, scrubbing palms, scrubbing the back of the hand, scrubbing between fingers, scrubbing under fingernails, and air drying or drying with a clean towel were counted as elements of effective handwashing technique. In addition, scrubbing the fingertips was included. The duration of handwashing or handscrubbing was not considered, because growing evidence suggests that it is less relevant for handwashing effectiveness (Amin et al., 2014; Fuls et al., 2008; Lucet et al., 2002). Thoroughness of handscrubbing was operationalized through a similar sum score which included the number of scrubbing steps performed. Scrubbing palms, scrubbing the back of the hand, scrubbing between fingers, scrubbing under fingernails, and scrubbing the fingertips were counted. Soap use was measured dichotomously and included use of liquid and bar soap. Running water use was also measured dichotomously and represented use of taps with a piped water connection which were installed at kitchen or outside sinks. Tippy taps or containers with valves were not used by participants.

Psychosocial factors of handwashing were selected and measured according to the RANAS model (Mosler, 2012). Factors were measured through single or multiple items. Health and action knowledge were surveyed through open questions with multiple, prespecified answer categories, from which the enumerator selected the answers given by the respondent. The ratio of correct answers given by the respondent to the total number of possible answers was aggregated to indices forming the constructs for health and action knowledge. Action planning was surveyed through dichotomous items asking the respondents whether he/she had concrete plans regarding specific aspects of handwashing, such as where to keep soap or which device to use. Perceived handwashing frequency was computed as the mean of multiple items in which the participants rated the frequency of handwashing on a scale from 0 to 10 for various key handwashing situations (before eating, before cooking, before breastfeeding, before feeding a child, after defecation, after cleaning up a child's bottom, after other contact with stool). All remaining factors were surveyed using unipolar items ranging from 1 to 5. Diarrhoea was explained to respondents using the United Nations Children's Fund and World Health Organisation (2009) definition as the condition of having at least three loose or liquid bowel movements per day. Diarrhoea incidence in primary caregivers and children of the household during the two weeks prior to data collection was recorded. The daily time spent on water collection was measured through two open items that surveyed the time spend to collect water once and the number of times per day that water was collected, which were then multiplied. The household's total water storage capacity, the presence of separate handwashing facilities for food- and stool-related handwashing, and the presence of a functioning water tap was measured through spot checks. Item wordings, descriptive statistics, and inter-correlations of constructs are available from the authors on request.

Analysis

All statistical analyses were performed using IBM SPSS Statistics 22. Only independent variables that correlated significantly with the respective measure of handwashing technique were included in the multivariate models. Since some of the variables were non-normally distributed, Spearman correlations were applied. Five multivariate models were computed to predict overall handwashing technique, the thoroughness of handscrubbing, soap use, running water use, and air drying. To predict the overall handwashing technique and the thoroughness of handscrubbing, multiple linear regression models with two steps were fitted to the data. Structural factors were entered in the first step. In the second step, psychosocial and additional factors were included, while structural factors which had been insignificant in the first model were removed. To identify the determinants of soap use, running water use, and air drying, binary logistic regression was performed. The same hierarchical procedure as in the linear regression was used.

4.4 Results

Complications

Since the model predicting air drying of hands did not fit the data well (R^2 = .11 (Nagelkerke), Model X^2 (9) = 34.85 $p < 0.001$), it is not reported in the following sections. It is available from the authors on request.

Participants

421 participants (97%) were female and 13 participants (3%) were male. On average, the participants had attended 10 years of formal education (SD = 2.5) and were 38 years old (SD = 11.9). The average household size of participants amounted to 5.6 household members (SD = 1.9), and the average household income was 315 USD (SD = 290).

Descriptive analysis of handwashing technique

Participants' handwashing technique is presented in Table 1. The absolute and relative number of participants who performed each handwashing step is displayed. On average, participants performed 4.7 (SD = 7.1) of the 8 steps of effective handwashing. On average, participants performed 2.9 (SD = 1.1) of 5 scrubbing steps.

Table 3. Number of participants who performed each handwashing step.

Handwashing step	n	%
Scrubbing steps		
Scrubbed the palm *	425	98
Scrubbed back *	374	86
Scrubbed between fingers *	243	56
Scrubbed under nails *	108	25
Scrubbed fingertips	111	26
Soap use		
Used soap *	235	54
Did not use soap	199	46
Moistening / Rinsing		
Used running water *	213	49
Poured water on hands	83	19
Dipped hands into water	138	32
Drying		
Air dried *	319	74
Used clean towel *	26	6
Used dirty towel	31	7
Rubbed hands on clothes	58	13

Note: N=434. Handwashing steps marked with a * are recommended by the CDC. While performing the marked scrubbing steps is recommended, either air-drying or using a clean towel is required.

Determinants of handwashing technique

Table 2 presents the results of the hierarchical multiple linear regressions of structural and psychosocial determinants of handwashing on general handwashing technique and the number of handscrubbing steps performed and the hierarchical multiple binary logistic regressions explaining soap use and running water use.

Table 4. Hierarchical multiple linear regression explaining handwashing technique and number of scrubbing steps performed and hierarchical multiple binary logistic regression explaining soap use and use of running water.

	Overall technique			Thoroughness of scrubbing			Soap use			Running water use		
Predictor	B	95% CI	Beta	B	95% CI	Beta	B	Odds Ratio	95% CI	B	Odds Ratio	95% CI
Model 1												
(Constant)	3.72 ***	[3.34, 4.1]		2.57 ***	[2.32, 2.82]		-0.91 ***	0.40		-2.42 ***	0.09	
Water collection time * frequency	0.00	[0, 0]	-0.04	0.00	[0, 0]	-0.03				-0.01 *	0.99	[0.99, 1]
Separate handwashing facilities food / stool	0.24	[-0.14, 0.62]	0.06	0.17	[-0.1, 0.44]	0.06	0.43 (*)	1.54	[0.94, 2.52]			
Functioning tap	1.15 ***	[0.84, 1.47]	0.33	0.34 **	[0.11, 0.56]	0.15	0.56 **	1.74	[1.16, 2.61]	3.17 ***	23.75	[13.53, 41.7]
Situation: Stool related	0.29 (*)	[-0.01, 0.59]	0.09				0.77 ***	2.15	[1.46, 3.19]	0.87 **	2.38	[1.44, 3.94]
R^2 (adjusted) / R^2 (Nagelkerke)	0.13			0.02			0.09			0.51		
F / X^2	17.16 ***			4.54 **			29.09 ***			206.90 ***		
Model 2												
(Constant)	0.70	[-0.97, 2.38]		0.35	[-0.8, 1.5]		-4.09 *	0.02		-3.74 ***	0.02	
Water collection time * frequency										-0.01 *	0.99	[0.99, 1]
Functioning tap	1.02 ***	[0.76, 1.28]	0.30	0.25 *	[0.03, 0.48]	0.11	0.03	1.03	[0.56, 1.87]	3.12 ***	22.72	[12.76, 40.47]
Situation: Stool related							1.06 ***	2.87	[1.77, 4.66]	0.84 **	2.31	[1.37, 3.89]
Perceived vulnerability	0.26 *	[0.01, 0.5]	0.08	0.12	[-0.05, 0.29]	0.06	0.45 *	1.57	[1, 2.46]			
Perceived severity							-0.37 *	0.69	[0.52, 0.92]			
Health knowledge	0.10	[-0.12, 0.32]	0.04	0.19 *	[0.03, 0.34]	0.11						
Investment							-0.29 **	0.75	[0.62, 0.91]			
Return							0.15	1.16	[0.78, 1.72]			
Example	-0.48 ***	[-0.69, -0.27]	-0.18	-0.17 *	[-0.31, -0.02]	-0.09	-0.88 ***	0.42	[0.27, 0.63]			
Descriptive norm house	0.08	[-0.04, 0.2]	0.05	0.00	[-0.08, 0.08]	0.00	0.25 (*)	1.28	[0.98, 1.67]	0.17	1.19	[0.94, 1.5]
Descriptive norm community							-0.11	0.90	[0.57, 1.43]			
Action knowledge time	-0.06	[-0.23, 0.22]	0.00	0.03	[-0.13, 0.18]	0.01						
Action knowledge steps	0.74 ***	[0.57, 0.91]	0.37	0.55 ***	[0.43, 0.66]	0.41	0.28 (*)	1.33	[0.99, 1.79]			
Self-efficacy	0.07	[-0.1, 0.24]	0.04	0.10 (*)	[-0.01, 0.22]	0.08	0.02	1.02	[0.74, 1.41]			
Action planning	0.22 **	[0.08, 0.37]	0.12	0.03	[-0.07, 0.13]	0.03	0.44 **	1.55	[1.17, 2.06]	0.19	1.21	[0.9, 1.64]
Action control	0.05	[-0.24, 0.33]	0.02	-0.02	[-0.21, 0.18]	-0.01	0.34	1.40	[0.81, 2.43]			
Used running water				-0.02	[-0.24, 0.21]	-0.01	0.69 *	2.00	[1.1, 3.62]			
Used soap				0.48 ***	[0.28, 0.68]	0.21				0.41	1.50	[0.84, 2.69]
Air dried				0.39 ***	[0.19, 0.59]	0.15						
Handwashing frequency	0.24 **	[0.09, 0.4]	0.13	-0.06	[-0.17, 0.05]	-0.05	0.86 ***	2.37	[1.75, 3.2]	0.00	1.00	[0.73, 1.35]
R^2 (adjusted) / R^2 (Nagelkerke)	0.39			0.37			0.42			0.52		
F / X^2	26.34 ***			18.85 ***			161.69 ***			216.90 ***		

Note: N=434; (*) p < .1, * p < .05, ** p < .01, *** p < .001.

Determinants of the overall handwashing technique

Model 1 included structural factors and accounted for 13% of the variance in handwashing technique. However, the inclusion of psychosocial factors and the perceived frequency of handwashing with soap increased the model fit to 39%. Standardized regression coefficients revealed that knowing the handwashing steps that constitute effective technique (action knowledge) and having a functioning tap as handwashing facility were the most relevant predictors of handwashing technique. Counterintuitively, the participants' perception that they showed a good example to children when washing hands in the recommended way (example), was negatively associated with effective handwashing technique. The perceived frequency of handwashing with soap, planning where to wash hands and store soap (action planning), and the perceived risk of contracting diarrhoea (perceived vulnerability) were further significant determinants.

Determinants of thorough handscrubbing

While merely 2% of the variance in the number of performed scrubbing steps was explained by structural factors, adding psychosocial factors, handwashing frequency, and performance of other handwashing steps increased the explained variance to 37%. Knowing the steps of effective handwashing was the strongest predictor in the model. Further, participants who used soap, air dried their hands and had a functioning tap also scrubbed their hands more thoroughly. Having basic knowledge about diarrhoea and its prevention (health knowledge) and feeling capable of complying with the recommended handwashing technique (self-efficacy) was also associated with performing more handscrubbing steps. The participants' perception that they showed a good example to children when washing hands in the recommended way was negatively associated with thorough handscrubbing.

Determinants of soap use

While the model including structural factors correctly estimated soap use for 60% of participants, the model additionally including psychosocial factors correctly estimated 76%. The data show that soap was related to the handwashing situation: Soap was more frequently used when stool-related handwashing was demonstrated. Further, washing hands with running water and higher perceived frequency of handwashing with soap in daily life was related to soap use. Unstandardized parameter estimates of the psychosocial factors, which were all coded from 1 to 5, can be directly compared: The perception that participants showed a good example to children when washing hands in the recommended way was negatively related to soap use and the strongest psychosocial determinants in the model. Further, participants who felt less vulnerable to diarrhoea when washing hands with the effective technique used soap more frequently. Participants who had a concrete plan where to wash hands and keep soap for handwashing and participants who perceived diarrhoea to be less severe used soap more frequently. Further determinants of soap use included the perception that performing effective handwashing technique was effortful, knowledge of the steps of effective handwashing, and perceiving other household members washing hands with soap too.

Determinants of running water use

The model including structural factors correctly estimated running water use for 74% of the participants, and including psychosocial factors did not improve the model fit further. The availability of running water at the handwashing facility was the most prominent determinant of actually using running water for handwashing. In addition, participants used running water more frequently for stool-related than food-related handwashing. Interestingly, the preliminary correlational analyses revealed that socio-demographic characteristics of the households, such as the number of household members and household income, and of the participants, such as age and education, were not found to be related to any of the above measures of handwashing technique.

4.5 Discussion

The goal of this study was to identify the contextual and psychosocial determinants of performing effective handwashing technique and, based on the results, develop data-driven and population-tailored behaviour change interventions. In a cross-sectional survey, we observed the handwashing technique of 434 primary caregivers of primary school children in Harare and surveyed psychosocial and structural determinants through quantitative structured interviews and spot checks. Knowledge of how to wash hands effectively, availability of a handwashing station with functioning water tap, self-reported frequency of handwashing, perceived vulnerability, and action planning were the main determinants of performing effective handwashing technique. Creative memory aids, guided practice, personalized risk messages, and daily routine planning are proposed to change the identified determinants and trigger behaviour change towards more effective handwashing technique.

Interpretation of results and practical implications

Performing effective handwashing technique was found to be related to frequent handwashing. This suggests that promoting frequent handwashing at key handwashing situations is also a promising strategy to increase handwashing effectiveness.

Performance of the different components of handwashing technique was interdependent. Participants who used soap and air dried hands also scrubbed hands more thoroughly. Using running water from a tap and using soap were strongly associated with each other. This means that promoting a single element of effective handwashing technique might also prompt participants to improve on other components.

Having a place for handwashing with a functioning tap was the strongest structural determinant of effective overall handwashing technique. This stems from the fact that participants who had a functioning tap at the time of visit actually used it for handwashing. This is not trivial: Despite having a functioning water tap, people could still prefer to moist hands by dipping them into a bowl with water, which is a traditional way of handwashing in Zimbabwe (Kaltenthaler et al., 1991). Further, those who had a tap scrubbed hands more thoroughly. As a consequence, promoting and supporting tap acquisition is a promising strategy for improving handwashing technique.

Lower perceived vulnerability to diarrhoea when washing hands with effective technique was related to better overall handwashing technique. According to the RANAS model, perceived vulnerability is targeted by personalized risk messages. A modified version of the handwashing experiment reported by (Scott et al., 2008) is proposed; this visualized the remaining hand contamination after ineffective and effective handwashing and highlighted the resulting risks of contracting diarrhoea.

The perception of the respondents that they showed a good example to children when washing hands as recommended was negatively related to the overall handwashing technique. This surprising result stems primarily from the negative association with soap use. Possible explanations are that participants believed that it was a waste of soap if children used it or that encouraging children to use soap might prompt them to play with it. Actually using soap made this belief more salient and resulted in the negative association detected in the bivariate correlations and regression models. This hypothesis is supported by findings from the qualitative prestudy of this survey, in which participants reported being worried that children might waste soap. Since this explanation suggests reverse causality, interventions targeting this factor are not proposed.

Action knowledge was the strongest predictor of overall handwashing technique and thoroughness of handscrubbing. Knowing how to perform the behaviour is a precondition for its execution (Mosler, 2012). To increase action knowledge, the RANAS model suggests knowledge transfer. This could be achieved, first, through guided practice during the handwashing experiment and, second, through a memory aid in the form of a handwashing song which enumerates all the steps of the effective technique.

Action planning was a significant predictor of overall handwashing technique, which stems from the association between action planning and soap use. According to the RANAS model, action planning is increased by daily routine planning. Planning where, when, and how to maintain a designated place for handwashing would empower participants to maintain an enabling environment in which to perform effective handwashing technique. Plans should also account for possible disruptions of the daily life, for example through power or water cuts. This may also be a promising intervention strategy to partly substitute the availability of a functioning water tap.

Limitations and future directions

This paper proposes interventions to increase compliance with existing handwashing recommendations. Compliance with complex recommendations might be inconvenient or even not practicable in some contexts (Bloomfield et al., 2007; Sandhu & Goodnight, 2014). This calls for additional studies in low-income settings of developing countries to establish which of the presently recommended handwashing steps are both, practicable during the daily life or participants and relevant for removing pathogens. This should inform the content of future handwashing recommendations.

Handwashing technique that is frequently repeated in the same contexts during the daily routine may be strongly habit driven. It may thus not be predominantly determined by the behavioural factors postulated in the RANAS model but be triggered by cues such as location and preceding actions. Implementation intentions and installation of prompts are proposed to counter the possibly strong habit of washing hands with the usual, mostly insufficient technique and complement the data-driven interventions (Gollwitzer, 1999; Tobias, 2009).

Being directly observed while washing hands may have prompted participants to wash their hands in an ideal way. However, despite being observed, participants washed hands with a suboptimal technique. To reduce the observation bias, participants were explicitly reminded that they would help their community most if they supported the study by washing hands in the usual way, and that all data were handled confidentially. Further, the primary aim of this study was not to objectively survey compliance with handwashing guidelines in the study communities but to uncover correlational associations between handwashing technique and structural and psychosocial factors. Even if the observed handwashing technique had been subject to biases, it would not per se have affected the relation to the determinants of handwashing. Assessing handwashing technique through structured observations would probably yield a less biased measure of handwashing technique. Comparing the values obtained from demonstrations to the values obtained from structured observations would provide valuable insights on whether handwashing demonstrations are valid proxy measures for observed handwashing technique.

Most of the behavioural determinants of handwashing technique were surveyed on single-item scales which results in less reliability of the constructs. However, those items which were measured on multiple-item scales showed acceptable internal reliability. Further, this study was purely cross-sectional and, consequently, no causality can be inferred. This calls for field experiments to manipulate these behavioural determinants with the proposed interventions and test whether changes in the determinants would actually result in behaviour change and habit formation. Long-term evaluations, are recommended to assess the sustainability of the interventions.

Conclusions

This study is the first to apply a data- and theory-driven procedure to designing interventions that target a largely unheeded dimension of domestic hand hygiene: handwashing technique. This study suggests guided practice, creative memory aids, such as a handwashing song, personalized risk messages, and daily routine planning to target the most important behavioural determinants and so improve handwashing technique in the target population. This study presents interventions to improve handwashing technique in low-income settings where environmental contamination is high and effective handwashing is most needed.

4.6 Acknowledgements

We thank Dr Robert Tobias, for his valuable contribution to the survey design, the field coordinators Belladonnah Muzavazi and Eustace Sangoya, the enumerator team, Dr Simon Milligan for proof reading and all study participants in Harare.

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

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A similar version of this chapter is submitted for publication.

5.1 Abstract

Consistent hand hygiene at key times can prevent diarrhoeal 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.

We used a cluster-randomized, factorial, controlled trial to test the effects of two handwashing interventions on the behaviour 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 faecal hand contamination before and after handwashing.

Combining the direct and indirect interventions resulted in 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. However, no statistically significant group differences in faecal hand contamination before or after handwashing were detected.

The results provide strong evidence that the campaign successfully improved both 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 behaviour change. We did not find evidence that children acted as strong agents of handwashing behaviour 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.

5.2 Introduction

Diarrhoea 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 diarrhoeal and other infectious diseases (Borghi et al., 2002; Curtis & 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 faecal contact (Curtis, Danquah, & Aunger, 2009; Freeman et al., 2014). This calls for effective handwashing promotion, particularly in low-income countries, where the diarrhoeal disease burden is highest.

Social-cognitive theories have predominantly been used to explain health behaviours (Conner & Norman, 2005). However, few studies have applied them to inform the design of handwashing campaigns; (see Contzen and Inauen (2015); Contzen, Meili, et al. (2015); Luby et al. (2010) for examples). In this study, the risks, attitudes norms, abilities, and self-regulation (RANAS) approach (Mosler, 2012) was used to design the interventions. It has been previously applied in several studies to gain a deeper understanding of the behavioural factors that drive water, sanitation, and hygiene behaviours in developing countries and to derive interventions that specifically target the relevant factors (Lilje et al., 2015; Mosler, 2012; Sonego & Mosler, 2014; Stocker & Mosler, 2015).

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, Meili, 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., 2014; Biran et al., 2009); 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 behaviour 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); Biran et al. (2009); Contzen, Meili, 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 these studies 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 behaviour 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 behavioural and microbial outcomes and to assess the interrelation of outcome measures.

5.3 Methods

Trial design

This study was a cluster-randomized, factorial, 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. The four intervention 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 additional 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, Piaggio, Elbourne, & Altman, 2012).

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 neighbourhood 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 third 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 third next household was selected. Informed written consent was sought from all participants. Masking of participants was not possible, because the consent procedure included, per requirement of the Medical Research Council of Zimbabwe, informing participants about the content of the study.

Sample size

Sample size was estimated using G*Power 3.1.9.2 and yielded a sample size of 305 participants required to detect medium effects in Cohens f^2 >0.25 at Type 1 error probability of .05 and statistical power of .95. Since drop-out rates were uncertain at baseline, we decided to assume a worst-case drop-out rate of nearly 50% and enrol 600 participants in the study. The sample sizes at both cluster and individual levels are displayed in the flowchart of the sample (Figure 2).

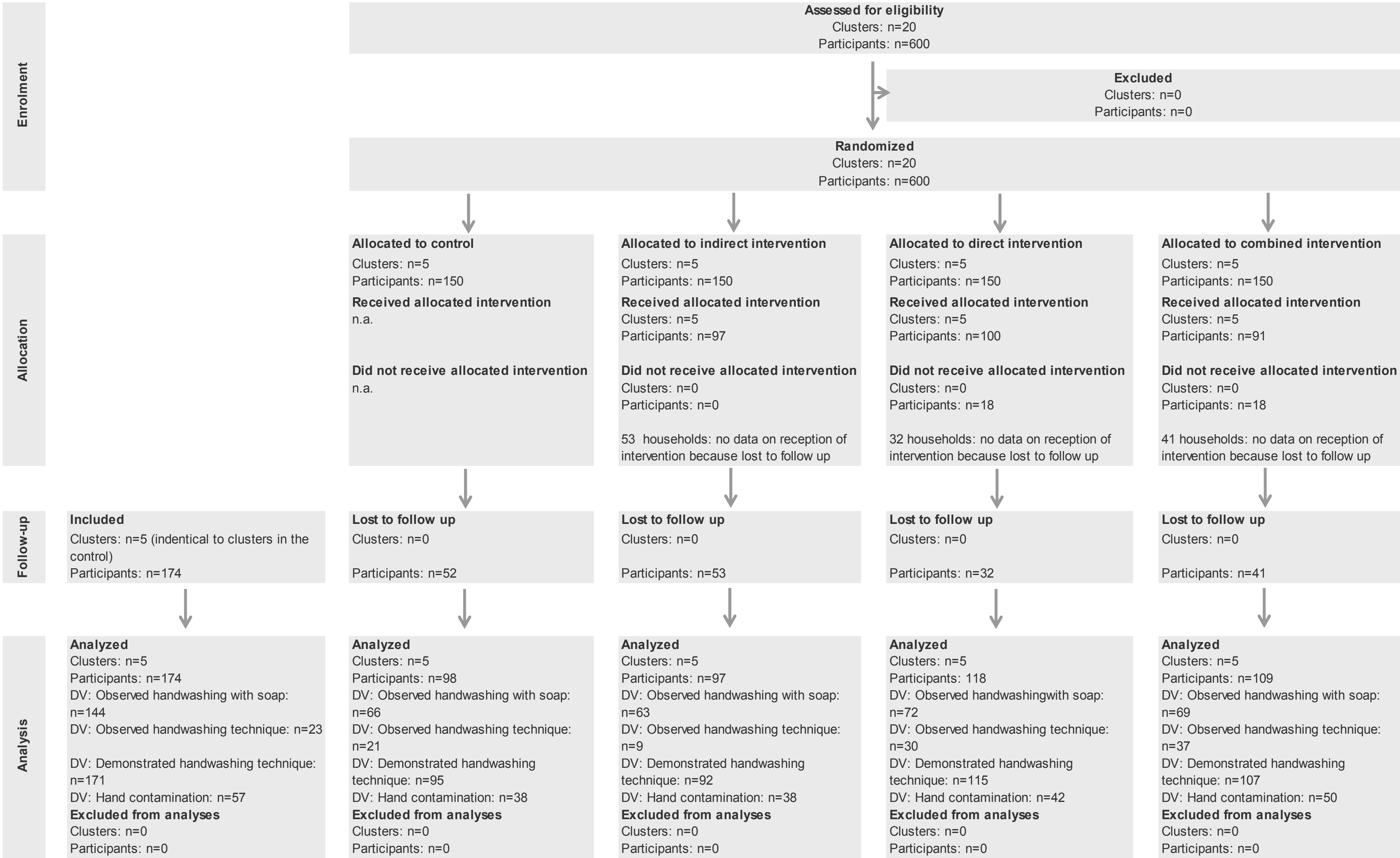

Figure 2: Flow diagram of the sample. Note: DV=Dependent variable.

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.

Interventions

All interventions used a data-driven approach to tailor the interventions to the specific characteristics of the target population. We used the risks, attitudes, norms, abilities, and self-regulation (RANAS) approach to systematic behaviour change (Mosler, 2012). The RANAS approach combines leading social-cognitive theories from health and environmental psychology and constitutes a guide to the design and evaluation of behaviour change interventions. The factors steering handwashing behaviour in the target population were identified through a quantitative survey of handwashing behaviour and behavioural factors. To change these factors and, consequently, change handwashing behaviour, specific behaviour change techniques (BCTs) were selected to target each relevant factor. These BCTs were combined into intervention strategies, and each strategy was implemented in a 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 key stakeholders, including health promoters, local health centre staff, school teachers, school heads, councillors, and members of the residence association, and the campaign was revised accordingly. The structure and content of the community and school level interventions are displayed in Table 5 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.

The community-based direct interventions were implemented by the staff of the local health centres, and the school-based interventions were implemented by teachers at the local primary schools. Each intervention strategy was implemented in one week. The health centre 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.

Table 5: Structure and content of the direct interventions with caregivers.

Strategy caregivers	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 behaviour	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 behaviour	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 behaviour	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 with the barriers of not washing hands with soap when in a hurry or not feeling like washing hands at the right moment.	Confidence in performance + Others' (dis)approval
			BCT 30 Prompt coping with barriers		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 6: Structure and content of the indirect interventions targeting caregivers indirectly through their children.

Strategy children	Slogan	Communication channel	BCT	Activities	RANAS factor targeted
1	Handwashing? Of course! It helps me stay healthy!	Interpersonal: Class-room activity	BCT 1 Present facts	The teacher asks the students what diarrhoea is, how diarrhoea is spread, and how it can be prevented. Discussion of faecal-oral route poster.	Health knowledge
			BCT 2 Present scenarios	Students reflect when the processes shown on the faecal-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	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. Colourful 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
			BCT 34 Use memory aids and environmental prompts		Remembering
		Interpersonal: Class-room 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 diarrhoea risk.	Vulnerability
3	Handwashing? Of course! We can do it!	Interpersonal: Class-room 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 behaviour	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: Class-room 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).

Data collection & outcomes

Outcome variables were assessed at baseline and follow-up by trained local data collectors. The training included one week of theoretical and practical training on observation, interviewing, and sampling techniques. Behavioural 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 of 270 participants through 3-hour 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. This 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-hour 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 correctly performed handwashing steps 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 fingertips, (7) scrubbing under the fingernails, and (8) drying hands using a clean towel or air drying. 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).

Hand contamination before handwashing was measured as the number of *E.coli* bacteria in hand rinse samples, as previously reported (Pickering, Boehm, 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 observations. In households which 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. (in press). Bacterial counts were log transformed for analyses.

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 one-hour structured interview on self-reported handwashing behaviour and the social-cognitive factors of handwashing.

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 handwashing frequency 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. 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. All analyses were conducted using SPSS 22.

5.4 Results

Baseline characteristics

At baseline, intervention and control households had very similar socio-demographic characteristics (Table 7). 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 are not reported, because they were not part of the baseline observation protocol.

Table 7: 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								
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	
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								
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 (%)	1.3	(3.0)	8.9	(6.1)	9.4	(7.1)	3.1	(4.3)
Mean (SD) Demonstrated handwashing technique	4.8	(0.5)	4.5	(0.6)	4.5	(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)	1.8	(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.

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 additional control, 5% in the control, and 2% in the indirect intervention group (Figure 3, left). Handwashing frequency in the direct intervention group was significantly higher than in the indirect intervention group ($p < .001$). The comparisons of additional control vs. control, control vs. indirect intervention, and direct vs. combined intervention did not yield significant differences.

Effects on observed handwashing technique

Observed handwashing technique (Figure 3, right) was similar in the additional 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 groups were statistically significant ($p < .005$).

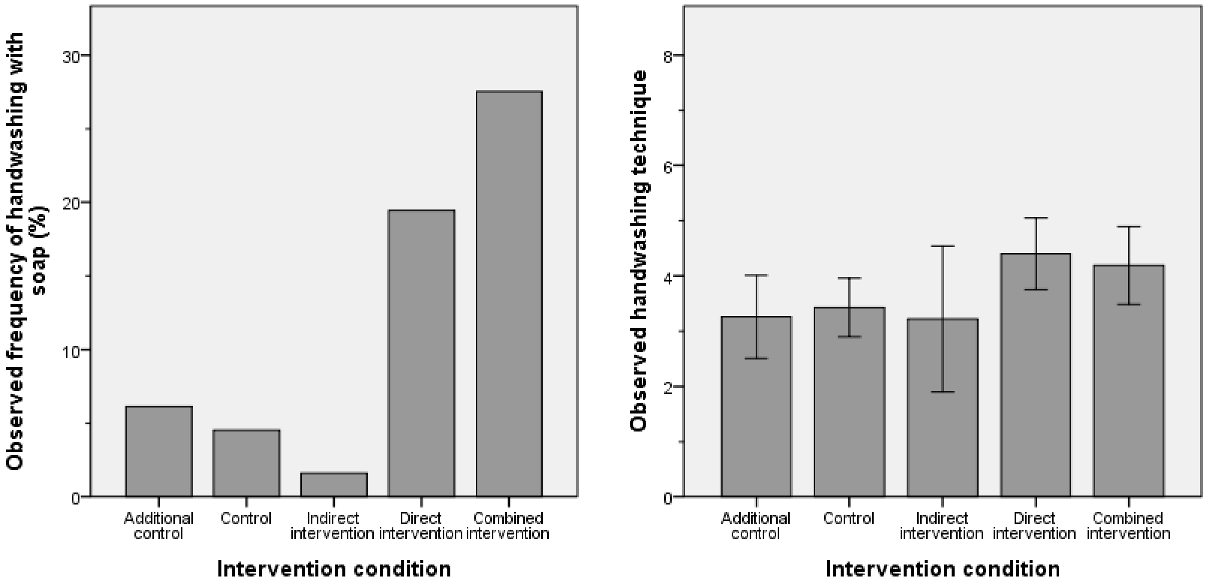

Figure 3: Observed frequency of handwashing with soap (left) and observed handwashing technique (right) at six weeks follow-up after the interventions.

Effects on demonstrated handwashing technique

Figure 4 shows the mean rates in demonstrated handwashing technique. It was significantly higher in the control group (5.2 steps) than in the additional control group (4.5 steps, $p < .001$) and significantly higher in the direct intervention group (6.2 steps) than in the indirect intervention group (6.8 steps, $p = .004$).

Effects on hand contamination and bacteria removal

Hand contamination measured before and after the handwashing demonstration (Figure 4) 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.

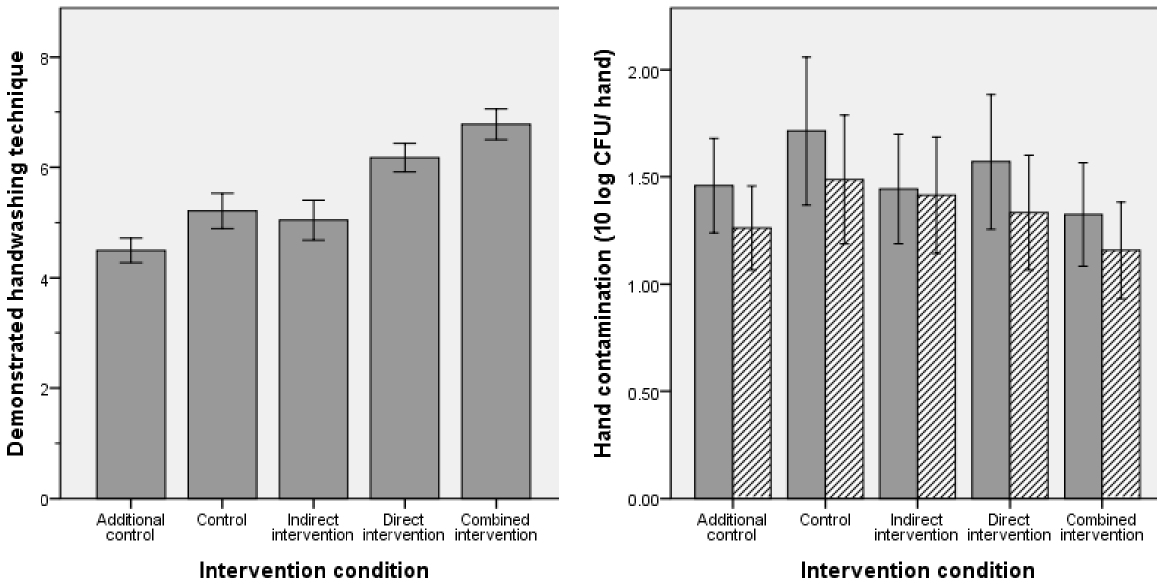

Figure 4: Observed demonstrated handwashing technique (left) and *E.coli* hand contamination (right) before handwashing (solid bars) and after handwashing (hatched bars) at six weeks follow-up after interventions.

Correlation of outcome measures

The correlation of outcome measures is displayed in Table 8. All behavioural 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 bacteria were not correlated significantly.

Table 8: 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	**.484*****								
Demonstrated handwashing technique	186	**.253*****	51	**.494*****						
Hand contamination before washing	79	.000	26	.117	222	-.084				
Hand contamination after washing	79	-.087	26	.081	222	**-.177****	225	**.555*****		
Removal of hand contamination	79	-.020	26	-.069	222	-.095	225	**-.561*****	225	**.298*****

Note: r = Spearman's rho; * p < .05, ** p<.01, *** p<.001.

5.5 Discussion

The aims of this study were twofold: First, to evaluate a handwashing campaign which aimed at improving both handwashing frequency and technique using behavioural and microbial outcome indicators and second, to compare the relative effectiveness of handwashing promotions targeting caregivers directly with indirect promotions through their children. In a cluster-randomized, factorial, controlled trial we compared the two approaches and a combination of both and assessed the impact on observed handwashing frequency, handwashing technique, and faecal hand contamination before and after handwashing.

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. The direct intervention with caregivers was the single most effective strategy to increase their handwashing frequency and technique at key handwashing times. Implemented alone, the interventions targeting children did not have a significant effect on caregivers' handwashing behaviour. In contrast to previous findings, (Bresee, Caruso, Sales, Lupele, & Freeman, 2016; Mwanga et al., 2008; Onyango-Ouma et al., 2005) our results do not provide support for the hypothesis that children can be strong agents of change for hygiene. 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 behaviour upon request from their children.

Behavioural outcomes were interrelated. The strong correlation of observed handwashing frequency and observed handwashing technique suggest that both dimensions of handwashing behaviour 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 correlation between demonstrated handwashing technique and hand contamination after washing provides further evidence for this effect.

Several reasons may underlie the, however, surprisingly low correlation between handwashing technique and 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, Malik, Cooper, Looker, & Michaels, 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 mainly on those steps which are less relevant for microbial handwashing effectiveness. Quantification of the relative effectiveness of the handwashing steps supports this hypothesis (Friedrich et al., in press). The study showed that scrubbing the fingertips and scrubbing under nails were most strongly related to reduced post-wash hand contamination, while scrubbing the backs of hands or between fingers was not associated with reductions in hand contamination. An increase in handwashing technique score due to scrubbing the back of the hand would consequently not have resulted in increased handwashing effectiveness.

Despite strong effects on handwashing frequency, the campaign did not significantly impact pre-wash hand contamination. Recontamination is likely to explain this finding. Recontamination of hands to pre-wash levels after 30 minutes has been reported by Devamani et al. (2014), and Ram et al. (2011) reported substantial recontamination within 2 hours. 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.

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.

Protocol deviations were noted during the implementation of the campaign. In BCT 8 of the direct intervention (Table 5), the discussion focused on the risk of not washing hands with soap instead of focusing on disgust. In BCT 26, not all behavioural plans were documented correctly, and self-monitoring calendars (BCT 27) were, in some communities, distributed late at a revisit. BCT 1 (Table 6) of the intervention with children was partly implemented without posters explaining the faecal-oral route. 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 behaviour, despite the protocol deviations.

Although structured observations are the preferred method of surveying handwashing behaviour (Ram, 2013), they are likely to be subject to reactivity; participants modify their handwashing behaviour when they know that they are being observed (Kohli et al., 2009). Values of observed handwashing behaviour should consequently be considered an optimistic measure of actual behaviour. 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.

To our knowledge, this campaign evaluation is the first of its kind to report considerable improvements in handwashing frequency and technique using a sound operationalization of both dimensions of handwashing behaviour. 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 behaviour 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.

5.6 Acknowledgements

This work was funded by the Swiss Agency for Development and Cooperation (SDC) and Eawag. SDC and Eawag have not officially endorsed this publication and the views expressed may not represent the views of SDC and Eawag. We are grateful to Health Services at the City of Harare, Ministry of Primary and Secondary Education of Zimbabwe, Health Centre Staff and Teachers for implementing the campaign; ActionAid Zimbabwe, Farm Community Trust of Zimbabwe and the Combined Harare Residence Association for coordination of the campaign implementation and logistic support; Dr. Tamuka Nhiwatiwa for his collaboration and support throughout the project; Innocent Hove, Friederike Neiske Pablo Streich, Ellen Struve and Karin Stögerer for their laboratory contributions; Marcel Lauber, Nadine Romann and our field coordinators Belladonnah Muzavazi and Eustace Sangoya for their valuable contributions to the data collection; the enumerator team; and all study participants in Harare.

6 Summary of results and general discussion

This chapter discusses the general implications of the three empirical chapters. First, the results are summarized. Second, their implications for how handwashing behaviour affects hand contamination are discussed. Third, the behavioural factors of handwashing technique are put in context with those commonly associated with handwashing frequency. Fourth, the implications for handwashing behaviour change are debated. Fifth, the findings are combined into an integrated framework for changing handwashing behaviour and hand contamination. Last, the strengths and limitation of this thesis are debated and general conclusions are drawn.

6.1 Summary of results

In this section, the findings of the empirical chapters are summarized with regard to each research question. Each chapter has already placed its findings in the context of the available literature, so this is not repeated here.

In Chapter 3, the handwashing technique of caregivers in Harare was observed at their homes, and hand rinse samples were taken before and after handwashing. Handwashing technique was operationalized as the number of handwashing steps recommended by the Centers for Disease Control and Prevention (n.d.) that were actually performed by participants. In response to Research Question 1a

> *Which handwashing technique is (a) effective in decontaminating hands in low-income settings in developing countries?*

generalized linear models were used to quantify how each handwashing step predicted handwashing effectiveness, that is reduced hand contamination after washing. Statistically relevant steps comprised moistening hands under a tap, soap use, scrubbing under the fingernails, scrubbing the fingertips, and drying hands by rubbing them on clothes being worn. Neither the total handwashing time nor a scrubbing time of at least 20 seconds was associated with handwashing effectiveness.

In response to Research Question 1b

Which handwashing technique is (b) practicable in low-income settings in developing countries?

for each handwashing step, the number of participants who practised it was determined. This showed that most steps recommended by the Centers for Disease Control and Prevention (n.d.), were practised by a considerable number of people in the study population. Findings for Research Question 1 are discussed further in Section 6.2.1.

In response to Research Question 3

Are general hand contamination and handwashing effectiveness interrelated?

general hand contamination was introduced as a predictor in the generalized model described for Research Question 1. This identified general hand contamination as a highly significant predictor. If general contamination was high, hand contamination after washing remained high. This was further corroborated by correlational analysis presented in Chapter 5.

In Chapter 4, the behavioural factors steering handwashing technique were identified by modelling the handwashing technique performed by study participants at their homes as a function of social-cognitive and contextual behavioural factors. In response to Research Question 4

Which behavioural factors steer handwashing technique?

four factors were identified: knowledge of how to wash hands effectively, availability of a handwashing station with functioning water tap, perceived vulnerability to contracting diarrhoea, and action planning. A considerable share of variance in handwashing technique (39%) could be explained by the model. To target these factors and increase handwashing technique, four interventions were proposed: Memory aids and guided practice were suggested to consolidate action knowledge; personalized risk messages should increase the perceived vulnerability to contracting diarrhoea; and planning where, when, and how to maintain a designated place for handwashing with sufficient soap and water was proposed to increase action planning. The behavioural factors steering handwashing effectiveness are discussed further in Section 6.3.

In response to Research Question 2

Are handwashing frequency and handwashing technique interrelated?

self-reported handwashing frequency was used as an independent variable to predict handwashing technique. This revealed a positive association of handwashing technique and handwashing frequency. This was corroborated through bivariate correlations reported in Chapter 5.

In Chapter 5, interventions to enhance handwashing technique and frequency were evaluated using 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 intervention targeting caregivers through their children and to determine the effect of combining the interventions. In response to Research Question 5

Can theory-based interventions enhance both (a) handwashing technique and (b) frequency?

the evaluation revealed that the campaign significantly enhanced both dimensions of handwashing behaviour. Combining direct and indirect interventions resulted in observed handwashing with soap at 28% of key handwashing situations, 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 steps, while the control averaged 3.4 steps. Demonstrated handwashing technique increased to a mean of 6.8 steps; the control averaged 5.2 steps. Campaign effects on behaviour are discussed further in Section 6.4.

In response to Research Question 6

Which mode of delivery, (1) targeting caregivers directly, (2) targeting caregivers indirectly through their children, or (3) a combination of both, is most effective in changing handwashing behaviour?

the evaluation showed that the direct intervention was significantly more successful in changing caregivers' handwashing behaviour than the indirect one. The indirect intervention did not trigger any statistically significant change in caregivers' behaviour. Comparison of the direct with the combined intervention did not yield significant group differences. Despite that, values for both technique and frequency were higher in the combined intervention group than in the indirect one. Potential reasons why the indirect campaign failed are discussed in Section 6.4.2.

In response to Research Question 7

> *Does enhancing handwashing technique increase microbial handwashing effectiveness?*

Chapter 5 revealed that handwashing effectiveness was similar throughout the control and all intervention groups, despite significant improvements in handwashing technique in the direct and combined intervention groups. Improvements in handwashing technique thus did not result in enhancements in handwashing effectiveness. The implications of this finding on handwashing recommendations are discussed in Section 6.2.1.

In response to Research Question 8

> *Does enhancing handwashing frequency reduce general hand contamination?*

the campaign evaluation showed that general hand contamination was similar across all groups, despite strong increases in handwashing frequency in the direct and combined intervention groups. Improvements in handwashing frequency thus did not result in reduced general hand contamination. This finding is discussed further in Section 6.2.2.

6.2 Handwashing and hand contamination

This section discusses the main findings of this thesis on the relationship between handwashing behaviour and hand contamination. First, implications are discussed for the existing recommendations of handwashing technique. The second issue addressed is the problem of recontamination and strategies to achieve sustained hand cleanliness beyond key handwashing situations.

6.2.1 Discussion of existing recommendations for effective handwashing

Handwashing needs to be both effective in removing pathogens from hands and practicable for individuals during their daily lives (Bloomfield et al., 2007). This section discusses the applicability of handwashing recommendations from industrialized countries to low-income contexts in developing countries. The discussion is primarily based on results in response to Research Question 1. Since only the Centers for Disease Control and Prevention (n.d.) refer specifically to domestic handwashing, the discussion focuses on this recommendation. In the following paragraphs, each recommended handwashing step is reviewed individually. Longitudinal findings in response to Research Question 7 are also included.

Use of clean running water

In the population of this case study, functioning water taps were not available in all households. This limitation constituted a physical constraint to compliance with the recommendation to moisten and rinse hands using clean, running water from a tap. Similarly, Sandhu and Goodnight (2014) identified the availability of clean water in large quantities as a major challenge in low-income contexts. The practicability of tap use is thus doubtful. But is tap use actually necessary for effective handwashing?

Chapter 3 showed that washing hands using running water from a tap yielded more effective handwashing, that is, reduced hand contamination after washing, than moistening hands by dipping them into a vessel with water or by pouring water on hands manually. This suggests that, in this case study, tap use was indeed an important step in effective handwashing. Reflecting on the underlying reasons may provide first indications on how generalizable this finding is. Three mechanisms may explain the relevance of tap use found in Chapter 3: First, higher handwashing effectiveness when using a tap could be a consequence of tap water being less contaminated. This is in line with previous findings indicating higher contamination of stored water (Genthe et al., 1997; Levy et al., 2008; Palit et al., 2012; Pickering, Davis, et al., 2010). Second, using a tap allows handscrubbing during hand moistening and rinsing, which may lead to additional removal of germs. However, this is not supported by Chapter 4, which showed that tap use was not associated with more intensive handscrubbing. Third, tap users might have used more tap water for handwashing because it was available in larger quantities than stored water; this may have resulted in more effective handwashing. This is supported by Hoque, Mahalanabis, Alam, et al. (1995), who found that use of larger quantities of water for handwashing was associated with more effective handwashing. In summary, quality and quantity of tap water may explain the higher handwashing effectiveness associated with tap use. If these assumptions hold, tap use per se would not automatically result in more effective handwashing. In contrast, tap water would also have to be of superior quality than alternatives and be available in larger quantities. The first point in particular is likely to be context specific, as the quality of tap water has been found to be highly variable in developing countries (Lee & Schwab, 2005). In summary, tap use was consistently associated with more effective handwashing in this study, but this result may be confounded by water quality and quantity. More studies that control for these confounders are needed to determine whether tap use per se should be part of handwashing recommendations for low-income countries.

Handscrubbing

As a first of its kind, Chapter 3 quantified which handscrubbing steps are most relevant for effective handwashing. The findings suggest that scrubbing the fingertips and scrubbing under fingernails were essential for effective handwashing. Comparing the magnitude of effects yields more than fourfold effects for scrubbing the fingertips and under nails than for soap use or running water use. This suggests that these steps should be an integral element of handwashing recommendations. In contrast, insignificant effects suggest that scrubbing the backs of hands and between fingers should not be recommended. Additional studies are needed to corroborate these findings, as general conclusions cannot be drawn from this study alone. In addition, the effectiveness of each scrubbing step is likely to depend on the pre-wash contamination levels on particular parts of the hand. For example, if fingertips were clean before washing, scrubbing them during handwashing would not yield any added value. Quantifying the spatial distribution of hand contamination in different settings and in the context of different activities would provide valuable data to corroborate more generalizable recommendations.

A minimum scrubbing time of 20 seconds was not related to more effective handwashing, which is in line with previous experimental findings (Amin et al., 2014; Fuls et al., 2008; Lucet et al., 2002). Minimum scrubbing times have been discussed as a particular barrier to compliance with handwashing recommendations (Bloomfield et al., 2007). This suggests that minimum scrubbing times may complicate handwashing recommendations without increasing effectiveness and should thus be excluded from handwashing recommendations.

Soap use

In line with previous evidence (e.g. Amin et al., 2014; Pickering, Boehm, et al., 2010), Chapter 3 showed that soap use resulted in more effective handwashing. However, effect sizes of soap use were far smaller than for specific scrubbing steps. This is surprising, as experimental studies have shown that soap use at least doubles handwashing effectiveness over using water alone (Amin et al., 2014; Burton et al., 2011). One potential explanation is that, in those studies, soap use was confounded with more intensive handscrubbing: Participants who had been assigned to using soap might also have performed more scrubbing steps than those participants who had been assigned to washing hands with water only. The association of soap use with more intensive handscrubbing, identified in Chapter 4 of this thesis, supports this hypothesis.

If soap was actually less relevant for effective handwashing than assumed so far, this would have crucial implications for future handwashing promotions, as the practicability of consistent soap use has been questioned (Sandhu & Goodnight, 2014). Particularly in institutional settings such as schools, soap may be scarce and its consistent supply and use thus not practicable. Promoting handwashing with water only and the crucial scrubbing steps seems significantly more feasible. If this did not entail substantial losses in handwashing effectiveness, it would provide a most valuable alternative to the promotion of soap use. Clearly, more studies are needed to quantify the effectiveness of soap use when controlling for the intensity of handscrubbing and other handwashing steps.

Hand-drying

Compared to air-drying, rubbing hands on the clothes being worn and drying hands using a clean towel led to more effective handwashing. This may be the effect of additional physical removal of remaining bacteria (Huang et al., 2012). The effectiveness of hand drying on clothes may strongly depend on the contamination of clothes, as high contamination would lead to recontamination of hands. The present study was conducted in an urban setting. As a consequence, contamination of clothes may be less than in rural contexts, where drying hands on clothes correlated with higher hand contamination (Hoque, Mahalanabis, Pelto, et al., 1995). The findings of this study provide support for the recommendation to use clean towels for hand drying. However, it clearly questions the CDC's recommendation of air drying. If clean towels are unavailable, drying hands on clothes may be considered preferable. Again, more studies from different contexts are needed to generalize this finding.

Longitudinal findings

Further doubts about the CDC recommendations are raised by the longitudinal findings in response to Research Question 7. Although the handwashing technique, as recommended by CDC, improved considerably following the household and combined interventions, no significant effects were detected on handwashing effectiveness. One potential explanation is that, although participants strongly improved their handwashing technique overall, they did not improve greatly the steps actually relevant to effectiveness. As discussed above, the effectiveness of the handwashing steps showed strong variation, with some steps being highly relevant (e.g. scrubbing under nails), some without much effect (e.g. scrubbing backs of hands) and even some less effective than their unrecommended alternatives (e.g. air drying). For example, a participant who adopted scrubbing the backs of hands and shifted from drying hands on clothes to air drying would have improved his technique, according to the CDC. However, scrubbing the backs of hands might not have changed effectiveness, and air drying could even have resulted in less removal of bacteria than drying hands on clothes.

The practicability of existing handwashing recommendations is supported by the longitudinal evidence from Chapter 5: As a consequence of the campaign, participants' compliance with the recommended handwashing technique increased significantly. Also Chapter 3 suggests that, with the exception of tap use, the recommended handwashing technique is indeed practicable in the study community of this case study. However, these findings on practicability are likely to be very context specific, as the availability of soap, running tap water, and clean towels may vary substantially between different settings. Further, handwashing technique remained suboptimal despite the interventions. This suggests that, although the individual steps are practicable, the CDC recommended technique as a whole might be too complex for full compliance.

Taken together, these findings suggest that handwashing technique influences handwashing effectiveness. However, while some of the handwashing steps were found to be highly effective, others seem unnecessary. Considering that compliance with complex recommendations is questionable, this suggests limiting recommendations for handwashing technique to the effective steps only. Before changes to the CDC recommendations can be proposed, though, corroborative studies are needed in other settings.

6.2.2 Sustaining hand cleanliness

Sustaining hand cleanliness beyond the key handwashing situations is crucial, because pathogen transfer from hands to mouth can occur at any time during routine activities (Nicas & Best, 2008; Rusin, Maxwell, & Gerba, 2002). Thus, hands should be clean not only directly after washing but also for as long as possible; general hand contamination should be low. This section discusses the problem of recontamination preventing sustained hand cleanliness raised by the response to Research Question 8.

Chapter 5 did not reveal significant improvements in general hand contamination as a consequence of increased handwashing frequency. Additional correlational analyses also yielded insignificant results. This missing relationship is likely to originate from recontamination. According to a study in Guatemala, detectable recontamination of the hands of street food vendors occurred within one hour in 46% of study participants; the equivalent figure for beverage vendors was 23% (Sobel et al., 1998). Evidence from rural Bangladesh showed 100% recontamination of participants' hands with faecal coliform bacteria within two hours; the equivalent figure for *E. coli* was 80% (Ram et al., 2011). Evidence from India showed even quicker recontamination to baseline levels within one hour (Devamani et al., 2014).

However, two studies have shown that handwashing interventions targeting frequent handwashing with soap can achieve reductions in hand contamination despite potential recontamination. The first study (Pinfold & Horan, 1996) reported reductions in general hand contamination of 55% and 65% from baseline to follow-up in intervention groups compared to 34% in a non-intervention control. A major shortcoming of this study stems from measuring hand contamination as the number of fingers found to be contaminated by direct imprints of fingertips on media plates. This method may strongly underestimate hand contamination, as only the fingertips are sampled, and varies substantially from the currently common practice of taking hand rinse samples applied in Chapters 3 and 5. The second intervention study (Luby et al., 2001) included twice-weekly revisits to all study households to provide antibacterial soap. It was probably not primarily designed to be a scalable behaviour change campaign, as those of this thesis were. In contrast, it was presumably aimed at manipulating handwashing behaviour as strongly as possible to evaluate effects on hand contamination. Changes in behaviour were not reported, but they were thus likely to be much stronger than in the campaign tested for this thesis and may have counteracted recontamination from the environment. Furthermore, the provision and use of antibacterial soap may have prevented recontamination. In summary, the results from both those studies are hardly comparable to this thesis. While the first used a very different technique to quantify hand contamination, the second involved a very intensive and non-scalable handwashing campaign.

Based on the findings of Chapter 5 and the literature discussed, it can be concluded that even substantial changes in the frequency of handwashing with regular soap, such as were achieved in this project, are unlikely to result in changes in general hand contamination. In line with previous studies, hand recontamination is proposed to be the primary reason for this missing effect. A first step to approaching the problem of recontamination would be to understand the underlying reasons.

There is substantial evidence that generally high environmental contamination levels are a major reason for hand recontamination. In their risk-based approach to domestic hygiene, Bloomfield and Scott (1997) proposed a variety of sources of hand contamination with gastrointestinal pathogens, including infected persons, contaminated food, contaminated cleaning cloths and utensils, and contaminated hand-contact surfaces. Experimental findings from Tanzanian households showed that various routine activities, namely cleaning dishes, preparing food, defecating, cleaning toilets, bathing, cleaning up child’s faeces, sweeping, and urinating led to significantly more hand contamination than a non-activity control (Pickering et al., 2011). The fact that all these activities were related to higher

E.coli counts on hands suggests that recontamination is not a consequence of a few specifically contaminating activities but of a generally high environmental contamination level. This argument is supported by a study of rural households in Peru that found the majority of kitchen utensils (58%) to be faecally contaminated (Gil et al., 2014). According to additional findings from the campaign evaluation (Navab-Daneshmand, Friedrich, Mosler, & Julian, in preparation), general hand contamination was associated with household soil contamination. This corroborates the argument that environmental contamination is an important source of hand recontamination potentially occurring through various activities.

The fact that the mechanisms which lead to high environmental contamination and hand recontamination are not well understood points to considerable challenges for future hand hygiene promotion. What should be the target behaviours of future campaigns? First, decontaminating hands directly before likely ingestion of pathogens, such as before eating or feeding a child, seems even more important. This proposal is in line with epidemiological findings that provide more compelling evidence for the health impact of handwashing before food consumption than of stool-related situations (Luby et al., 2011a; Luby et al., 2011b). Second, it is necessary to identify the mechanisms which lead to recontamination. Observational studies are needed to link specific activities to hand recontamination. In addition, more studies are needed on the contamination levels of hand-contact surfaces and objects touched during routine activities. Quantifying the sources and activities by which hand recontamination occurs would provide the first step towards evidence-based recommendations to reduce hand recontamination. Based on such findings, the next step would be to identify specific behaviours to mitigate hand recontamination. Such behaviours could be those that reduce contamination of the household environment and thus reduce the potential for recontamination. In addition, an extension of the key situations of handwashing might be needed after activities in which hand contamination cannot be prevented.

Until specific behaviours to prevent hand recontamination are identified, a more general approach might be worth considering. Recent evidence from Burundi has shown that different domains of hygiene behaviours are closely interrelated (Sonego & Mosler, 2016). The authors showed that children's hygiene, primary caregivers' hygiene, cleanliness of water containers, cleanliness of latrines, cleanliness related to animals, and the hygiene of households can all be understood as dimensions of a single underlying construct, which they termed general hygiene practice. Targeting general hygiene practice through interventions could thus be a promising approach to improving households' general hygiene and, as a consequence, reducing faecal household contamination and hand recontamination. General hygiene practice was found to be closely related to higher commitment to hygiene behaviours (Sonego & Mosler, 2016). This suggests that general hygiene practice can be at least partly understood using social-cognitive theory. And in consequence, using social-cognitive theory to design interventions to improve general hygiene practice and reduce hand recontamination seems worth considering.

A clear limitation to this approach is that general hygiene practice and its dimensions have, so far, not been linked to actual environmental contamination. It is thus possible that changes in general hygiene practice or in some of its domains would not necessarily translate into reduced environmental contamination or reduced hand recontamination. To assess the relationship between the domains of general hygiene practice, household contamination, and hand contamination, an additional study (Navab-Daneshmand et al.), is currently in preparation.

In summary, changing handwashing through a handwashing campaign is unlikely to result in changes in general hand contamination. There is evidence that this is due to hand recontamination from the household environment during routine activities. Consequently, handwashing before otherwise likely pathogen ingestion, such as before eating, seems crucial. Clearly, more studies are needed to reveal the mechanisms underlying environmental contamination and hand recontamination.

6.3 Behavioural factors steering handwashing

This section places the behavioural factors of handwashing technique, identified in response to Research Question 4, in context with the factors steering handwashing frequency reported in previous studies. A discussion of how the behavioural factors of handwashing technique should be targeted by behaviour change intervention is already given in Chapter 4.

The behavioural factors steering handwashing technique differed substantially from those reported in previous studies for handwashing frequency (e.g. Contzen & Mosler, 2015; Seimetz, Boyayo, et al., 2016; compare Section 1.3.2). Knowledge of the correct handwashing technique was the strongest determinant of handwashing technique. In contrast, knowledge of the relevant times for handwashing, which would be the corresponding action knowledge for handwashing frequency, was not a relevant predictor of handwashing frequency in either previous studies or this study population (compare Section 1.3.2 and Annex III). Conversely, neither norm factors nor self-efficacy were found to predict handwashing technique, although they have consistently been found to be associated with handwashing frequency. Why are the behavioural factors of the two dimensions of handwashing so different?

One potential explanation is a strong observation bias, leading to exaggerated scores of handwashing technique. Participants could have demonstrated ideal handwashing technique to the best of their knowledge, instead of showing, as requested, the handwashing technique that they actually performed in their daily lives. Similar processes as those shown to be associated with over-reporting of handwashing frequency, such as social desirability or cognitive dissonance (Contzen, De Pasquale, et al., 2015), are potential reasons for biased handwashing demonstrations. However, some strong arguments corroborate the validity of measuring handwashing technique through demonstration.

First, the demonstrated handwashing technique that was used as the dependent variable for the identification of its behavioural factors has been validated using structured behavioural observations. Structured behavioural observations are commonly recommended as the most valid measure of handwashing behaviour (Ram, 2013) and have already been described in Section 1.4.3. Each time a participant washed hands, a data collector unobtrusively observed and recorded the applied technique. In addition, handwashing demonstrations were used to measure handwashing technique. Correlating both measures of handwashing technique yielded a strong correlation ($r = .494$). This shows that the values for handwashing technique obtained from demonstrations served as an acceptable proxy for handwashing technique measured through structured observations. Moreover, the interventions that were matched to the behavioural factors identified as steering handwashing technique changed both measures of handwashing technique (compare Chapter 5). Second, handwashing technique is probably less affected by observation bias than handwashing frequency (Pedersen, Keithly, & Brady, 1986). While the presence of an observer influences the handwashing frequency of public restroom users, the study showed that the presence of an observer did not lead to longer handwashing durations among those who washed hands. Of course, long handwashing duration is not equivalent to handwashing technique; however, it could be considered as a proxy. Third, employing data collectors previously unknown to study participants reduces reactivity to handwashing observations, as was shown in a hospital-based study by Kohli et al. (2009). All data collectors employed in this study were previously unknown to the study participants.

In summary, there are strong arguments that demonstrations constitute a valid measure of handwashing technique. This suggests that identification of the behavioural factors steering handwashing technique was not fundamentally distorted by observation bias. It can thus be concluded that the behavioural factors identified as steering handwashing technique genuinely differ from those found to steer handwashing frequency in previous studies.

At first sight, this finding is not surprising. As the RANAS model suggests, factors steering one behaviour may differ strongly between different contexts. To design effective interventions, they need to be empirically determined in each context (Mosler, 2012). However, the studies reviewed above suggest that some behavioural factors steering handwashing frequency seem to be relevant across almost all the contexts in which the studies were conducted. None of those factors was relevant to handwashing technique in this study. Although more studies would be needed to generalize this finding, it provides a valuable starting point for reflection.

Performing effective handwashing technique could be mainly habit-driven. Orbell and Verplanken (2010) define habit as a behaviour that is frequently and automatically executed and triggered through situational cues in a stable context. Handwashing technique, being frequently repeated during the daily routine in a stable context such as the designated place for handwashing, fits this definition closely. Handwashing technique can also be seen as a sequence of individual steps, in which performing one step would automatically trigger performance of the next.

Substantial evidence indicates that habit moderates the effect of intention on behaviour; when habits are strong, intention and its antecedents have less influence on behaviour (Limayem, Hirt, & Cheung, 2007; Ouellette & Wood, 1998; Verplanken, Aarts, Knippenberg, & Knippenberg, 1994). Notably, it is mostly factors that were originally proposed to determine intentions that were found to steer handwashing frequency in previous studies. Consequently, the behavioural factors steering handwashing technique may differ strongly from those steering handwashing frequency because technique could be driven by habits more than is frequency.

The RANAS model explicitly includes habit as an outcome variable, and it has been successfully applied to predict habitual latrine cleaning (Sonego & Mosler, 2014) and water consumption habits (Inauen, Tobias, & Mosler, 2013). However, it might not capture all aspects of habit building, since it does not represent the moderating effects of existing habits, which may conflict with the target behaviour.

6.4 Changing handwashing behaviour

This section discusses conclusions for handwashing behaviour change. First, implications for theory-based handwashing promotion are debated. Second, children are considered as potential agents of handwashing behaviour change. The effects of changes in handwashing behaviour on hand contamination have already been discussed in Section 6.2.

6.4.1 Changing handwashing frequency and technique using theory-based interventions

As shown in response to Research Question 5, the handwashing campaign enhanced both handwashing frequency and technique. It is the first campaign whose effects on handwashing technique were quantified using sound operationalization in line with existing recommendations (Centers for Disease Control and

Prevention, n.d.; World Health Organisation, 2009). It thus provides a prototype for how handwashing technique can be changed by a campaign. The correlation of handwashing frequency and technique reported in response to Research Question 2 and the substantial behaviour changes in both dimensions of handwashing suggest that targeting handwashing technique and frequency simultaneously is a successful strategy.

The effectiveness of the campaign to change handwashing behaviour provides evidence in support of the underlying design approach. As suggested by Michie et al. (2008) and specified in the RANAS approach (Mosler, 2012; Mosler & Contzen, 2016), the campaign was designed to change behaviour by changing the specific factors that steer the behaviour (see Chapter 4 and Annex III). The strong effects of the theory-driven interventions of this campaign are in line with previous findings on the successful promotion of frequent handwashing (Contzen, Meili, et al., 2015). This study thus broadens the evidence base that a systematic approach based on social-cognitive theory can be used to design powerful interventions for handwashing behaviour change. It contributes to a growing body of literature supporting the more general claim that theory-based designs yield powerful interventions for health behaviour change (Abraham & Kools, 2011; Michie et al., 2008).

However, it cannot be concluded that the design approach implemented in this study was superior to its alternatives, the standard approach of risk- and knowledge-based handwashing promotion and a solely theory-driven design without formative research in the study population. The present data and theory-driven design would have to be directly compared to its alternatives to conclude which works best. While several studies have shown that theory and data-driven interventions applied to the promotion of handwashing and safe drinking water consumption were indeed more impactful than the standard risk- and knowledge-based approach (Contzen, Meili, et al., 2015; Huber, Tobias, & Mosler, 2014; Inauen & Mosler, 2013), the value that data-driven intervention design can add to solely theory-driven design remains to be demonstrated. In contrast, the aim of this study's experimental design was to further investigate which mode of delivery, direct, indirect through children, or a combination of both, was most effective in changing the handwashing behaviour of caregivers. This is discussed in the next section.

6.4.2 Were children agents of handwashing behaviour change?

In response to Research Question 6, Chapter 5 clearly showed that the school campaign alone did not affect the handwashing behaviour of caregivers. This contradicts previous studies, which hypothesized (Mwanga et al., 2008) and quantified (Blanton et al., 2010) the effects of targeting children on their caregivers' behaviour. Why did the school campaign fail to change caregivers' behaviour? Qualitative research suggests that the effects of a handwashing campaign in schools are transferred to caregivers through three mechanisms: First, the campaign prompts children to wash hands at home, which in turn prompts adults to adopt handwashing (Xuan, Rheinländer, Hoat, Dalsgaard, & Konradsen, 2013). Second, children might influence their parents verbally by telling them about their experiences with handwashing at school or reminding their parents to wash hands (Xuan et al., 2013). This could improve health and action knowledge, change the risk perceptions and attitudes of caregivers, and support them in remembering to wash hands in key handwashing situations. Third, children might influence parents by changing the household environment. This is supported by evidence from rural Kenya, where children constructed tippy taps[1] at home as a consequence of a campaign in schools (Onyango-Ouma et al., 2005). In the present study, children learnt to build soap dispensers from plastic bottles at school and were instructed to build soap dispensers with their parents at home too.

The school campaign may have failed either because it did not prompt children to promote handwashing at home through these mechanisms or because the caregivers did not change their behaviour despite their children promoting it at home. The first reason seems less likely, because the school campaign included explicit activities in which children should involve their parents, such as building a soap dispenser with their parents or discussing the importance of handwashing at home. Findings from eastern Zambia suggest that children there were very eager

[1] Tippy taps are low-cost handwashing devices which allow unassisted rinsing of both hands. They are commonly constructed of a water container which is installed on a wooden stand and which can be tilted using a foot pedal.

to promote handwashing at home following school activities, and even exceeded the specific instructions (Bresee et al., 2016). In addition, the school campaign successfully changed the observed handwashing behaviour of children at school (see Annex III). Alternatively, it may be that caregivers did not change their behaviour because they did not accept their children in the role of health promoters. To change behaviour at their children's prompting, parents have to perceive their children as truthful sources of information (Mwanga et al., 2008; Onyango-Ouma et al., 2005). However, power and status in many cultures are associated with old age (Mwanga et al., 2008), rendering children less credible and caregivers less likely to follow their example or instructions. Nonetheless, Bresee et al. (2016) reported from Zambia that parents trusted their children because they trusted in their childrens' education. This effect may have been even stronger in our study in Zimbabwe, where the general level of education was high[2]. It is also possible that the children's promotion did not change the relevant behavioural factors in their parents. The school campaign was primarily designed to target the behavioural factors which were found relevant for children's behaviour. However, whether the children's promotion behaviour at home targeted the behavioural factors which steered caregivers' handwashing remains uncertain. Additional analyses through an ongoing master thesis quantify the extent to which the school campaign prompted children to promote handwashing at home and whether such promotion was associated with changes in behavioural factors among caregivers.

6.5 Integrated framework for changing handwashing behaviour and hand contamination

The overall aim of this thesis was to combine environmental microbiology and health psychology to promote effective handwashing. Accordingly, the main findings are summarized in an integrated framework for changing handwashing behaviour and hand contamination (Figure 5). In line with the structure of this thesis, the framework distinguishes two dimensions of handwashing behaviour: hand-

[2] In the study population, participants had attended 10 years of formal education on average (see Chapter 4).

washing frequency (shown in the upper half of the diagram) and handwashing technique (shown in the lower half of the diagram). The framework proposes causal relations from handwashing promotion to behavioural factors steering handwashing, from the behavioural factors to handwashing behaviour, and from handwashing behaviour to faecal hand contamination. Hand recontamination from the household environment is proposed to be the main factor disrupting the effect of handwashing behaviour on hand contamination. In addition to this causal chain, the framework also shows direct effects from handwashing promotion to behaviour and from handwashing promotion to hand contamination. These direct effects were included in the framework for empirical reasons; many studies have reported such direct effects without reporting the intermediate ones.

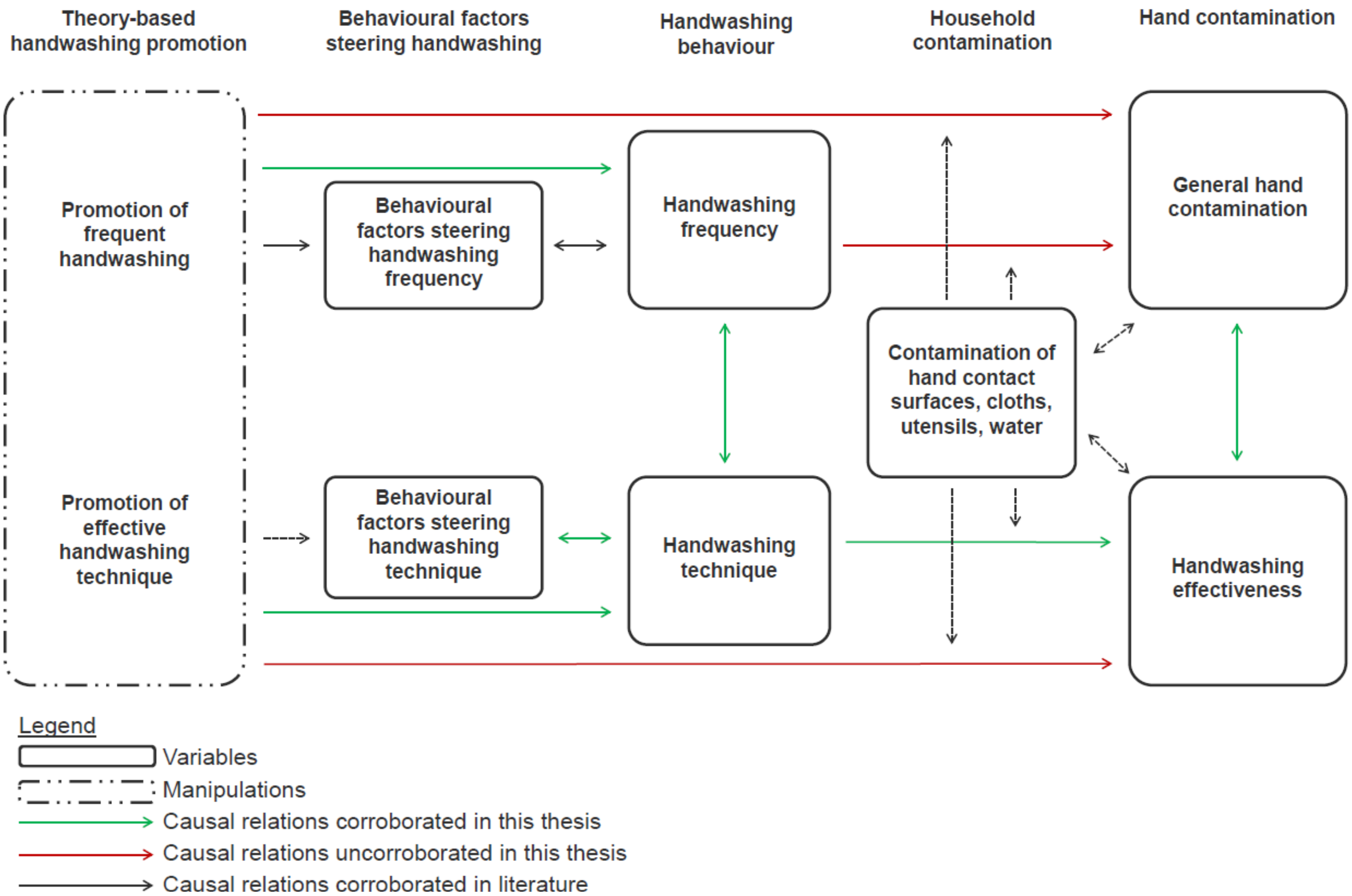

Figure 5: Integrated framework for changing handwashing behaviour and hand contamination.

Handwashing and hand contamination

This thesis demonstrates that handwashing technique influences handwashing effectiveness. However, only some steps of the handwashing technique recommended by the CDC were found to be relevant. Overall improvements in CDC recommended technique did not result in improvements in handwashing effectiveness. This calls for a critical evaluation of the handwashing guidelines to ensure that they include only handwashing steps which are actually effective.

Increasing handwashing frequency through the interventions did not reduce general hand contamination. Recontamination from the household environment is proposed to explain the missing link between handwashing frequency and general hand contamination. Recontamination can occur at any time during the daily routine when touching contaminated surfaces and utensils or through direct contact with faeces. Conversely, contaminated hands can lead to contamination of the household environment, as indicated by double arrows. Recontamination may also occur during handwashing itself from contaminated surfaces, handwashing water, or towels. Recontamination may thus also reduce handwashing effectiveness. Furthermore, this thesis showed that general hand contamination and handwashing effectiveness are interrelated: Where general hand contamination was high, hands remained more contaminated despite handwashing.

Behavioural factors steering handwashing

In line with the RANAS model and others used to explain health behaviours, handwashing frequency and technique are proposed to be a function of specific behavioural factors. For handwashing frequency, the underlying behavioural factors have been subject to several previous studies, which is indicated by a solid black arrow in the framework (compare with Section 1.3). As such substantial evidence exists on the behavioural factors steering handwashing frequency, they were not the subject of the present thesis. The behavioural factors steering handwashing technique were systematically identified in this thesis. Since the reported evidence is cross-sectional, the direction of causality has not been determined, which is indicated by the double arrow. Furthermore, handwashing frequency and handwashing technique were interrelated: Participants who washed hands more frequently also washed them with better technique. This is indicated by a green double arrow.

Changing handwashing behaviour

In line with the social cognition approach, the RANAS model, and others used to explain health behaviours, the framework indicates that changing handwashing behaviour is achieved through manipulating the factors which steer handwashing behaviour. Studies reporting mediation analyses provide corroborating evidence for these mechanisms to change handwashing frequency (compare Section 1.3). This study showed that interventions which targeted the behavioural factors steering handwashing technique and frequency considerably enhanced both dimensions of handwashing. This study thus provides strong evidence not only for the interventions but also for the underlying approach to handwashing behaviour change. It further shows that targeting handwashing frequency and technique concurrently is a successful strategy for handwashing promotion.

Implications and future directions

Handwashing campaigns should put particular emphasis on promoting the elements of handwashing technique which are actually effective in removing pathogens. This thesis provides recommendations for effective handwashing from only one context, and more studies are needed to allow general conclusions. Assessing the relative importance of handwashing steps as compared to each other is proposed to identify the most important. In particular, the effectiveness of specific scrubbing steps and comparison of methods of hand-drying should be the focus of future research. Further, studies are required to quantify how water quality and quantity influence handwashing effectiveness. These studies are urgently needed to revise existing recommendations and provide corroborating evidence for promoting effective handwashing technique. Further longitudinal evidence is needed to test whether promoting the steps identified to be relevant actually increases handwashing effectiveness.

Handwashing campaigns can be designed based on social-cognitive theory, as this approach has been shown to be very successful in changing behaviour in this and previous studies. The RANAS model proved to be effective in identifying the behavioural factors of handwashing technique in this case study. Similar studies should be conducted in other contexts to determine whether some behavioural factors consistently influence handwashing technique and how changing these affects behaviour. In addition, the role of habit should be elucidated by future research. Future handwashing campaigns should target both handwashing frequency and technique.

Handwashing promotion is not alone sufficient to decrease general hand contamination. Clearly, more research is needed to identify the processes and behaviours which lead to hand recontamination. The RANAS approach could also constitute a promising tool to reduce hand recontamination: As discussed in Section 6.2.2, hand recontamination may depend largely on specific activities, either those which increase contamination of the household environment and thus create the preconditions for hand recontamination, or those that lead directly to hand recontamination. Once such activities have been defined, the behavioural factors steering those activities should be identified and behaviour change interventions tested to target these factors.

6.6 Strengths and limitations

The core strength of this thesis is that it combines approaches from environmental microbiology and health psychology. Interlinking research questions and methodological approaches of both disciplines within the same thesis allowed work on handwashing technique from several perspectives and conclusions beyond individual disciplines.

Accordingly, this thesis provides the first comprehensive evaluation of existing recommendations for effective handwashing technique in developing countries and, building on that, systematically quantifies the behavioural factors steering handwashing technique. In combining microbiology and health psychology, this thesis does not merely emphasize the need to extend the target behaviour of handwashing campaigns to effective handwashing technique; in addition, it gives substantiated recommendations on how such campaigns should be designed.

Similarly, the campaign evaluation treated both handwashing behaviour and hand contamination as outcome variables. This combination added substantial value, as it provided longitudinal evidence that promoting and enhancing handwashing behaviour does not necessarily yield the desired effects on hand contamination.

The combination of environmental psychology and health psychology provided the rare opportunity to develop and test an interdisciplinary conceptual framework. The framework considers both frequency and technique as crucial dimensions of handwashing and extends the causal links between behaviour, behavioural factors, and their promotion, as proposed in the social-cognition approach, to hand contamination. In this sense, it provides a starting point for future interdisciplinary work on hand hygiene promotion.

The findings of this dissertation are of high practical relevance. The reviewed literature suggests that it is the first handwashing campaign in Zimbabwe which was evaluated using a rigorous experimental design and which showed substantial effects on the handwashing behaviour. A strong argument for the scalability of the campaign stems from its mode of delivery; in contrast to most scientifically evaluated handwashing campaigns, this campaign was implemented entirely by government health promoters and teachers. While this posed challenges to the intervention's fidelity, the effects can be seen as a more valid measure of what may be expected from upscaling through the government. The Swiss Agency for Development and Cooperation (SDC) and partners in Harare are at present preparing the ground for implementing the campaign at large scale through the government.

Nevertheless, this study has some substantial limitations. Critical points of the study design, the measures applied, the sample, and the proposed framework are discussed in the subsequent sections. Limitations referring specifically to each empirical chapter are presented there.

Study design

This study tested neither the individual effects of any of the applied behaviour change techniques (BCTs) nor the added effect of individual BCTs on top of others. As a consequence, we do not know whether some of the BCTs affected behaviour more strongly than others, and it is even possible that some of the BCTs had a negative impact on behaviour which was counteracted by other effective BCTs. Because we wanted to test the individual and combined effects of the direct and indirect interventions, it was not possible to test individual BCTs. Otherwise, the design would have yielded too many different intervention groups and groups would have become too small for sound statistical analysis. For the same reasons, the effects of BCTs specifically targeting handwashing frequency and those specifically targeting handwashing technique were not tested separately. It is thus possible that BCTs designed to target handwashing frequency also influenced handwashing technique and vice versa.

The time between baseline data collection and campaign implementation was very long (14 months), while the time between campaign and follow-up data collection amounted to only 6 to 8 weeks. This was due to substantial delays in the preparation of the campaign implementation. The lag between baseline and interventions may have resulted in external factors influencing handwashing behaviour. However, comparing intervention groups which received the campaign to a non-intervention control should control for such bias. The short time between interventions and follow-up means that the evaluation only measured the short-term effects of the campaign. Whether the campaign achieved sustainable behaviour change would require further long-term evaluations.

Only the campaign effects on caregivers are the subject of this dissertation. In contrast, the project also comprised a rigorous evaluation of the campaign effects on childrens' behaviour at schools. This revealed considerable changes of children's handwashing behaviour as a consequence of the school interventions. Within the time constraints of this thesis, it was not possible to additionally report those findings. An overview of the campaign effects on children can be found in Annex III.

Measures

E. coli concentrations obtained from culture-based methods are imperfect indicators of hand contamination. The measures of hand contamination presented in Chapters 3 and 5 may have overestimated faecal bacterial contamination by including false positives. Although Julian et al. (2015) observed low false positive rates for *E. coli* on hands in Bangladesh we did not attempt to confirm colonies isolated in this study. Molecular biological techniques were logistically not feasible. To at least increase the reliability of measured *E.coli* concentrations, all hand rinse samples were analysed in triplicate.

To evaluate handwashing effectiveness, both the log difference of hand contamination before and after washing (Amin et al., 2014; Pickering, Boehm, et al., 2010) and the log hand contamination after washing (Burton et al., 2011; Hoque, Mahalanabis, Alam, et al., 1995) have been used in other studies. In this study, hand contamination after washing was used to operationalize handwashing effectiveness because hand contamination has been shown to be directly associated with diarrhoea (Pickering, Davis, et al., 2010; Pinfold & Horan, 1996). In addition, using log differences would not differentiate between reductions of different magnitudes (e.g. reduction from 3 to 2 log CFU/hand amounting to 900 CFU/hand would be modelled in the same way as a reduction from 2 to 1 log CFU/hand amounting to 90 CFU/hand). However, reporting log differences would have provided additional valuable information on the effectiveness of handwashing steps.

A limitation of Chapter 4 is that many social-cognitive factors were measured on single-item scales. Scales built of several items showed acceptable reliability. Further, the validity of demonstrations has been questioned as a measure of handwashing technique. However, as discussed in Section 6.3, demonstrations were validated through structured behaviour observations, and all data were collected by individuals unknown to the study participants to reduce observation bias.

Participants and sample

Participants were recruited from 20 spatially separated high-density areas of Harare, Zimbabwe. Interventions were randomly assigned at area level. This clustered structure of the sample was necessary to avoid spill-over of interventions to households not meant to receive them, such as control households. However, the analyses performed in Chapters 2 and 3 did not control for the clustering of participants, which may have led to an increase in Type 1 errors, meaning that minor effects might have become significant. However, comparison of participants across clusters yielded negligible cluster effects, meaning that participants were very similar across all the clusters. As a consequence, any increase in Type 1 errors can be assumed to be very limited. Analyses in Chapter 5 controlled for the clustered structure of the sample using exchangeable correlation matrices.

The size of the subsamples for microbial hand sampling was defined by logistical and budget constraints and not determined by power analyses in advance. While statistical power for the cross-sectional analyses performed in Chapter 3 was acceptable, the power for the analysis of campaign effects in hand contamination was limited. However, the absolute values of hand contamination in the different experimental groups suggest very small effect sizes, unlikely to be detected even with a substantially larger sample.

Integrated framework

A few of the causal relations proposed in the framework were not empirically tested in this thesis. However, substantial evidence in the literature and additional analyses supports these causal relations. Several studies exist on how social-cognitive and contextual factors influence handwashing frequency (e.g. Contzen & Mosler, 2015; Seimetz, Boyayo, et al., 2016; Seimetz et al., submitted). In addition, two studies have reported mediation analyses on how theory-driven handwashing campaigns changed behavioural factors steering handwashing frequency, which in turn resulted in changes in behaviour or intention (Contzen & Inauen, 2015; Seimetz, Kumar, et al., 2016). Similar analyses on how the interventions targeted the behavioural factors steering handwashing technique and how changes in these factors triggered changes in handwashing technique were delivered in the official evaluation report of this project to SDC (Friedrich & Mosler, 2016). These results show that the campaign changed handwashing technique by changing the behavioural factors identified in this thesis.

The moderating effects of household contamination on the relation of handwashing behaviour and hand contamination have not been empirically tested, nor has the direct effect on hand contamination been tested. The results of Research Questions 7 and 8 and the reviewed literature suggest its future testing.

6.7 General conclusions

Despite huge efforts, diarrhoeal diseases still claim hundreds of thousands of lives each year, in particular of children in low-income countries. Promoting handwashing with soap has been shown to be an effective weapon in the battle against diarrhoeal disease. Although handwashing technique is considered of paramount importance in many domains, such as healthcare and the food industry, it has received little attention in handwashing promotion in low-income settings in developing countries. The primary reasons for this neglect may be, firstly, that little evidence exists to show whether handwashing technique actually matters for effective handwashing in such settings. Secondly, no intervention studies have so far demonstrated how handwashing technique, and consequently handwashing effectiveness, could be enhanced. This thesis aims to fill these knowledge gaps by a case study in low-income suburbs of Harare, Zimbabwe. Findings show that handwashing technique influenced handwashing effectiveness. The handwashing interventions, designed using the RANAS approach of systematic behaviour change, substantially enhanced handwashing technique. However, handwashing effectiveness did not increase substantially, presumably as a consequence of also promoting ineffective handwashing steps. In conclusion, more research is clearly needed to critically evaluate existing recommendations on handwashing technique for low-income settings in developing countries. Future handwashing campaigns should promote handwashing technique and frequency equally. Interventions systematically designed using the RANAS approach provide an effective approach to changing both these dimensions of handwashing. In addition, identification of measures to control hand recontamination and strategies to promote such measures is urgently needed. Hopefully, the findings will contribute to putting the promotion of effective handwashing technique and prevention of recontamination higher on the agenda of researchers and practitioners so as to make handwashing as impactful as possible where it is most needed.

7 References

Abraham, C., & Kools, M. (2011). *Writing Health Communication: An Evidence-Based Guide*. Thousand Oaks, CA: Sage.

Ajzen, I. (1991). The Theory of Planned Behavior. *Organizational Behavior and Human Decision Processes, 50*(2), 179-211.

Ajzen, I., & Fishbein, M. (1980). *Understanding Attitudes and Predicting Social Behavior*. Englewood-Cliff, NJ: Prentice-Hall.

Amin, N., Pickering, A. J., Ram, P. K., Unicomb, L., Najnin, N., Homaira, N., . . . Luby, S. P. (2014). Microbiological Evaluation of the Efficacy of Soapy Water to Clean Hands: A Randomized, Non-Inferiority Field Trial. *The American Journal of Tropical Medicine and Hygiene, 91*(2), 415-423.

Arnold, B., Arana, B., Mäusezahl, D., Hubbard, A., & Colford, J. M. (2009). Evaluation of a Pre-Existing, 3-Year Household Water Treatment and Handwashing Intervention in Rural Guatemala. *International Journal of Epidemiology, 38*(6), 1651-1661.

Aunger, R., Schmidt, W.-P., Ranpura, A., Coombes, Y., Maina, P. M., Matiko, C. N., & Curtis, V. (2010). Three Kinds of Psychological Determinants for Hand-Washing Behaviour in Kenya. *Social Science and Medicine, 70*(3), 383-391.

Bandura, A. (1977). Self-Efficacy: Toward a Unifying Theory of Behavioral Change. *Psychological Review, 84*(2), 191-215.

Benjamini, Y., & Hochberg, Y. (1995). Controlling the False Discovery Rate: A Practical and Powerful Approach to Multiple Testing. *Journal of the Royal Statistical Society. Series B (Methodological), 57*(1), 289-300.

Biran, A., Schmidt, W.-P., Varadharajan, K. S., Rajaraman, D., Kumar, R., Greenland, K., . . . Curtis, V. (2014). Effect of a Behaviour-Change Intervention on Handwashing with Soap in India (Superamma): A Cluster-Randomised Trial. *The Lancet Global Health, 2*(3), 145-154.

Biran, A., Schmidt, W.-P., Wright, R., Jones, T., Seshadri, M., Isaac, P., . . . Curtis, V. (2009). The Effect of a Soap Promotion and Hygiene Education Campaign on Handwashing Behaviour in Rural India: A Cluster Randomised Trial. *Tropical Medicine and International Health, 14*(10), 1303-1314.

Blanton, E., Ombeki, S., Oluoch, G. O., Mwaki, A., Wannemuehler, K., & Quick, R. (2010). Evaluation of the Role of School Children in the Promotion of Point-of-Use Water Treatment and Handwashing in Schools and Households—Nyanza Province, Western Kenya, 2007. *The American Journal of Tropical Medicine and Hygiene, 82*(4), 664-671.

Bloomfield, S. F., Aiello, A. E., Cookson, B., O'Boyle, C., & Larson, E. L. (2007). The Effectiveness of Hand Hygiene Procedures in Reducing the Risks of Infections in Home and Community Settings Including Handwashing and

Alcohol-Based Hand Sanitizers. *American Journal of Infection Control, 35*(10), 27-64.

Bloomfield, S. F., & Scott, E. (1997). Cross-Contamination and Infection in the Domestic Environment and the Role of Chemical Disinfectants. *Journal of Applied Microbiology, 83*(1), 1-9.

Borghi, J., Guinness, L., Ouedraogo, J., & Curtis, V. (2002). Is Hygiene Promotion Cost-Effective? A Case Study in Burkina Faso. *Tropical Medicine and International Health, 7*(11), 960-969.

Bresee, S., Caruso, B. A., Sales, J., Lupele, J., & Freeman, M. C. (2016). 'A Child Is Also a Teacher': Exploring the Potential for Children as Change Agents in the Context of a School-Based Wash Intervention in Rural Eastern Zambia. *Health Education Research, 31*(4), 521-534.

Burton, M., Cobb, E., Donachie, P., Judah, G., Curtis, V., & Schmidt, W.-P. (2011). The Effect of Handwashing with Water or Soap on Bacterial Contamination of Hands. *International Journal of Environmental Research and Public Health, 8*(1), 97-104.

Campbell, M. K., Piaggio, G., Elbourne, D. R., & Altman, D. G. (2012). Consort 2010 Statement: Extension to Cluster Randomised Trials. *BMJ, 2012; 345:e5661*.

Centers for Disease Control and Prevention. (2002). *Guideline for Hand Hygiene in Healthcare Settings: Recommendations of the Healthcare Infection Control Practices Advisory Committee and the Hicpac/Shea/Apic/Idsa Hand Hygiene Task Force.* Retrieved from https://www.cdc.gov/mmwr/pdf/rr/rr5116.pdf:

Centers for Disease Control and Prevention. (n.d.). When and How to Wash Your Hands. Retrieved from http://www.cdc.gov/handwashing/when-how-handwashing.html

Chase, C., & Do, Q.-T. D. (2012). *Handwashing Behavior Change at Scale Evidence from a Randomized Evaluation in Vietnam*. Washington, D.C.: The World Bank, Sustainable Development Network, Water and Sanitation Program & Development Research Group, Poverty and Inequality Team.

Chudleigh, J., Fletcher, M., & Gould, D. (2005). Infection Control in Neonatal Intensive Care Units. *Journal of Hospital Infection, 61*(2), 123-129.

Cialdini, R. B., Reno, R. R., & Kallgren, C. A. (1990). A Focus Theory of Normative Conduct: Recycling the Concept of Norms to Reduce Littering in Public Places. *Journal of Personality and Social Psychology, 58*(6), 1015.

Conner, M., & Norman, P. (2005). *Predicting Health Behavior: A Social Cognition Approach* (M. Conner & P. Norman Eds.). Maidenhead: McGraw-Hill Education.

Conover, D. M., & Gibson, K. E. (2016). A Review of Methods for the Evaluation of Handwashing Efficacy. *Food Control, 63*, 53-64.

Contzen, N. (2014). *Handwashing: Population-Tailored Promotion and the Problem of Selfreporting.* (Dissertation), University of Zurich, Zürich.

Contzen, N., De Pasquale, S., & Mosler, H.-J. (2015). Over-Reporting in Handwashing Self-Reports: Potential Explanatory Factors and Alternative Measurements. *PloS One, 10*(8), e0136445.

Contzen, N., & Inauen, J. (2015). Social-Cognitive Factors Mediating Intervention Effects on Handwashing: A Longitudinal Study. *Journal of Behavioral Medicine, 38*(6), 956-969.

Contzen, N., Meili, I. H., & Mosler, H.-J. (2015). Changing Handwashing Behaviour in Southern Ethiopia: A Longitudinal Study on Infrastructural and Commitment Interventions. *Social Science and Medicine, 124*(0), 103-114.

Contzen, N., & Mosler, H.-J. (2012). Factors Determining the Effectiveness of Oxfam's Public Health Promotion Approach in Haiti. *Journal of Public Health, 21*(6), 559-573.

Contzen, N., & Mosler, H.-J. (2013). Impact of Different Promotional Channels on Handwashing Behaviour in an Emergency Context: Haiti Post-Earthquake Public Health Promotions and Cholera Response. *Journal of Public Health, 21*(6), 559-573.

Contzen, N., & Mosler, H.-J. (2015). Identifying the Psychological Determinants of Handwashing: Results from Two Cross-Sectional Questionnaire Studies in Haiti and Ethiopia. *American Journal of Infection Control, 43*(8), 826-832.

Curtis, V., & Cairncross, S. (2003). Effect of Washing Hands with Soap on Diarrhoea Risk in the Community: A Systematic Review. *The Lancet Infectious Diseases, 3*(5), 275-281.

Curtis, V., Danquah, L. O., & Aunger, R. V. (2009). Planned, Motivated and Habitual Hygiene Behaviour: An Eleven Country Review. *Health Education Research, 24*(4), 655-673.

Devamani, C., Norman, G., & Schmidt, W.-P. (2014). A Simple Microbiological Tool to Evaluate the Effect of Environmental Health Interventions on Hand Contamination. *International Journal of Environmental Research and Public Health, 11*(11), 11846-11859.

Devine, J., Karver, J., Coombes, Y., Chase, C., & Hernandez, O. (2012). *Behavioral Determinants of Handwashing with Soap among Mothers and Caretakers: Emergent Learning from Senegal and Peru*. Washington, D.C.: World Bank, Water and Sanitation Program.

Dobe, M., Mandal, R. N., & Jha, A. (2013). Social Determinants of Good Hand-Washing Practice (Ghp) among Adolescents in a Rural Indian Community. *Family and Community Health, 36*(2), 172-177.

Feachem, R. G. (1984). Interventions for the Control of Diarrhoeal Diseases among Young Children: Promotion of Personal and Domestic Hygiene. *Bulletin of the World Health Organization, 62*(3), 467-476.

Fischer Walker, C. L., Rudan, I., Liu, L., Nair, H., Theodoratou, E., Bhutta, Z. A., . . . Black, R. E. (2013). Global Burden of Childhood Pneumonia and Diarrhoea. *The Lancet, 381*(9875), 1405-1416.

Food and Drug Administration. (2013). *Food Code*. Retrieved from http://www.fda.gov/downloads/Food/GuidanceRegulation/RetailFoodProtection/FoodCode/UCM374510.pdf:

Freeman, M. C., Stocks, M. E., Cumming, O., Jeandron, A., Higgins, J. P. T., Wolf, J., . . . Curtis, V. (2014). Hygiene and Health: Systematic Review of Handwashing Practices Worldwide and Update of Health Effects. *Tropical Medicine and International Health, 19*(8), 906-916.

Friedrich, M. N. D. (2016). *Design, Implementation and Evaluation of a Handwashing Campaign in Harare, Zimbabwe. A Case Study Applying the Practical Guide Systematic Behavior Change in Water Sanitation and Hygiene*. Dübendorf, Switzerland: Eawag.

Friedrich, M. N. D., Julian, T. R., Kappler, A., Nhiwatiwa, T., & Mosler, H.-J. (in press). Handwashing, but How? Microbiological Effectiveness of Existing Handwashing Practices in High-Density Suburbs of Harare. *American Journal of Infection Control*.

Friedrich, M. N. D., & Mosler, H.-J. (2016). *Campaign Evaluation: Handwashing in Urban Zimbabwe*. Dübendorf, Switzerland: Eawag.

Fuls, J. L., Rodgers, N. D., Fischler, G. E., Howard, J. M., Patel, M., Weidner, P. L., & Duran, M. H. (2008). Alternative Hand Contamination Technique to Compare the Activities of Antimicrobial and Nonantimicrobial Soaps under Different Test Conditions. *Applied and Environmental Microbiology, 74*(12), 3739-3744.

Genthe, B., Strauss, N., Seager, J., Vundule, C., Maforah, F., & Kfir, R. (1997). The Effect of Type of Water Supply on Water Quality in a Developing Community in South Africa. *Water Science and Technology, 35*(11–12), 35-40.

Gil, A. I., Lanata, C. F., Hartinger, S. M., Mäusezahl, D., Padilla, B., Ochoa, T. J., . . . Verastegui, H. (2014). Fecal Contamination of Food, Water, Hands, and Kitchen Utensils at the Household Level in Rural Areas of Peru. *Journal of Environmental Health, 76*(6), 102-106.

Gollwitzer, P. M. (1999). Implementation Intentions: Strong Effects of Simple Plans. *American Psychologist, 54*(7), 493.

Gould, D. (1994). Nurses' Hand Decontamination Practice: Results of a Local Study. *Journal of Hospital Infection, 28*(1), 15-30.

Greene, L. E., Freeman, M. C., Akoko, D., Saboori, S., Moe, C., & Rheingans, R. (2012). Impact of a School-Based Hygiene Promotion and Sanitation Intervention on Pupil Hand Contamination in Western Kenya: A Cluster Randomized Trial. *The American Journal of Tropical Medicine and Hygiene, 87*(3), 385.

Griffith, C. J., Malik, R., Cooper, R. A., Looker, N., & Michaels, B. (2003). Environmental Surface Cleanliness and the Potential for Contamination During Handwashing. *American Journal of Infection Control, 31*(2), 93-96.

Gustafson, D. R., Vetter, E. A., Larson, D. R., Ilstrup, D. M., Maker, M. D., Thompson, R. L., & Cockerill Iii, F. R. (2000). Effects of 4 Hand-Drying

Methods for Removing Bacteria from Washed Hands: A Randomized Trial. *Mayo Clinic Proceedings, 75*(7), 705-708.

Hartung, C., Lerer, A., Anokwa, Y., Tseng, C., Brunette, W., & Borriello, G. (2010). *Open Data Kit: Tools to Build Information Services for Developing Regions*. Paper presented at the Proceedings of the 4th ACM/IEEE International Conference on Information and Communication Technologies and Development, London, United Kingdom. Retrieved from http://dl.acm.org/citation.cfm?doid=2369220.2369236

Hoque, B., Mahalanabis, D., Pelto, B., & Alam, M. (1995). Research Methodology for Developing Efficient Handwashing Options: An Example from Bangladesh. *The Journal of Tropical Medicine and Hygiene, 98*(6), 469-475.

Hoque, B. A., Mahalanabis, D., Alam, M. J., & Islam, M. S. (1995). Post-Defecation Handwashing in Bangladesh: Practice and Efficiency Perspectives. *Public Health, 109*(1), 15-24.

Huang, C., Ma, W., & Stack, S. (2012). The Hygienic Efficacy of Different Hand-Drying Methods: A Review of the Evidence. *Mayo Clinic Proceedings, 87*(8), 791-798.

Huber, A. C., & Mosler, H.-J. (2013). Determining Behavioral Factors for Interventions to Increase Safe Water Consumption: A Cross-Sectional Field Study in Rural Ethiopia. *International Journal of Environmental Health Research, 23*(2), 96-107.

Huber, A. C., Tobias, R., & Mosler, H. J. (2014). Evidence-Based Tailoring of Behavior-Change Campaigns: Increasing Fluoride-Free Water Consumption in Rural Ethiopia with Persuasion. *Applied Psychology: Health and Well-Being, 6*(1), 96-118.

Huda, T. M. N., Unicomb, L., Johnston, R. B., Halder, A. K., Yushuf Sharker, M. A., & Luby, S. P. (2012). Interim Evaluation of a Large Scale Sanitation, Hygiene and Water Improvement Programme on Childhood Diarrhea and Respiratory Disease in Rural Bangladesh. *Social Science and Medicine, 75*(4), 604-611.

Huttly, S. R., Lanata, C. F., Gonzales, H., Aguilar, I., Fukumoto, M., Verastegui, H., & Black, R. E. (1994). Observations on Handwashing and Defecation Practices in a Shanty Town of Lima, Peru. *Journal of Diarrhoeal Diseases Research, 12*(1), 14-18.

Inauen, J., & Mosler, H.-J. (2013). Developing and Testing Theory-Based and Evidence-Based Interventions to Promote Switching to Arsenic-Safe Wells in Bangladesh. *Journal of Health Psychology, 19*(12), 1483-1498.

Inauen, J., Tobias, R., & Mosler, H.-J. (2013). Predicting Water Consumption Habits for Seven Arsenic-Safe Water Options in Bangladesh. *BMC Public Health, 13*(1), 417.

Julian, T. R., Islam, M. A., Pickering, A. J., Roy, S., Fuhrmeister, E. R., Ercumen, A., . . . Schwab, K. J. (2015). Genotypic and Phenotypic Characterization of Escherichia Coli Isolates from Feces, Hands, and Soils in Rural

Bangladesh Via the Colilert Quanti-Tray System. *Applied and Environmental Microbiology, 81*(5), 1735-1743.

Kaltenthaler, E., Waterman, R., & Cross, P. (1991). Faecal Indicator Bacteria on the Hands and the Effectiveness of Hand-Washing in Zimbabwe. *The Journal of Tropical Medicine and Hygiene, 94*(5), 358.

Kampf, G., & Kramer, A. (2004). Epidemiologic Background of Hand Hygiene and Evaluation of the Most Important Agents for Scrubs and Rubs. *Clinical Microbiology Reviews, 17*(4), 863-893.

Kohli, E., Ptak, J., Smith, R., Taylor, E., Talbot, E. A., & Kirldand, K. B. (2009). Variability in the Hawthorne Effect with Regard to Hand Hygiene Performance in High- and Low-Performing Inpatient Care Units. *Infection Control and Hospital Epidemiology, 30*(3), 222-225.

Lam, B., Lee, J., & Lau, Y. L. (2004). Hand Hygiene Practices in a Neonatal Intensive Care Unit: A Multimodal Intervention and Impact on Nosocomial Infection. *Pediatrics, 114*(5), 565-571.

Lee, E. J., & Schwab, K. J. (2005). Deficiencies in Drinking Water Distribution Systems in Developing Countries. *Journal of Water and Health, 3*(2), 109-127.

Levy, K., Nelson, K. L., Hubbard, A., & Eisenberg, J. N. (2008). Following the Water: A Controlled Study of Drinking Water Storage in Northern Coastal Ecuador. *Environmental Health Perspectives, 116*(11), 1533-1540.

Lilje, J., Kessely, H., & Mosler, H.-J. (2015). Factors Determining Water Treatment Behavior for the Prevention of Cholera in Chad. *The American Journal of Tropical Medicine and Hygiene, 93*(1), 57-65.

Limayem, M., Hirt, S. G., & Cheung, C. M. K. (2007). How Habit Limits the Predictive Power of Intention: The Case of Information Systems Continuance. *MIS Quarterly, 31*(4), 705-737.

Lin, C.-M., Wu, F.-M., Kim, H.-K., Doyle, M. P., Michaels, B. S., & Williams, L. K. (2003). A Comparison of Hand Washing Techniques to Remove Escherichia Coli and Caliciviruses under Natural or Artificial Fingernails. *Journal of Food Protection, 66*(12), 2296-2301.

Luby, S., Agboatwalla, M., Raza, A., Sobel, J., Mintz, E., Baier, K., . . . Qureshi, S. (2001). Microbiologic Effectiveness of Hand Washing with Soap in an Urban Squatter Settlement, Karachi, Pakistan. *Epidemiology and Infection, 127*(2), 237-244.

Luby, S. P., Agboatwalla, M., Bowen, A., Kenah, E., Sharker, Y., & Hoekstra, R. M. (2009). Difficulties in Maintaining Improved Handwashing Behavior, Karachi, Pakistan. *American Journal of Tropical Medicine and Hygiene, 81*(1), 140.

Luby, S. P., & Halder, A. K. (2008). Associations among Handwashing Indicators, Wealth, and Symptoms of Childhood Respiratory Illness in Urban Bangladesh. *Tropical Medicine and International Health, 13*(6), 835-844.

Luby, S. P., Halder, A. K., Huda, T., Unicomb, L., & Johnston, R. B. (2011a). The Effect of Handwashing at Recommended Times with Water Alone and with

Soap on Child Diarrhea in Rural Bangladesh: An Observational Study. *PLoS Medicine, 8*(6), e1001052.

Luby, S. P., Halder, A. K., Huda, T. M., Unicomb, L., & Johnston, R. B. (2011b). Using Child Health Outcomes to Identify Effective Measures of Handwashing. *The American Journal of Tropical Medicine and Hygiene, 85*(5), 882.

Luby, S. P., Kadir, M. A., Yushuf Sharker, M. A., Yeasmin, F., Unicomb, L., & Sirajul Islam, M. (2010). A Community-Randomised Controlled Trial Promoting Waterless Hand Sanitizer and Handwashing with Soap, Dhaka, Bangladesh. *Tropical Medicine and International Health, 15*(12), 1508-1516.

Lucet, J. C., Rigaud, M. P., Mentre, F., Kassis, N., Deblangy, C., Andremont, A., & Bouvet, E. (2002). Hand Contamination before and after Different Hand Hygiene Techniques: A Randomized Clinical Trial. *Journal of Hospital Infection, 50*(4), 276-280.

Maddux, J. E., & Rogers, R. W. (1983). Protection Motivation and Self-Efficacy: A Revised Theory of Fear Appeals and Attitude Change. *Journal of Experimental Social Psychology, 19*(5), 469-479.

Mattioli, M. C., Boehm, A. B., Davis, J., Harris, A. R., Mrisho, M., & Pickering, A. J. (2014). Enteric Pathogens in Stored Drinking Water and on Caregiver's Hands in Tanzanian Households with and without Reported Cases of Child Diarrhea. *PloS One, 9*(1), e84939.

Michie, S., Johnston, M., Francis, J., Hardeman, W., & Eccles, M. (2008). From Theory to Intervention: Mapping Theoretically Derived Behavioural Determinants to Behaviour Change Techniques. *Applied Psychology, 57*(4), 660-680.

Mosler, H.-J. (2012). A Systematic Approach to Behavior Change Interventions for the Water and Sanitation Sector in Developing Countries: A Conceptual Model, a Review, and a Guideline. *International Journal of Environmental Health Research, 22*(5), 431-449.

Mosler, H.-J., Blöchliger, O. R., & Inauen, J. (2010). Personal, Social, and Situational Factors Influencing the Consumption of Drinking Water from Arsenic-Safe Deep Tubewells in Bangladesh. *Journal of Environmental Management, 91*(6), 1316-1323.

Mosler, H.-J., & Contzen, N. (2016). *Systematic Behavior Change in Water, Sanitation and Hygiene. A Practical Guide Using the Ranas Approach. Version 1.1.* Dübendorf, Switzerland: Eawag.

Mwanga, J. R., Jensen, B. B., Magnussen, P., & Aagaard-Hansen, J. (2008). School Children as Health Change Agents in Magu, Tanzania: A Feasibility Study. *Health Promotion International, 23*(1), 16-23.

Navab-Daneshmand, T., Friedrich, M., Mosler, H.-J., & Julian, T. R. (in preparation). Impact of Environmental Fecal Contamination on Hand Hygiene in Urban Harare.

Nicas, M., & Best, D. (2008). A Study Quantifying the Hand-to-Face Contact Rate and Its Potential Application to Predicting Respiratory Tract Infection. *Journal of Occupational and Environmental Hygiene, 5*(6), 347-352.

Onyango-Ouma, W., Aagaard-Hansen, J., & Jensen, B. B. (2005). The Potential of Schoolchildren as Health Change Agents in Rural Western Kenya. *Social Science and Medicine, 61*(8), 1711-1722.

Onyango-Ouma, W., Aagaard-Hansen, J., & Jensen, B. B. (2004). Changing Concepts of Health and Illness among Children of Primary School Age in Western Kenya. *Health Education Research, 19*(3), 326-339.

Orbell, S., & Verplanken, B. (2010). The Automatic Component of Habit in Health Behavior: Habit as Cue-Contingent Automaticity. *Health Psychology, 29*(4), 374.

Ouellette, J. A., & Wood, W. (1998). Habit and Intention in Everyday Life: The Multiple Processes by Which Past Behavior Predicts Future Behavior. *Psychological Bulletin, 124*(1), 54.

Palit, A., Batabyal, P., Kanungo, S., & Sur, D. (2012). In-House Contamination of Potable Water in Urban Slum of Kolkata, India: A Possible Transmission Route of Diarrhea. *Water Science and Technology, 66*(2), 299-303.

Patel, M. K., Harris, J. R., Juliao, P., Nygren, B., Were, V., Kola, S., . . . Quick, R. (2012). Impact of a Hygiene Curriculum and the Installation of Simple Handwashing and Drinking Water Stations in Rural Kenyan Primary Schools on Student Health and Hygiene Practices. *The American Journal of Tropical Medicine and Hygiene, 87*(4), 594-601.

Pedersen, D. M., Keithly, S., & Brady, K. (1986). Effects of an Observer on Conformity to Handwashing Norm. *Perceptual and Motor Skills, 62*(1), 169-170.

Pickering, A. J., Boehm, A. B., Mwanjali, M., & Davis, J. (2010). Efficacy of Waterless Hand Hygiene Compared with Handwashing with Soap: A Field Study in Dar Es Salaam, Tanzania. *The American Journal of Tropical Medicine and Hygiene, 82*(2), 270-278.

Pickering, A. J., & Davis, J. (2012). Freshwater Availability and Water Fetching Distance Affect Child Health in Sub-Saharan Africa. *Environmental Science & Technology, 46*(4), 2391-2397.

Pickering, A. J., Davis, J., Walters, S. P., Horak, H. M., Keymer, D. P., Mushi, D., . . . Boehm, A. B. (2010). Hands, Water, and Health: Fecal Contamination in Tanzanian Communities with Improved, Non-Networked Water Supplies. *Environmental Science & Technology, 44*(9), 3267-3272.

Pickering, A. J., Julian, T. R., Mamuya, S., Boehm, A. B., & Davis, J. (2011). Bacterial Hand Contamination among Tanzanian Mothers Varies Temporally and Following Household Activities. *Tropical Medicine and International Health, 16*(2), 233-239.

Pinfold, J. V., & Horan, N. J. (1996). Measuring the Effect of a Hygiene Behaviour Intervention by Indicators of Behaviour and Diarrhoeal Disease. *Transactions of the Royal Society of Tropical Medicine and Hygiene, 90*(4), 366-371.

Porzig-Drummond, R., Stevenson, R., Case, T., & Oaten, M. (2009). Can the Emotion of Disgust Be Harnessed to Promote Hand Hygiene? Experimental and Field-Based Tests. *Social Science and Medicine, 68*(6), 1006-1012.

Prochaska, J. O., & DiClemente, C. C. (1983). Stages and Processes of Self-Change of Smoking: Toward an Integrative Model of Change. *Journal of Consulting and Clinical Psychology, 51*(3), 390.

Prüss-Ustün, A., Bartram, J., Clasen, T., Colford, J. M., Cumming, O., Curtis, V., . . . Cairncross, S. (2014). Burden of Disease from Inadequate Water, Sanitation and Hygiene in Low- and Middle-Income Settings: A Retrospective Analysis of Data from 145 Countries. *Tropical Medicine and International Health, 19*(8), 894-905.

Ram, P. (2013). *Practical Guidance for Measuring Handwashing Behavior: 2013 Update*. Washington, D.C.: The World Bank.

Ram, P., Jahid, I., Halder, A. K., Nygren, B., Islam, M. S., Granger, S. P., . . . Luby, S. P. (2011). Variability in Hand Contamination Based on Serial Measurements: Implications for Assessment of Hand-Cleansing Behavior and Disease Risk. *The American Journal of Tropical Medicine and Hygiene, 84*(4), 510.

Ram, P., Luby, S., Halder, A. K., Islam, M. S., & Granger, S. (2010). *Improving Measures of Handwashing Behavior.* Washington, D.C.: World Bank.

Rogers, R. W. (1975). A Protection Motivation Theory of Fear Appeals and Attitude Change. *The Journal of Psychology, 91*(1), 93-114.

Rosenstock, I. M. (1974). Historical Origins of the Health Belief Model. *Health Education and Behavior, 2*(4), 328-335.

Rudan, I., El Arifeen, S., Black, R. E., & Campbell, H. (2007). Childhood Pneumonia and Diarrhoea: Setting Our Priorities Right. *The Lancet Infectious Diseases, 7*(1), 56-61.

Rusin, P., Maxwell, S., & Gerba, C. (2002). Comparative Surface-to-Hand and Fingertip-to-Mouth Transfer Efficiency of Gram-Positive Bacteria, Gram-Negative Bacteria, and Phage. *Journal of Applied Microbiology, 93*(4), 585-592.

Saboori, S., Greene, L. E., Moe, C. L., Freeman, M. C., Caruso, B. A., Akoko, D., & Rheingans, R. D. (2013). Impact of Regular Soap Provision to Primary Schools on Hand Washing and E. Coli Hand Contamination among Pupils in Nyanza Province, Kenya: A Cluster-Randomized Trial. *The American Journal of Tropical Medicine and Hygiene, 89*(4), 698-708.

Sandhu, M. P., & Goodnight, J. (2014). Community Handwashing Guide: Utilizing Available Resources to Initiate a Handwashing Intervention. *World Medical & Health Policy, 6*(1), 39-50.

Schwartz, S. H. (1977). Normative Influences on Altruism. *Advances in Experimental Social Psychology, 10*(1), 221-279.

Schwarzer, R. (2008). Modeling Health Behavior Change: How to Predict and Modify the Adoption and Maintenance of Health Behaviors. *Applied Psychology, 57*(1), 1-29.

Scott, B., Schmidt, W., Aunger, R., Garbrah-Aidoo, N., & Animashaun, R. (2008). Marketing Hygiene Behaviors: The Impact of Different Communication Channels on Reported Handwashing Behavior of Women in Ghana. *Health Education Research, 23*(3), 392 - 401.

Scott, B. E., Lawson, D. W., & Curtis, V. (2007). Hard to Handle: Understanding Mothers' Handwashing Behaviour in Ghana. *Health Policy and Planning, 22*(4), 216-224.

Seimetz, E. (2015). *Behaviour, Cognitions, and the Environment: The Influence of Contextual Factors and Social-Cognitive Determinants on Handwashing Practices in Infrastructure-Restricted Settings.* (Dissertation), University of Zürich, Zürich.

Seimetz, E., Boyayo, A.-M., & Mosler, H.-J. (2016). The Influence of Contextual and Psychosocial Factors on Handwashing. *The American Journal of Tropical Medicine and Hygiene, 94*(6), 1407-1417.

Seimetz, E., Kumar, S., & Mosler, H.-J. (2016). Effects of an Awareness Raising Campaign on Intention and Behavioural Determinants for Handwashing. *Health Education Research, 31*(2), 109-120.

Seimetz, E., Slekiene, J., Friedrich, M. N. D., & Mosler, H.-J. (submitted). Identifying Behavioural Determinants for Interventions to Increase Handwashing Practices among Primary School Children in Rural Burundi and Urban Zimbabwe.

Sickbert-Bennett, E. E., Weber, D. J., Gergen-Teague, M. F., & Rutala, W. A. (2004). The Effects of Test Variables on the Efficacy of Hand Hygiene Agents. *American Journal of Infection Control, 32*(2), 69-83.

Sobel, J., Mahon, B., Mendoza, C. E., Passaro, D., Cano, F., Baier, K., . . . Mintz, E. (1998). Reduction of Fecal Contamination of Street-Vended Beverages in Guatemala by a Simple System for Water Purification and Storage, Handwashing, and Beverage Storage. *American Journal of Tropical Medicine and Hygiene, 59*(3), 380-387.

Sonego, I. L., & Mosler, H.-J. (2014). Why Are Some Latrines Cleaner Than Others? Determining the Factors of Habitual Cleaning Behaviour and Latrine Cleanliness in Rural Burundi. *Journal of Water Sanitation and Hygiene for Development, 4*(2), 257-267.

Sonego, I. L., & Mosler, H.-J. (2016). Spot-Checks to Measure General Hygiene Practice. *International Journal of Environmental Health Research, 26*(5-6), 554-571.

Song, I. H., Kim, S.-A., & Park, W.-S. (2013). Family Factors Associated with Children's Handwashing Hygiene Behavior. *Journal of Child Health Care, 17*(2), 164-173.

Stocker, A., & Mosler, H. J. (2015). Contextual and Sociopsychological Factors in Predicting Habitual Cleaning of Water Storage Containers in Rural Benin. *Water Resources Research, 51*(4), 2000-2008.

Tobias, R. (2009). Changing Behavior by Memory Aids: A Social Psychological Model of Prospective Memory and Habit Development Tested with Dynamic Field Data. *Psychological Review, 116*(2), 408.

Trafimow, D., & Sheeran, P. (1998). Some Tests of the Distinction between Cognitive and Affective Beliefs. *Journal of Experimental Social Psychology, 34*(4), 378-397.

United Nations Children's Fund, World Health Organisation. (2009). *Diarrhoea: Why Children Are Still Dying and What Can Be Done*. Retrieved from http://apps.who.int/iris/bitstream/10665/44174/1/9789241598415_eng.pdf:

Verplanken, B., Aarts, H., Knippenberg, A., & Knippenberg, C. (1994). Attitude Versus General Habit: Antecedents of Travel Mode Choice. *Journal of Applied Social Psychology, 24*(4), 285-300.

World Health Organisation. (2009). *Who Guidelines on Hand Hygiene in Health Care.* Retrieved from http://apps.who.int/iris/bitstream/10665/44102/1/9789241597906_eng.pdf:

Xuan, L. T. T., Rheinländer, T., Hoat, L. N., Dalsgaard, A., & Konradsen, F. (2013). Teaching Handwashing with Soap for Schoolchildren in a Multi-Ethnic Population in Northern Rural Vietnam. *Global Health Action, 6*, e20288.

Annex I: Supplementary information Chapter 4

Item wordings of the psychological and structural factors and Cronbach's alphas

Descriptive statistics

Results of hierarchical multiple binary logistic regression explaining air drying of hand

Table AI 1. Item wording of the structural and psychological factors and internal reliability for constructs measured with multiple items.

Factor group	Construct	Item	α
Structural factors	Age	How old are you? (Open-ended question)	–
	Education	How many years of formal education did you attend? (Open-ended question)	–
	Household size	How many people live in this household? (Open-ended question)	–
	Household income	What is the monthly income of your household? (Open-ended question)	–
	Water collection time	On a regular day last week, how long (in minutes) did it take to go to the water source, wait and come back? (Open-ended question)	–
	Water collection frequency	On a regular day last week, how often did you collect water? (Open-ended question)	–
	Water storage capacity	Spot-check: What is the total transport and storage capacity for water in the household (in l)? (Open-ended question)	–
	Separate HW facility food / stool related HW	Spot-check: Is there a specific place for handwashing after contact with stool? (1 = *Yes, but it is the same as for washing hands before handling food*; 2 = *Yes, it is different from the place for washing hands before handling food*, 3 = *No*)	
	Functional water tap	Spot-check: Does this household have a water tap? (1 = *Yes*, 0 = *No*)	–
		Spot-check: Is there water? (1 = *Yes*, 0 = *No*)	–
	Diarrhoea caregiver	During the last week, did you have diarrhoea? (1 = *Yes*, 0 = *No*)	–
	Diarrhoea children	During the last week, did the index child have diarrhoea? (1 = *Yes*, 0 = *No*)	n/a
		How many other children aged below 5 years had diarrhoea during the last week? (Open-ended question)	
		Including the index child, how many children aged 5-12 years or more had diarrhoea during the last week? (Open-ended question)	
Handwashing frequency		In the following situations, how often do you wash your hands with soap and water?	.89
		1 … before eating?	
		2 … before breastfeeding a child?	
		3 … before feeding a child	
		4 … before preparing/cutting food?	
		5 … after defecating?	
		6 … after cleaning up a child's bottom?	
		7 … after other contact with stool?	
Risk factors	Vulnerability	If you always wash hands like you just did, how high do you feel is the risk that you contract diarrhoea? (1 = *No risk at all* to 5 = *Very high risk*).	–
	Severity	Imagine you contracted diarrhoea, how severe would be the impact on your daily life? (1 = *No risk at all* to 5 = *Very high risk*).	–
	Health knowledge	What are the consequences of diarrhoea?	.73
		(Open-ended question. Answers were scored according to correctness. 0 = *No knowledge* to 4 = *Maximal knowledge*)	
		What are typical ways how you can get diarrhoea? (0 = *No knowledge* to 4 = *Maximal knowledge)*	
		What can you do not to get diarrhoea? (0 = *No knowledge* to 5 = *Maximal knowledge*)	
		What are the effects of washing hands with soap and water? (0 = *No knowledge* to 3 = *Maximal knowledge*)	
Attitude factors	Investment	How effortful do you think is washing hands like this? (1 = *Not effortful at all* to 5 = *Extremely effortful*)	–
	Return	How certain are you that always washing hands like you just did prevents you from getting diarrhoea? (1 = *Not certain at all* to 5 = *Extremely certain*)	–

Factor group	Construct	Item	α
	Example	How strongly do you think that you give a good example to your children if you wash your hands like you just did? (1 = *Not strongly at all* to 5 = *Extremely strongly*)	–
	Liking	How much do you like washing hands like you just did? (1 = *I don't like at all* to 5 = *I like very much*)	–
Norm factors	Descriptive norm, house	How many people of your household wash hands like you just did? (1 = *Almost nobody* to 5 = *Almost all of them*)	–
	Descriptive norm, community	How many people of your community wash hands like you just did? (1 = *Almost nobody* to 5 = *Almost all of them*)	–
Ability factors	Action knowledge, time	In which situations is it critical to wash hands with soap? (Open question format. Answers were scored according to correctness. 0 = *No knowledge* to 8 = *Maximal knowledge*)	–
	Action knowledge, steps	What are the different steps for good handwashing? (Open question format. Answers were scored according to correctness. 0 = *No knowledge* to 11 = *Maximal knowledge*)	–
	Self-efficacy	If you wash your hands: how confident are you that you can wash hands like you just did? (1 = Not confident at all to 5 = Extremely confident) How confident are you that you can always wash hands like you just did, even if circumstances are difficult? (1 = Not confident at all to 5 = Extremely confident)	.73
Self-regulation factors	Action planning	1 Do you have a plan which device you use to dispense water for washing hands before handling food? 2 Do you have a plan which device you use to dispense water for washing hands after contact with stool? 3 Do you have a plan to always wash your hands with soap and water before handling food at a specific location? 4 Do you have a plan to always wash your hands with soap and water after contact with stool at a specific location? 5 Do you have a plan where you keep the soap for hand washing before handling food? 6 Do you have a plan where you keep the soap for hand washing after contact with stool? (1 = *Yes* to 2 = *No*)	.74
	Action control	If you wash your hands: How aware are you of your goal to wash hands like you just did? (1 = *Not aware at all* to 5 = *Extremely aware*)	–
	Commitment	If you wash hands: How committed are you to wash your hands like you just did? ? (1 = *Not committed at all* to 5 = *Extremely committed*)	–

Note: HW = Handwashing; n/a = not applicable: Items which were combined to scales due to theoretical reasons but for which common variance was not expected; If not marked as spot-checks, items were surveyed through interview.

Table AI 2. Descriptive statistics.

Groups	**Variable**	**Range**		***SD***	***dn***	**Skew**	**Kurtosis**
Behaviour	Overall handwashing technique	0-8	4.73	1.70	5.00	-0.02	-0.59
	Thoroughness of scrubbing	0-5	2.91	1.13	3.00	0.25	-0.47
	Soap use	0-1	0.54	0.50	1.00	-0.17	-1.98
	Running water use	0-1	0.49	0.50	0.00	0.04	-2.01
	Air dry	0-1	0.74	0.44	1.00	-1.07	-0.86
	Handwashing frequency	1-5	3.31	0.93	3.40	-0.54	-0.12
Contextual factors	Gender	0-1	0.97	0.17	1.00	-5.53	28.76
	Age	16-74	37.55	11.90	34.00	1.00	0.57
	Education	0-17	10.14	2.48	11.00	-1.69	4.73
	Household size	2-16	5.59	1.88	5.00	1.31	3.66
	Income	0-3000	315.21	290.52	250.00	3.72	23.40
	Water collection time * frequency (min)	0-3600	34.17	199.97	0.00	14.32	241.14
	Water storage cap (l).	0-2020	138.93	171.11	100.00	6.13	54.03
	Separate handw. facility food/stool	0-1	0.79	0.40	1.00	-1.47	0.15
	Functional tap	0-1	0.59	0.49	1.00	-0.38	-1.87
	Situation: stool related	0-1	0.54	0.50	1.00	-0.15	-1.99
	Diarrhoea caregiver	0-1	0.03	0.16	0.00	6.06	34.90
	Diarrhoea children	0-1	0.04	0.20	0.00	4.62	19.39
Risk factors	Perceived vulnerability	1-5	4.75	0.52	5.00	-3.02	14.20
	Perceived severity	1-5	4.38	0.88	5.00	-1.61	2.38
	Health knowledge	1-5	3.04	0.64	2.98	0.06	-0.12
Attitudinal factors	Investment	1-5	3.95	1.33	5.00	-1.01	-0.35
	Return	1-5	4.39	0.65	4.00	-1.06	2.20
	Example	1-5	4.25	0.63	4.00	-0.53	0.67
	Liking	1-5	4.26	0.73	4.00	-1.12	2.21
Norm factors	Descriptive norm house	1-5	1.77	1.16	1.00	1.57	1.53
	Descriptive norm community	1-5	1.62	0.60	2.00	0.53	0.10
	Injunctive norm	1-5	3.29	1.12	3.50	-0.43	-0.60
Ability factors	Action knowledge time	0-1	0.29	0.15	0.25	0.59	0.60
	Action knowledge steps	0-1	0.53	0.21	0.50	0.07	-0.75
	Self-efficacy	1-5	3.70	0.83	4.00	-0.96	1.11
Self-regulation factors	Action planning	1-5	4.37	0.94	5.00	-1.58	1.93
	Action control	1-5	4.06	0.56	4.00	-0.53	0.74
	Commitment	1-5	4.12	0.78	4.00	-1.04	1.84

Note: (N = 434).

Table AI 3. Hierarchical multiple binary logistic regression explaining air dry.

	Air dry		
Predictor	B	Odds Ratio	95% CI
Model 1			
(Constant)	0.63 **	1.87	
Separate handwashing facilities food / stool	0.51 *	1.66	[1.01, 2.74]
R^2 (Nagelkerke)	0.01		
χ^2	3.83 *		
Model 2			
(Constant)	0.63	1.88	
Separate handwashing facilities food / stool	0.47	1.59	[0.38, 2.71]
Perceived vulnerability	0.36	1.44	[0.96, 2.14]
Health knowledge	0.14	1.14	[0.78, 1.68]
Example	-0.19	0.83	[0.55, 1.25]
Liking	-0.16	0.85	[0.58, 1.25]
Injunctive norm	-0.15	0.86	[0.69, 1.07]
Action knowledge time	1.73 *	5.65	[1.10, 28.90]
Action knowledge steps	1.19 *	3.25	[1.01, 10.48]
Commitment	-0.28	0.76	[0.52, 1.10]
R^2 (Nagelkerke)	0.11		
χ^2	9.25 ***		

Note: (N = 434).

Annex II: Project photos

Figure AII 1: Areal view, showing a high-density suburb of Harare.

Figure AII 2: Role plays during the training of data collectors.

Figure AII 3: Caregiver, rinsing hands by dipping them into water during hand-washing demonstration.

Figure AII 4: Interview during the baseline survey.

Figure AII 5: Collection of hand rinse sample during the pre-test of the baseline survey.

Figure AII 6: Processing of hand rinse samples in the laboratory of the Department of Biology, University of Zimbabwe.

Figure AII 7: Counting of *E.coli* colonies on media plates.

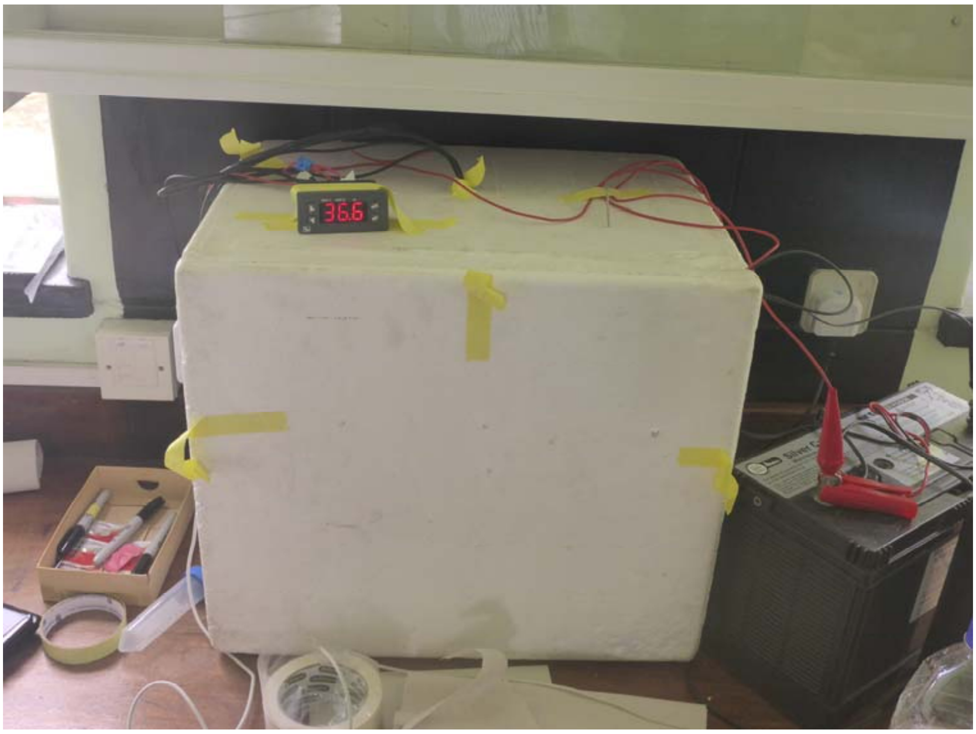

Figure AII 8: Portable incubator with power back-up, developed for this project.

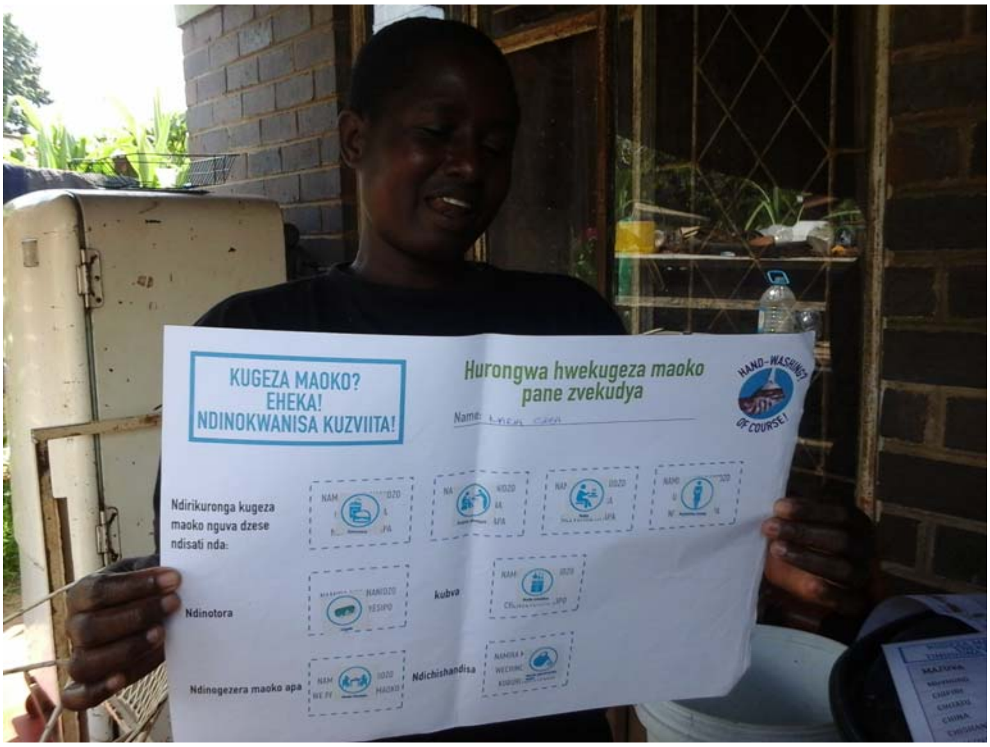

Figure AII 9: Planning form of when, where and with which device to wash hands, used in Intervention Blocks 2 and 3.

Figure AII 10: Self-monitoring calendar of handwashing behaviour, used in Intervention Blocks 2 and 3.

Figure AII 11: Public commitment ceremony, performed in Intervention Block 4. Photo: ActionAid Zimbabwe.

Figure AII 12: Certificate awarded after Intervention Block 4.

Figure AII 13: Data collection team of follow-up survey.

Annex III: Design, implementation and evaluation of a handwashing campaign in Harare, Zimbabwe: A case study applying the practical guide *systematic behaviour change in water sanitation and hygiene*

Friedrich, M.N.D. (2016)

A similar version of this document is available online at

http://www.eawag.ch/en/department/ess/empirical-focus/environmental-and-health-psychology-ehpsy/

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Overview

Consistent hand hygiene can reduce morbidity and mortality from diarrheal and respiratory diseases. Diarrhea and pneumonia are still the leading causes of mortality among children under five years of age in low-income and middle-income countries. Recent findings suggest that interventions promoting handwashing with soap lead to a 40% reduction in the risk of diarrhea. Despite its health impact, handwashing with soap is seldom practiced. It is estimated that less than 20% of people worldwide wash hands with soap after contact with feces, with a mean prevalence of 13% to 17% in low- and middle-income regions. Considering these low handwashing rates, interventions promoting handwashing behavior are of paramount importance.

The objectives of our project were to promote handwashing with soap at critical times among school children, caregivers, and policy makers in Harare, Zimbabwe and to disseminate the results among international actors in the water, sanitation, and hygiene (WaSH) sector.

The handwashing campaign is part of the second phase of the Handwashing in India and Africa project initiated and funded by the Swiss Agency for Development and Cooperation (SDC). High-density suburbs of Harare, Zimbabwe and the province of Ngozi in rural Burundi were chosen as pilot areas for the handwashing campaigns. While the political situation in Burundi did not allow the project to be completed there, the part in Zimbabwe was largely implemented as planned and is the subject of this case study.

The campaign was designed by Eawag in collaboration with the Università della Svizzera Italiana and WASH United. The data collection was implemented by Eawag in collaboration with the University of Zimbabwe. The campaign was implemented by ActionAid Zimbabwe and in collaboration with the Ministry of Health and Child Welfare of the Government of Zimbabwe and Eawag.

This case study aims at illustrating how *Systematic Behavior Change in Water, Sanitation and Hygiene. A practical guide using the RANAS approach* by Hans-Joachim Mosler and Nadja Contzen[1] (referred to in this case study as *Systematic Behavior Change*) was applied in a real project. The structure of this case study follows the steps of *Systematic Behavior Change* exactly: It presents how we put each *phase*, *step*, and *key action* described in *Systematic Behavior Change* into practice during our handwashing campaign in Zimbabwe and what the results were. Our aims are to bridge the gap between the steps described in *Systematic Behavior Change* and their application in the field and to inspire practitioners to follow our example.

[1] Mosler, H.-J., & Contzen, N. (2016). Systematic behavior change in water, sanitation and hygiene. A practical guide using the RANAS approach. Version 1.1. Dübendorf, Switzerland: Eawag

Phase 1: Identify potential psychosocial and contextual factors

Step 1.1: Define the behavior to be changed and the specific population group to be targeted

Key actions

Define the target behavior

The high-density suburbs of Harare suffer from frequent cyclic outbreaks of diarrheal disease. Since open defecation is rarely practiced, inadequate hand hygiene and consumption of unsafe drinking water are the two most likely causes of these outbreaks. Whereas numerous projects have focused on provision of safe drinking water, the current project was focused on handwashing promotion.

Preconditions for handwashing with soap comprise the availability of a place and device for handwashing and the presence of soap. Consequently, making water and soap readily available for handwashing are considered preparatory behaviors.

We preliminarily defined washing hands with soap and effective technique, including adequate hand drying, in key handwashing situations as the main target behavior. We defined key handwashing situations as:

- After using the toilet
- After other contact with feces, e.g. changing diapers, cleaning toilet
- Before preparing food
- Before eating.

Adequate handwashing technique was preliminarily defined as:

- Rinsing hands using a tap or pouring water from a jug
- Applying soap
- Scrubbing the palms, backs and finger tips of both hands, scrubbing between the fingers and scrubbing under finger nails
- Rinsing hands using a tap or pouring water from a jug
- Drying hands using a clean towel or air drying.

We aimed to assess the actual handwashing practices in the field and find out whether there was a real need for improvement through a qualitative pre-study in potential intervention areas. We visited approximately 20 households, interviewed participants about when and how they washed hands, observed their manner of handwashing, and inspected the local handwashing facilities. Handwashing with water only was common in the potential study areas, whereas handwashing with soap was rarely practiced. Besides, the way in which respondents reported and showed washing their hands varied considerably between respondents. In summary, there was potential for improvement regarding both frequency and technique of handwashing.

In addition, we assessed the potential for a handwashing campaign in schools. Since the permits to work in primary schools were still pending, we were not able to visit primary schools and had to base our pre-study on expert interviews. We interviewed representatives of the Ministry of Primary and Secondary Education and of NGOs that had worked on handwashing promotion. According to the responses of the experts, washing hands with water only at sinks was common in schools where the necessary infrastructure and water supply were present. The prevalence of washing hands with soap and water was reported to be low. Furthermore, interviews indicated that few activities had been implemented to promote handwashing in schools. Taken together, the potential for improvement of handwashing practices was likely to exist both in schools and the wider community.

Select the target population group

Effective hand hygiene should be practiced by everyone. We identified primary caregivers, the persons taking care of children and household work, as the individuals whose handwashing behavior probably has the highest influence on the family's health. Consequently, the campaign activities to be implemented in the community focused on primary caregivers as the primary target group. The campaign activities to be implemented in schools focused on primary school children as the primary target group. We defined remaining household members as a secondary target group to be included in campaign activities whenever possible. The household visits during the pre-study indicated that primary caregivers were, as expected, mostly female. In numerous households, at least one person was working away from the house. Consequently, reaching the working household members as part of the secondary target group was challenging.

Since changing the behavior of children was expected to require different behavior change strategies than changing adults' behavior, we decided to design strategies specifically for children and other strategies specifically for adults. The design, implementation, and evaluation of both the strategies for caregivers and the strategies for children are presented in this case study.

We focus here on the strategies designed to increase handwashing frequency in key situations. To keep this case study as concise as possible, we do not report the strategies implemented to improve handwashing technique.

Step 1.2: Collect information on psychosocial and contextual factors that might influence the target behavior

Key actions

Conduct short qualitative surveys and spot-check observations

Individual qualitative interviews were conducted with approximately 20 caregivers in several high-density suburbs of Harare. Besides assessing the target behavior, the main goals of these interviews were to find out about the water infrastructure available, the health situation, and potential behavioral factors affecting handwashing with soap. In addition, we wanted to find out what kind of handwashing campaigns had already been implemented in the target areas. Since primary caregivers had been specified as the primary target population, most but not all interviews were conducted with primary caregivers.

The following questions were used to guide the qualitative interviews:

- How common are diarrhea and other water-borne diseases?
- What are the main sources of drinking and domestic water?
- Are there seasonal changes in the hygiene situation?
- What are major health concerns of the respondents?
- How readily available is water?
- How readily available is soap?
- What are the local handwashing facilities?
- What are reasons for washing or not washing hands with soap?
- Which promotion activities for handwashing have been implemented?
- By whom, when, and where were they implemented?

Since we were unable to enter primary schools during the pre-study, qualitative information on factors that potentially influenced handwashing in school was based on expert interviews and interviews with children when they were at home.

Analyze the surveys

The interviews confirmed that diarrhea was common and that periodic epidemics of typhoid occurred in several potential study areas. Diarrhea was reported to occur throughout the year, with peaks during the rainy seasons. Water availability depended strongly on the area; in some areas, running water from a tap was readily available, while in others, taps had been dry for weeks, and respondents had to rely on public wells. Preventing the spread of HIV and cholera epidemics, such as occurred in 2008, were among the most frequently mentioned health concerns.

All households had water taps; however, these were dry in about half of the households visited. In addition to washing hands in a sink, hands were frequently washed by pouring water from a jug or dipping them into a vessel containing water. Soap was available in all households and commonly used for laundry, dishes, washing the body, and sometimes handwashing.

The most commonly stated reason for washing hands with soap was to prevent water-borne diseases. The most common reasons people gave for not washing hands with soap was that they were not convinced of the benefits of using soap, forgot to wash hands in key handwashing situations, or decided not to wash their hands when in a hurry. Frequent and long-lasting water cuts were probably another hindrance to handwashing. Participants used tap, well, or borehole water for handwashing.

There had been previous handwashing campaigns implemented by local community health promoters. However, few respondents remembered the exact content of the activities. During the cholera epidemic in 2008, numerous activities to promote handwashing had been implemented, and handwashing devices (in the form of buckets with a tap) and soap had been distributed.

With regard to handwashing in schools, the interviews with experts and children yielded that most schools in suburbs of Harare had sanitation and handwashing facilities.

Providing these facilities was a requirement of government regulations. The functionality of the facilities was, however, questionable. Some schools provided soap to students; however, few provided soap in sufficient quantities.

Children stated that they washed their hands to follow the instructions of teachers and caregivers and out of fear of diarrheal diseases and cholera. When asked about the reasons for not washing hands, children mentioned the lack of water and soap, forgetting to wash hands, being in a hurry, and considering handwashing boring. In addition, the interviewed experts assumed that children did not know why handwashing was important.

Step 1.3: Allocate psychosocial and contextual factors to the RANAS mode

Key actions

To allocate the potential psychosocial and contextual factors to the RANAS factors

We considered all the original RANAS factors as psychosocial factors potentially steering handwashing behavior in primary caregivers. In addition, we examined the findings from the qualitative interviews to identify additional factors which are not part of the RANAS model but which may be relevant to our study community. The most frequently stated reason for washing hands with soap was to prevent diarrhea. This was allocated to the factor *Vulnerability* in the risk factor block. The statement that participants did not wash hands with soap because they did not see the benefits of doing so was allocated to *Beliefs about costs and benefits* under attitude factors. Deciding not to wash hands with soap in key situations, particularly when in a hurry, was also given as a reason for not washing hands. Since such barriers did not fit the RANAS factors, we decided to treat them as additional factors.

Among contextual factors, we identified the availability of soap, water, and a handwashing device that allows unassisted handwashing as potentially relevant behavioral factors.

With the primary school children, we decided to exclude some of the original RANAS factors from the data collection. *Confidence in recovery* turned out to be a construct that was extremely difficult to explain to children. Also, *Action planning* and *Barrier planning* were not further considered. The idea of planning was difficult to explain, and based on child development theory, we considered it unlikely that such specific and conscious planning would be a factor relevant to the behavior of primary school children.

The availability of soap and water at handwashing devices suitable for children were hypothesized to be major constraints of handwashing behavior. Both experts and children had mentioned a lack of soap and water and dry or broken taps in toilet building.

Phase 2: Measure the psychosocial factors and determine those steering the target behavior

Step 2.1: Develop a questionnaire to measure behavioral factors and the behavior and a protocol to conduct observations of the behavior

Key actions

Develop a questionnaire

As decided during Phase 1, our project aimed to raise the frequency of handwashing with soap at key handwashing times among primary caregivers and children. Consequently, we designed our questionnaire to obtain self-reported frequencies of handwashing with soap and the corresponding behavioral factors. To measure the behavior of caregivers, we used the items in the following table

Subsequently, psychosocial factors potentially steering caregivers' behavior were assessed.

Behavior
In the following situations, how often do you wash your hands with soap and water? Please tell us in how many out of 10 times you wash your hands with soap and water in the following situations… - *Before eating?* - *Before preparing/cutting food?* - *Female respondents with young children: before breastfeeding a child?* - *Respondents with young children: before feeding a child?* - *After urinating?* - *After defecating?* - *Respondents with young children: after cleaning a child's bottom?* - *After other contact with stool?*

Risk factors	
Health knowledge	We assessed *Health knowledge* using three items in the format of open questions with given responses (see Tool 2.1.1). Data collectors recorded which of the prespecified and correct answers the respondent mentioned. Health knowledge was computed as the number of correct answers given divided by the number of total prespecified and correct answers. The items were: What are the consequences of diarrhea? - *Loose, watery stool / frequent toilet use* - *Loss of water/ salt from the body,* - *Loss of weight/ underweight* - *Fever, weakness, body/ stomach ache* - *I don't know* - *None of the previous points mentioned* What are typical ways you can get diarrhea? - *Don't wash hands with soap before handling food* - *Don't wash hands with soap after contact with stool* - *Consume contaminated food (germs, rotten)* - *Consume contaminated drinking water* - *I don't know* - *None of the previous points mentioned*

	What can you do to not get diarrhea? - *Wash hands with soap before handling food* - *Wash hands with soap after contact with stool* - *Don't consume contaminated food/ Boil, wash, peel, cover food* - *Don't consume contaminated water/ Treat water, consume safe water* - *Use toilets / cover toilets* - *I don't know* - *None of the previous points mentioned*
Vulnerability	We assessed *Vulnerability* using four items, with two items each asking for vulnerability with regard to stool and food related handwashing. The items for stool-related handwashing were: If you **always** wash your hands with soap and water after contact with stool, how high do you feel is the risk that you contract diarrhea? If you **never** wash your hands with soap and water after contact with stool, how high do you feel is the risk that you contract diarrhea? *No risk at all / Little risk / Medium risk / High risk / Very high risk*
Severity	Imagine you contracted diarrhea, how severe would be the impact on your daily life? *Not severe at all / Little severe / Medium severe / Very severe / Extremely severe*

Attitude factors	
Beliefs about costs and benefits	We surveyed *Beliefs about costs and benefits* using four items, with two items each for food and stool-related handwashing. The items for stool-related handwashing were: How effortful do you think is always washing hands with soap after contact with stool? *Not effortful at all / A little effortful / Medium effortful / Very effortful / Extremely effortful* How certain are you that always washing hands with soap and water after contact with stool prevents you from getting diarrhea? *Not certain at all / A little certain / Medium certain / Very certain / Extremely certain*
Feelings	We assessed *Feelings* using four items, with two items each for food and stool-related handwashing. The items for stool-related handwashing were: How much do you like washing hands with soap and water before handling food? *I don't like at all / I like a little / I quite like / I like it a lot / I like very much* How disgusting do you think is it to not always wash hands with soap and water before handling food? *Not disgusting at all / A little disgusting / Medium disgusting / Very disgusting / Extremely disgusting*

Normative factors	
Others' behavior	We assessed *Others' behavior* using four items, with two items each for food and stool-related handwashing. The items for stool-related handwashing were: How many people in your **household** always wash hands with soap and water after contact with stool? *(Almost) nobody / Some of them / Half of them / Most of them / (Almost) all of them* How many people in your **community** always wash hands with soap and water after contact with stool? *(Almost) nobody / Some of them / Half of them / Most of them / (Almost) all of them*

Other's (dis)approval	We assessed *Other's (dis)approval* using two items, with one item each for food and stool-related handwashing. The item for stool-related handwashing was: People who are important to you, how much do they think you should always wash your hands with soap and water after contact with stool? *Not at all / A little / Medium / A lot / Very much*

Ability factors	
How-to-do knowledge	We assessed *How-to-do knowledge* similarly to health knowledge using two items. How-to-do knowledge was computed as the number of correct given answers divided by the number of correct total answers. The items were: What are the different steps for good handwashing? - *Wet hands with water* - *Put soap* - *Rub hands (general)* - *Rub the palm of the hand* - *Rub between the fingers* - *Rub under the finger nails* - *Rub the finger tips* - *Rub the back of the hands* - *Rub for at least 20 seconds* - *Rinse hands with water* - *Dry hands with a clean towel / air dry hands* - *I don't know* In which situations is it critical to wash hands with soap? - *After defecating* - *After cleaning a child's bottom* - *After other contact with stool* - *Before breastfeeding a child* - *Before feeding a child* - *Before preparing food* - *Before handling drinking water* - *Before eating* - *I don't know*
Confidence in performance	We assessed *Confidence in performance* using two items, with one item each for food and stool-related handwashing. The item for stool-related handwashing was: How confident are you that you can always wash your hands with soap and water after contact with stool? *Not at all confident / A little confident / Quite confident / Very confident / Extremely confident*
Confidence in continuation	We assessed *Confidence in continuation* using two items, with one item each for food and stool-related handwashing. The item for stool-related handwashing was: How confident are you that you can always wash hands with soap and water after contact with stool, even if circumstances are difficult? *Not at all confident / A little confident / Quite confident / Very confident / Extremely confident*
Confidence in recovering	We assessed *Confidence in recovery* using one item: Imagine you have stopped always washing hands with soap and water before handling food and after contact with stool for several days, for example because there was no water or soap for handwashing. How confident are you that you will start washing hands again? *Not at all confident / A little confident / Quite confident / Very confident / Extremely confident*

Self-regulation factors	
Action planning	We assessed *Action planning* using six items, with three items each for food and stool-related handwashing. The items for stool-related handwashing were: Do you have a plan which device you use to dispense water for washing hands after contact with stool? *Yes / No* Do you have a plan to always wash your hands with soap and water after contact with stool at a specific location? *Yes / No* Do you have a plan where you keep the soap for handwashing after contact with stool? *Yes / No*
Action control	We assessed *Action control* using two items, with one item each for food and stool-related handwashing. The item for stool-related handwashing was: How aware are you of your goal to wash hands with soap and water after contact with stool? *Not aware at all / A little aware / Quite aware / Very aware / Extremely aware*
Barrier planning	We measured *Barrier planning* using three items with open response format without given responses. The three items were: Do you have a plan how to avoid forgetting to always wash hands with soap and water before handling food, and after contact with stool? Do you have a plan how you can wash your hands with soap and water before handling food and after contact with stool, even if you are in a hurry? Do you have a plan how you can wash your hands with soap and water before handling food and after contact with stool, even if there is no soap at home?
Remembering	We assessed *Remembering* using two items, with one item each for food and stool-related handwashing. The item for stool-related handwashing was: When you think about the last 24 hours, how often did it happen that you intended to wash hands with soap and water after contact with stool and then forgot to do so? These items investigated a frequency. The same answer format, ranging from “0 out of 10 times” to “10 out of 10 times”, as for behavior was used.
Commitment	We assessed *Commitment* using two items, with one item each for food and stool-related handwashing. The item for stool-related handwashing was: How committed are you to always washing your hands with soap and water after contact with stool? *Not committed at all / A little committed / Quite committed / Very committed / Extremely committed*

Additional items	
Hindrance	Lack of soap and water as hindrances of handwashing were assessed with two items: How often does it happen that you want to wash your hands with soap and water before handling food or after contact with stool, but there is no water at home? How often does it happen that you want to wash your hands with soap and water before handling food or after contact with stool, but there is no soap at home? Whether being in a hurry or not feeling like washing hands prevented participants from handwashing was assessed using four items with two items each for food and stool-related handwashing. The items for stool-related handwashing were: After contact with stool: How often does it happen that you do not wash your hands with soap and water because you don’t feel like doing it?

	After contact with stool: How often does it happen that you do not wash your hands with soap and water because you are in a hurry? These items investigated a frequency. The same answer format, ranging from “0 out of 10 times” to “10 out of 10 times”, as for behavior was used.

Develop an observation protocol

Self-reported data are subject to biases. Consequently, handwashing behavior was also surveyed through 3-hour structured observations. The observation protocol was as follows

Observations
What key situation happens? *Household member uses toilet / Household member changes diaper / Household member has other contact with stool / Household member eats / Household member drinks / Household member prepares food (direct food contact) / Household member prepares food (no direct food contact)*
Which household member was it? *Primary caregiver / Index child / …*
For food-related handwashing situations: Immediately before contact with food, did the person wash hands? *Yes / No / Could not see*
For stool-related handwashing situations: Immediately after contact with stool, did the person wash hands? *Yes / No / Could not see*
If hands were washed, how did the person wash hands? *Rinsed only the right hand with water / Rinsed only the left hand with water / Rinsed both hands with water / Washed only the right hand with soap / Washed only / the left hand with soap / Washed both hands with soap / Washed both hands with soapy water / Took a bath / I am not sure / could not see*

In addition to the direct observations of behavior, we performed spot checks to survey the presence of soap and water. First, this served as a proxy measure for handwashing behavior. Second, we wanted to find out how readily available the handwashing infrastructure was in the target households. The spot-check protocol was as follows.

Spot checks
Ask: Does this household have a water tap? *Yes / No*
Is there water? *Yes / No*
Ask: Is there a specific place for handwashing before handling food? *Yes / No*
Where is the place for handwashing before handling food? *Inside the house / Outside the house*
What kind of handwashing facility is it? *Tap from running water / Tap from reservoir / Bowl to dip hands / Small vessel, e.g. bowl, jug to pour water on hands / Jerry can / Other*
Is it accessible from the house without walking in the rain? *Yes / No*
Is there water? *Yes / No*
Is there soap? *Yes / No*
If yes, what kind of soap is there? *Yes / No*
Ask: Is there a specific place for handwashing after contact with stool? *Yes / No*
… Same items as for food-related handwashing facility.

To measure the handwashing behavior of children, we used the following items.

Behavior
Do you wash your hands with soap and water before eating at school?
Do you wash your hands with soap and water after using the toilet at school?
Not at all / a little / a medium amount / a great deal

Subsequently, psychological factors potentially steering children's' behavior at school were assessed. The response categories of all closed questions were the same. Only four response categories were used, and they read as follows:

Not at all / a little / a medium amount / a great deal

To assist children in choosing the appropriate answers, we wrote them on cards, which were placed in front of the children during the interview. Children could answer questions either by speaking their response or by pointing to the appropriate card.

Risk factors	
Health knowledge	We assessed *Health knowledge* using three items in the format of open questions with given responses (see Tool 2.1.1 of *Systematic Behavior Change*). Interviewers recorded which of the pre-specified and correct answers the child mentioned. Health knowledge was computed as the number of correct given answers divided by the number of total pre-specified and correct answers. The items were: What are the consequences of diarrhea? - *Loose, watery stool / frequent toilet use* - *Loss of water/ salt from the body,* - *Loss of weight/ underweight* - *Fever, weakness, body/ stomach ache* - *I don't know* - *None of the previous points mentioned* Can you tell me why people get diarrhea? - *Don't wash hands with soap before handling food* - *Don't wash hands with soap after contact with stool* - *Consume contaminated food (germs, rotten)* - *Consume contaminated drinking water* - *I don't know* - *None of the previous points mentioned* How can you protect yourself against diarrhea? - *Wash hands with soap before handling food* - *Wash hands with soap after contact with stool* - *Don't consume contaminated food/ Boil, wash, peel, cover food* - *Don't consume contaminated water/ Treat drinking water, consume only safe water* - *Use toilets / cover toilets* - *I don't know* - *None of the previous points mentioned*
Vulnerability	Do you feel you can get diarrhea often?
Severity	Is it bad for you if you get diarrhea?

Attitude factors	
Beliefs about costs and benefits	Do you have a better health if you wash your hands before eating? Do you have a better health if you wash your hands after toilet use? Does washing hands with soap and water take a lot of time? Is it hard for you to wash your hands with soap and water before eating at school? Is it hard for you to wash your hands with soap and water after toilet use at school?
Feelings	Do you like to wash your hands with soap and water? Do you feel dirty if you don't wash your hands before eating? Do you feel dirty if you don't wash your hands after using the toilet?

Normative factors	
Others‘ behavior	We assessed *Others' behavior* using four items, with two items each for food and stool-related handwashing. The items for stool-related handwashing were: Do other children at school wash hands with soap and water after toilet use? Do your family members wash hands with soap and water after toilet use?
Other's (dis)approval	We assessed *Others' (dis)approval* using four items, with two items each for food and stool-related handwashing. The items for stool-related handwashing were: Do your teachers think you have to wash your hands with soap and water after toilet use? Do people who look after you think you have to wash your hands with soap and water after toilet use?

Ability factors	
How-to-do knowledge	What do you need to wash your hands? - *Water* - *Soap* - *Ash* - *Mud* - *I don't know* In which situations is it critical to wash hands with soap? - *After defecating* - *After cleaning up a child's bottom* - *After other contact with stool* - *Before breastfeeding a child* - *Before feeding a child* - *Before preparing food* - *Before handling drinking water* - *Before eating* - *I don't know*
Confidence in performance	We assessed *Confidence in performance* using two items, with one item each for food and stool-related handwashing. The item for stool-related handwashing was: Are you sure that you can always wash your hands with soap and water after toilet use at school?
Confidence in continuation	Imagine you are very hungry. It is lunchtime or break at school. Your schoolmates are already eating. Are you sure, that in this situation, you will wash your hands with soap and water before eating? Imagine you need to go to the toilet at school, but your friends are waiting for you. They will not wait long. You are in a hurry! Are you sure that, in this situation, you will wash your hands with soap and water after toilet use?

Self-regulation factors	
Action control	We assessed *Action control* using two items, with one item each for food and stool-related handwashing. The item for stool-related handwashing was: Do you pay attention to always wash your hands with soap and water after toilet use?
Remembering	We assessed *Remembering* using two items, with one item each for food and stool-related handwashing. The item for stool-related handwashing was: Do you always remember to wash your hands with soap and water after toilet use?
Commitment	We assessed *Commitment* using two items, with one item each for food and stool-related handwashing. The item for stool-related handwashing was: Is it important to you to wash your hands with soap and water before eating?

Develop an observation protocol

In addition to the self-reported measures, handwashing was also observed for two consecutive days in each school. It was not possible to perform individual observations with children; these would have allowed us to track children during their day at school and record the key handwashing situations in which they washed their hands. Further, particular handwashing facilities for food-related handwashing were not present. Consequently, it was not possible to determine whether children washed hands before eating during the lunch breaks, and behavioral observations were only conducted for stool-related handwashing.

Observations
Did the child wash hands when leaving the toilet building? *Yes / No / Could not see*
If yes, how? *Rinsed hands with water / Washed hands with soap and water/ Rinsed hands with soapy water / Could not see*

Similar to the household survey, we performed spot checks to survey the presence of handwashing facilities, soap and water. Spot checks were conducted before the breaks, when the majority of key handwashing events occurred.

Spot checks
Is there a specific facility for handwashing **after contact with stool**? *Yes / No*
How many facilities for handwashing after contact with stool are there? *(Open question)*
Where are the handwashing facilities located? *Outside, on the compound of the school / Inside the building / Inside the toilet/ latrine building*
What kind of handwashing facilities are there? *Running water from a tap / Water containers with a valve and a collection vessel / Vessels to pour water and vessels to collect water / Vessels to pour water without vessels to collect water / Bowls or basins to dip hands / Other*
Is there soap? *Yes, in all cases / Yes, in most cases / Yes, in half of the cases / Yes, in some cases / No, in none of the cases*
Is there water? *Yes, in all cases / Yes, in most cases / Yes, in half of the cases / Yes, in some cases / No, in none of the cases*
Are there handwashing facilities inside or just outside the classrooms? *Yes, in all cases / Yes, in most cases / Yes, in half of the cases / Yes, in some cases / No, in none of the cases*
What kind of handwashing facilities are there? *Running water from a tap / Water containers with a valve and a collection vessel / Vessels to pour water and vessels to collect water / Vessels to pour water without vessels to collect water / Bowls or basins to dip hands / Other*
Is there soap? *Yes, in all cases / Yes, in most cases / Yes, in half of the cases / Yes, in some cases / No, in none of the cases*
Is there water? *Yes, in all cases / Yes, in most cases / Yes, in half of the cases / Yes, in some cases / No, in none of the cases*

Step 2.2 Conduct a baseline survey

Key actions

Translate the questionnaire into the local language

The questionnaires were translated from English into the local language, Shona, by the field supervisors of the project. The field supervisors had been working for the project since the beginning of the pre-study and were thus familiar with both the RANAS approach and the study communities. The questionnaires were then re-translated into English by a member of the data collection team. We next compared the original and the retranslated English versions of the questionnaires to identify translation mistakes and revised the Shona questionnaires.

Define the sample size and the sample selection procedure

Since the target population comprised caregivers and children from across Harare, it was not possible to survey the entire population. Instead, we decided to sample a total of 600 pairs of caregivers and children from 20 areas, that is, 30 pairs per area. From each area, we included one primary school in our survey, referred to as the project school. The children-caregiver pairs were selected randomly. Since a household register, required for true random sampling, was not available, we decided to select the pairs through random route sampling of households. Starting from randomly selected crossroads within each area, data collectors were to select every third house along their way. We selected only households which, first, had at least one child attending the project school in the area and, second, did not have any child attending any other project school.

We decided to perform interviews and spot checks in all 600 households and the behavior observations in a subsample of 300 households, due to financial constraints. We further decided to perform interviews with all 600 primary school children. We preferred conducting the interviews at school, to avoid biases potentially arising when interviewing children at home. Behavioral observations and interviews were conducted in all 20 project schools.

Schedule the field phase, define the number of data collectors to be employed and supervisors to appoint

To calculate the number of data collectors required, we estimated the capacity of one household data collector per day as follows.

Task	Required time
Observation household 1	3:00 hours
Interview household 1	1:30 hours
Spot checks household 1	0:30 hour
Transfer to household 2 and break	1:00 hour
Interview household 2	1:30 hours
Spot checks household 2	0:30 hour
Team transfer to area to be surveyed next day	1:00 hours
Consenting of households to be surveyed next day	1:00 hour
Total	**10:00 hours**

In order to sample the 30 households from one area in one day, we decided to work with a team of 15 household data collectors and train one additional data collector as stand-in. The timings above turned out to be a considerable underestimation. On most survey days, at least one data collector could not finish on time, and the entire team had to wait for that data collector before transferring to areas to be surveyed the next day for consenting. In addition, consenting turned out to be more time-consuming, due to caregivers being unavailable or unwilling to participate in the baseline survey.

We estimated the capacity of one school data collector as follows.

Task	Required time
Interviews with 5 children	2:30 hours
Observations during breaks	1:00 hours
Spot checks	0:30 hour
Transfer	2:00 hours
Extra time	2:00 hours
Total	**9:00 hours**

The timings of interviews, spot checks, and observations depended on the timetables of the schools. In addition, finding children and bringing them to the place where we conducted the interviews required close collaboration with the school staff. Consequently, we had to schedule sufficient time for data collectors to identify or wait for the next child to be interviewed. We decided to work with a team of eight data collectors for the school survey. This would allow us to visit each school on two consecutive days with a team of four data collectors.

Employ data collectors

We recruited data collectors through online job advertisements. A shortlist of 30 candidates was interviewed, and 24 data collectors were hired. In addition to the criteria listed in Box 2.2.2 of *Systematic Behavior Change*, primary selection criteria were previous experience in data collection and a social science background.

Organize the data collection

As a first step in organizing the data collection, we started applying for permits from the Government of Zimbabwe and other authorities 6 months prior to its start. We hired two local commuter buses to transport the team to the survey areas. Since the survey took place in Harare itself, data collectors could stay at home overnight. We visited all 20 areas and schools prior to the actual survey, to identify the exact streets where data were to be collected and to seek consent from the project schools.

Train the data collectors

Separate training was conducted for the school and household data collectors. Data collectors were trained for 5 days with two additional days of pre-testing in the field. During the first four days, the team was introduced to the project, the tools for data collection were discussed, and interviewing techniques were rehearsed. Both the English and the Shona versions of the questionnaire were included in the training, and the data collectors provided most valuable feedback to finalize the translation. On the last day, data collectors rehearsed the questionnaire in pairs, one data collector playing the role of a respondent and vice versa. Every day of training concluded with short participant feedback. The overall schedule of the data collection training was as follows.

Day	Activities
1	Introduction of the project Introduction RANAS approach Use of tablets for data collection
2	Questionnaire: behavior, risk factors, attitude factors Interviewing techniques Question types
3	Questionnaire: norm, ability and self-regulation factors Household selection procedure
4	Behavioral observations Spot checks Preparation for mock interviews
5	Mock interviews Briefing pre-test

Pretest of the survey instruments in the field

We pre-tested the household survey for two days in an area which was not one of the 20 areas to be surveyed during the actual data collection. On the first day of the pre-test with household data collectors, only the interview and spot checks were tested in the morning. In the afternoon, we returned to the training location to discuss the experience of the team. On the second day, the full survey protocol of observation, interview, and spot checks was tested. Again, experiences were discussed with the team in the afternoon. We pre-tested the school survey for two days at a primary school in the same area where the household survey had been tested; we discussed the experience of the team and changes to the survey tools after each day of pre-testing.

Revise the survey instruments

We revised the survey instruments after the team discussions on each pre-test day. However, scheduling an additional day for revision would have been preferable.

Conduct the data collection

We started with household data collection and began school data collection after the first two weeks of household data collection. Regular data collection in both households and schools took 20 working days. Households and schools with missing interview data were revisited to complete the questionnaires.

In households, behavioral observations were conducted from 6 a.m. to 9 a.m. At this time, most household members were present, and both food and stool-related key handwashing situations were most likely to be observed. The observations were followed by the interview. After a general introduction to the project, data collectors read each question to the respondents. For closed questions, the response options were also read aloud, and the respondent then chose one of the pre-specified response categories. If the respondent did not provide a pre-specified answer, the data collector probed further to obtain the exact response. Responses were entered directly onto tablet computers using ODKCollect data collection software. Finally, the spot checks were conducted.

In schools, behavioral observations of stool-related handwashing were conducted during breaks and after school, when most children used the toilets. Food-related handwashing was not observed, because there were no facilities for food-related handwashing. Interviews were conducted during the lessons. In each school, we were given a room in which to perform the interviews. We identified the children that we wanted to interview based on the data we had collected from their caregivers during the household data collection. These data comprised:

- Name of the child
- Age
- Class
- Teacher’s name.

Spot checks were conducted on the first day of data collection before the morning breaks.

Each data collection team was accompanied by one supervisor, who was also responsible for organizing the logistics of the survey and transferring the data from the tablets. Every day, data were checked for completeness, and feedback was given to the data collection team.

Step 2.3 Determine the psychosocial factors that steer the target behavior

Key actions

Enter, clean, and process the data

The data were collected electronically using ODKCollect on tablet computers. Consequently, data were already in an electronic format and did not have to be entered from paper-based documents. Further, we did not have to check whether the response options in the data file were within the possible range of response options in the questionnaire, since ODKCollect would only allow entry of values within the correct range.

Missing data were identified each day after the data collection. We used the conditional formatting function in Microsoft Excel to mark all empty cells. This enabled us to identify missing data through visual screening.

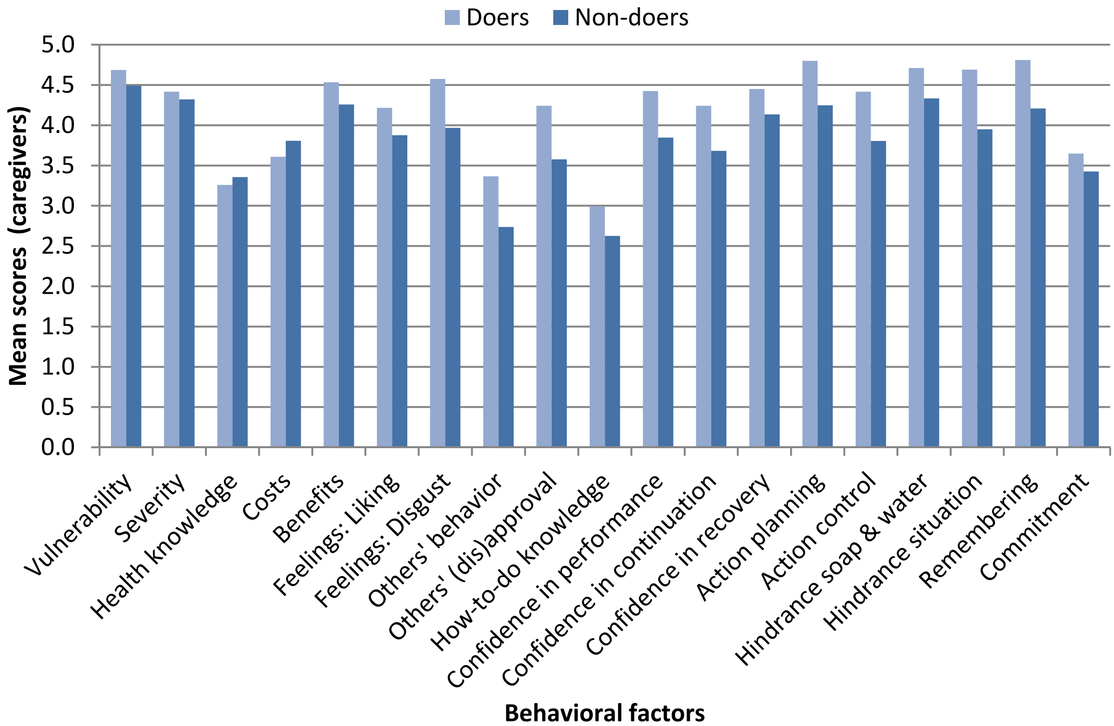
Some factors were measured through several items. In these cases, the mean of these items was computed for each participant to aggregate the individual items into one single value per factor.

Divide the sample into doers and non-doers of the target behavior

To divide the sample into doers and non-doers, we computed the mean self-reported handwashing frequency of each participant. This resulted in a measure ranging from 0 (For all key handwashing events, participant had reported never washing hands with soap) to 10 (For all key handwashing events, participant had reported washing hands in 10 out of 10 times). We defined caregivers as doers if their mean self-reported handwashing frequency was greater than or equal to 9 and as non-doers if this value was less than 9. This yielded 60 doers and 540 non-doers. We defined children as doers if their mean self-reported handwashing frequency was equal to 10 and as non-doers if this value was less than 10. This yielded 131 doers and 425 non-doers. The remaining 44 children were excluded from the analysis, because they were missing on the days of the survey or could not be located at the schools.

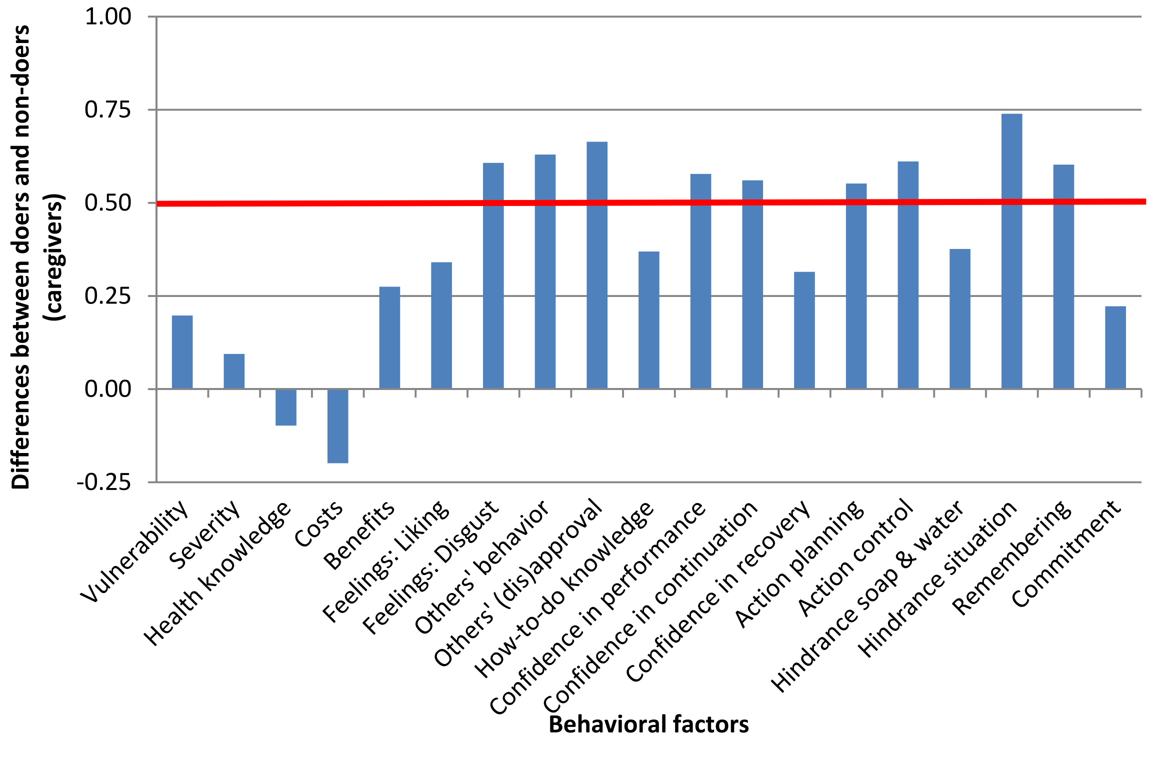
Calculate the mean scores of each psychosocial factor separately for doers and non-doers

The mean scores of doers and non-doers were calculated as explained in Example 2.3.3 of *Systematic Behavior Change*. Mean scores of behavior factors for caregivers are displayed below. Behavioral factors are aligned along the horizontal axis. For each behavioral factor, the mean score of the doers is presented as light blue bar, and directly next to it the mean score of the non-doers is displayed as a dark blue bar. The differences between doers and non-doers are indicated by different lengths of the bars and are further discussed in the next step.



Compare the mean scores between doers and non-doers to identify the behavior-steering factors

The differences between doers and non-doers are displayed for caregivers in the next graph. Again, behavioral factors are aligned along the horizontal axis. Here, the vertical axis displays the differences between doers and non-doers.



For caregivers, this yielded nine behavior factors that should be targeted by interventions:

- Feelings: Disgust
- Others' behavior
- Others' (dis)approval
- Confidence in performance
- Confidence in continuation
- Action planning
- Action control
- Hindrance situation
- Remembering.

Further, we measured *Barrier planning* using multiple-response questions. We determined the relevance of *Barrier planning* as a potential driver of handwashing behavior by selecting the response option most frequently mentioned by doers and the option most frequently mentioned by non-doers and comparing these two response options. For plans to avoid forgetting to wash hands with soap and water, 27% of doers reported keeping soap and water for handwashing near the place of defecation or food preparation, while 17% of non-doers reported doing so. For barrier plans on how to wash hands with soap even if the respondent was in a hurry, results were similar. For plans on how to cope with a lack of soap at home, 18% of doers and 15% of non-doers reported borrowing from neighbors. To summarize, there were only small differences between doers and non-doers in *Barrier planning*.

For children, the doer versus non-doer comparison yielded seven behavior factors to be targeted by the interventions (data not reported):

- Health knowledge
- Vulnerability
- Others' behavior
- Confidence in performance
- Confidence in continuation
- Action control
- Remembering.

In addition, the spot checks indicated that handwashing facilities in front of the toilet building were broken in most schools. Handwashing facilities in or in front of classrooms did not exist in any of the schools.

Phase 3: Select behavior change techniques (BCTs) and develop behavior change strategies

Step 3.1 Select BCTs to change the behavior-steering factors

Key actions

Select BCTs that correspond to the psycho-social factors according to the RANAS approach

For each behavior-steering factor, we selected the corresponding BCTs from the list (Tool 3.1.1 in *Systematic Behavior Change*).

For the additional factor *Hindrance situation*, we selected the BCTs targeting barrier planning. For caregivers, the behavior-steering factors and corresponding BCTs from the RANAS approach are displayed in the table below. The BCTs that we selected for our campaign are formatted in bold.

Behavior-steering factor (caregivers)	Corresponding BCTs from the list
Disgust	**BCT 8 Describe feelings about performing and about consequences of the behavior**
Others' behavior	BCT 9 Inform about others' behavior **BCT 10 Prompt public commitment**
Others' (dis)approval	BCT 11 Inform about others' approval/disapproval
Confidence in performance	BCT 16 Provide infrastructure BCT 17 Demonstrate and model behavior **BCT 18 Prompt guided practice** BCT 19 Prompt behavioral practice BCT 20 Facilitate resources **BCT 21 Organize social support** BCT 22 Use arguments to bolster self-efficacy BCT 23 Set graded tasks/goals
Confidence in continuation	BCT 24 Reattribute past successes and failures
Action planning	**BCT 26 Prompt specific planning**
Action control	**BCT 27 Prompt self-monitoring of behavior** BCT 28 Provide feedback on performance BCT 29 Highlight discrepancy between set goal and actual behavior
Remembering	**BCT 34 Use memory aids and environmental prompts**
Hindrance situation (additional factor)	**BCT 30 Prompt coping with barriers** BCT 31 Restructure the social and physical environment BCT 32 Prompt to resist social pressure BCT 33 Provide negotiation skills

For the factors with only one corresponding BCT, we selected that BCT. However, for *Others' approval*, *Confidence in performance*, *Action control*, and *Hindrance situation*, the list yielded more than one matching BCT. We selected *BCT 10, Prompt public commitment,* to target *Others' behavior*. We considered *BCT 10* more powerful because it made participants actually witness others making a commitment to washing hands with soap and water at key times. In contrast, *BCT 9* would have meant merely telling participants that their peers already washed hands with soap at key handwashing times, although the survey had indicated that only very few participants actually did it.

To target *Confidence in performance*, we selected *BCT 18*, *Prompt guided practice*, and *BCT 21*, *Organize social support*, because we hypothesized that these BCTs would also target the most relevant norm factors: If guided practice was implemented in a community event, participants would see each other washing hands using soap *(Others' behavior)*. Social support at household level would also suggest that household members want each other to wash their hands with soap (*Others' (dis)approval*).

To target *Action control*, we decided to use *BCT 27*, *Prompt self-monitoring of behavior*. We preferred this to *BCT 28*, *Provide feedback on performance*, because providing feedback to each participating household would have involved many monitoring visits and was judged to be too time-consuming. We also preferred it to *BCT 29*, *Highlight discrepancy between set goal and actual behavior*, because we feared that *BCT 29* might have a negative impact on *Confidence in performance*.

To target *Others' (dis)approval*, we did not choose an additional BCT because we thought that *BCT 21*, *Organize social support*, already targeted *Others' (dis)approval*.

We interpreted the strong relevance of *Confidence in continuation* not to be a problem of lacking confidence *per se* but a result of actual barriers which prevented the participants from washing hands with soap and water. This was in line with the finding that the additional factor *Hindrance situation* was relevant for behavior. Consequently, we chose *BCT 30*, *Prompt coping with barriers*, to enable participants to overcome the hindrances and thus also to become more confident in continuing the behavior.

For the children, the BCTs that target the behavior-steering factors are displayed below. The BCTs that we selected for the campaign in schools are formatted in bold.

Behavior-steering factor (children)	Corresponding BCTs from the List
Health knowledge	**BCT 1 Present facts** **BCT 2 Present scenarios**
Vulnerability	**BCT 3 Inform about and assess personal risk**
Others' behavior	BCT 9 Inform about others' behavior **BCT 10 Prompt public commitment**
Others' (dis)approval	BCT 11 Inform about others' approval/disapproval
Confidence in performance	**BCT 16 Provide infrastructure** BCT 17 Demonstrate and model behavior BCT 18 Prompt guided practice BCT 19 Prompt behavioral practice BCT 20 Facilitate resources **BCT 21 Organize social support** BCT 22 Use arguments to bolster self-efficacy BCT 23 Set graded tasks/goals
Confidence in continuation	BCT 24 Reattribute past successes and failures
Action control	**BCT 27 Prompt self-monitoring of behavior** **BCT 28 Provide feedback on performance** BCT 29 Highlight discrepancy between set goal and actual behavior
Remembering	**BCT 34 Use memory aids and environmental prompts**

To target behavior-steering factors which have only one corresponding BCT (Tool 3.1.1 of *Systematic Behavior Change*), we selected that particular BCT. In cases where several BCTs target a behavior-steering factor, we had to make choices.

To target *Health knowledge*, we preferred *BCT 2*, *Present scenarios*, since we considered these more illustrative for children than merely presenting facts. However, *Presenting facts* (*BCT 1*) by using an F-diagram and showing the fecal-oral route of infection was already widely used to transfer *Health knowledge* in Harare. Consequently, we decided to use both *BCT 1* and *BCT 2*.

To target *Others' behavior*, we chose *BCT 10*, *Prompt public commitment*, for the same reasons as we chose *BCT 10* for the interventions targeting caregivers.

The school spot checks had shown that handwashing facilities in front of the toilet buildings were not working properly in most cases, and handwashing facilities in or in front of classrooms were not present at all. In this context, we interpreted the result that

Confidence in performance and *Confidence in continuation* were important behavior-steering factors to be a consequence of lacking functional handwashing facilities. Consequently, we decided to focus on *BCT 16*, *Provide infrastructure*, to target *Confidence in performance* and decided not to employ BCTs which only manipulate the perceived ease of performing the behavior.

To support the maintenance of the handwashing facilities through students, we chose *BCT 21*, *Social support*. *BCT 21* focuses on how the students can organize themselves to make sure that soap and water are always available in classrooms and to create an enabling environment. During the stakeholder workshops, teachers had indicated that they were already overburdened with the daily school routine. Hence, it was crucial for the maintenance of handwashing facilities that student would take as much responsibility as possible.

To increase *Action control*, we chose *BCT 27*, *Prompt self-monitoring of behavior*, and *BCT 28*, *Provide feedback on performance*. We did not select *BCT 29*, *Highlight discrepancy between set goal and actual behavior*, because we feared that *BCT 29* could have a negative impact on *Confidence in performance*. We chose both *BCT 27* and *BCT 28*, because we intended to combine the two BCTs into one strategy in which children would monitor their behavior and teachers would give feedback. We hypothesized that feedback from teachers would, in addition, target *Others' (dis)approval*, because children would be made aware that their teacher wanted them to wash their hands with soap.

Step 3.2 Develop and design behavior change strategies

Key actions

Combine one or several BCTs with suitable communication channels to form a behavior change strategy AND Design behavior change strategies

Combining BCTs with suitable communication channels and designing the behavior change strategies was an iterative process. This was necessary because the selection of the communication channel strongly depended on the specific way in which the behavior change strategies should be implemented and vice versa.

For the campaign targeting caregivers, we had the opportunity to collaborate with health centers and community health promoters in our intervention areas. To make use of this opportunity, we decided to implement the BCTs through interpersonal communication, with community health promoters and health center staff acting as the promoters on the ground. For the campaign targeting children, we were able to work with primary school teachers as promoters. Consequently, interpersonal communication was also selected as the main communication channel for the school intervention.

We grouped BCTs into activities which should be implemented either at the beginning or at the end of the campaign. We further classified BCTs for caregivers on whether they were better delivered at the households (e.g. *Installation of prompts*) or better implemented in a community meeting (e.g. *Public commitment*). We decided to begin and end the campaign for caregivers with a community meeting so as to provide a formal kick-off and ending. The school campaign was implemented at classroom level. In addition, we decided to implement a school event to present and inaugurate the new infrastructure.

This resulted in grouping the strategies into four blocks each for the school and the community campaigns. Finally, we created one slogan for each intervention strategy in collaboration with social marketing experts. The intervention strategies, communication channels, slogans, BCTs, and RANAS factors targeted are displayed in the intervention matrices on the following two pages.

Strategy care-givers	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 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 with the barriers of not washing hands with soap when in a hurry or not feeling like washing hands at the right moment.	Confidence in performance + Others' (dis)approval
			BCT 30 Prompt coping with barriers		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

Strategy children	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	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
			BCT 34 Use memory aids and environmental prompts		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 events. 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

To organize soap supply to primary schools, the following strategies were considered. The strategies formatted in bold were selected. Soap supply accompanied the entire campaign implementation and continued for several months afterwards. At the time of writing, the implementing partner, School Development Council, and Ministry of Primary and Secondary Education were negotiating long-term soap supply to school.

Strategy	Reason for selection / not selection
Short term	
Schools purchase soap without external support	Schools face considerable financial challenges already
Income generating activities for schools to generate soap budget	School staff are already overburdened with ongoing routines
Voluntary donation from households (also soap rests)	Short term solution, might be difficult to maintain
Supply from project	**Not sustainable, only short term solution**
Long term	
Private-public partnership, soap donations from company	Only possible for a limited period of time
Soap production by school	School staff are already overburdened, safety concerns
School Development Council provides soap to schools	**Only possible for some schools, recommended by grassroots stakeholders**
Ministry of Primary and Secondary Education provides funds for soap	**Possible for all schools, difficult to initiate, limited resources at the Ministry**
Private-public partnership with Ministry, buy soap from company at a reduced rate in exchange for publicity in schools	Difficult to initiate, potentially sustainable

Phase 4: Implement and evaluate behavior change strategies

Step 4.1 Design an implementation protocol

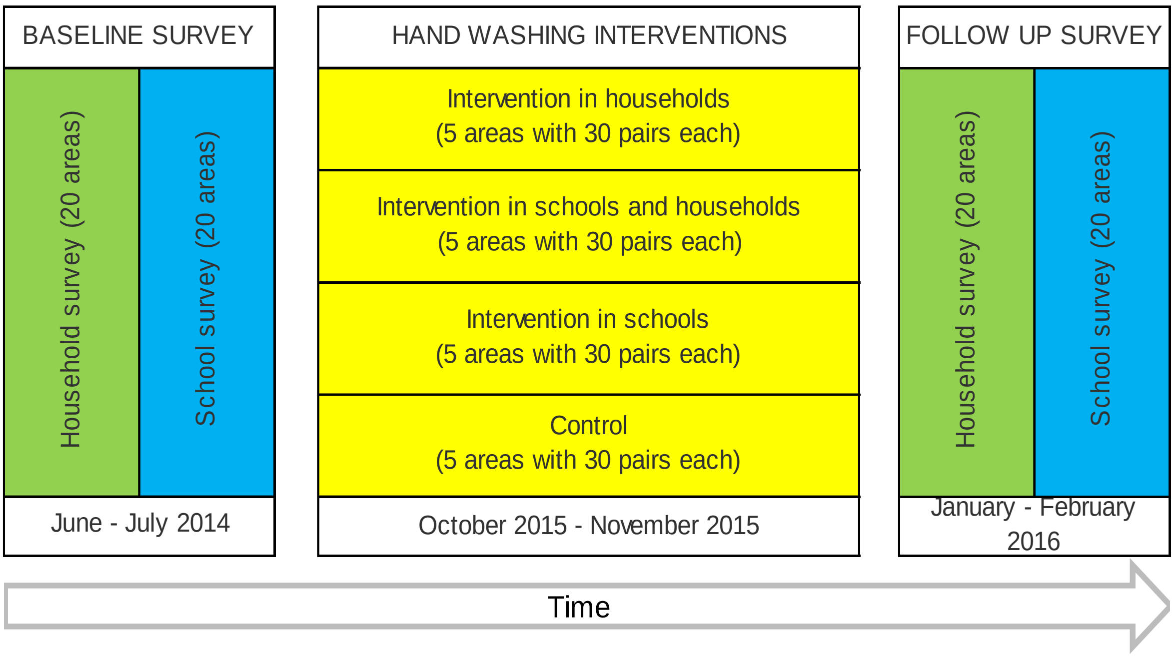
Key actions

Assign the strategies to project communities or project groups

From the total of 20 project areas, each with 30 pairs of caregivers and children, we decided to test the combination of the community and school interventions in five areas and compare it to a control condition in another five areas. The remaining 10 areas were used to test the effects of the community and school intervention when each was implemented separately (results not presented here). When selecting the project areas at the beginning of the project, we had carefully selected spatially separated areas with as little interaction between each other as possible. This was necessary to avoid spillover between, for example, an intervention area and a neighboring control area. The trial design is shown in the chart below.

Since we had minimized spillover, we considered all areas to be independent and decided randomly whether an area was to receive the intervention or be part of the control. To do so, we wrote the area names in one Microsoft Excel sheet and, for each area, created a random number. We then sorted the sheet using the randomly assigned numbers and assigned the control condition to the first five areas and the intervention condition to the next five areas.

Study design



Step 4.2 Implement behavior change strategies

Key action

Plan the implementation of the strategies

Before planning the campaign in detail, we conducted stakeholder workshops to present the campaign proposal and to gather feedback. One workshop was conducted with health promoters and local health center staff; one workshop was conducted with councilors and members of the residence association; and another workshop was conducted with teachers, school heads, and representatives of the School Development Council. As a result, it was decided that the campaign for caregivers was going to be implemented by the health promoters and health center staff (referred to below as community promoters) and that the school campaign was going to be implemented by primary school teachers.

The implementation of strategies was primarily planned by the local implementing partner, ActionAid Zimbabwe, which also coordinated the campaign implementation and conducted the training with the community promoters and school teachers. Based on our initial campaign proposal, ActionAid Zimbabwe drafted intervention protocols that specified exactly how each strategy was going to be implemented, where, and by whom.

Train promoters in implementing the strategies

Promoters were trained by ActionAid Zimbabwe based on the intervention protocols. Separate training was conducted for the community promoters and for the school teachers. For each strategy, the training was conducted on the Saturday prior to the beginning of implementation. During the training, ActionAid Zimbabwe performed role-plays with the promoters in which the ActionAid trainers acted as promoters and the promoters as either household caregivers or school children. All campaign materials were distributed at the meetings. Each strategy was implemented in one or two weeks.

Since it was logistically not possible to train all the teachers of the project schools, only two volunteering teachers of each project school were trained by ActionAid. These two teachers then trained their colleagues in their school.

Monitoring the implementation

The campaign implementation was monitored by one of the supervisors who had worked for the project from the very beginning. The supervisor attended all the training sessions. To monitor whether the campaign was implemented as planned, selected community meetings, household visits, classroom activities, and school events were visited. In addition, feedback on the campaign implementation was gathered from community promoters and teachers at each training session.

In the campaign targeting caregivers, this indicated that the community meetings for Strategy 1 were attended by the majority of the study participants and additional community members. However, in most locations only four to five volunteers performed the handwashing exercise visualizing dirt instead of all the participants at the meeting. In many communities, the plenary discussion after the experiment focused on the risk of not washing hands with soap instead of focusing on disgust. For Strategies 2 and 3, monitoring visits and feedback from community promoters revealed that planning forms and self-monitoring calendars were not delivered as planned during the training. Instead, they were delivered during the subsequent weeks. Activities for Strategy 4 were largely implemented according to the intervention protocols. In contrast to the protocol, participants who had not submitted the self-monitoring calendar were not issued a certificate. As a reward for participation in the campaign, participants received lunch money. Monetary rewards had not been mentioned in either the campaign proposal or the intervention protocols.

In the campaign targeting children, the campaign monitoring indicated that material was often not distributed to the teachers during or shortly after the training but in most cases later in the week. Strategy 1 was, as a consequence, partly implemented without the posters of the fecal-oral route, and Strategy 3 was often implemented without the templates of the self-monitoring calendar. In most classes, the handwashing exercise visualizing dirt was done by only one student instead of the entire class. Handwashing stations were delivered in sufficient quantities, with few exceptions.

The campaign implementation started in October 2015, 14 months after completing the baseline survey. The coordination with the local authorities during the campaign preparation, recruitment of the implementing partners, and development of the protocols and material had taken much longer than expected, which delayed the project considerably.

Step 4.3. Develop follow-up questionnaire and observation protocol and conduct survey

Key actions

Develop a follow-up questionnaire and observation protocol

We used the same questions, observations, and spot checks as in the baseline survey. In addition, we included questions and spot checks on which intervention strategies the participants had received. For each intervention strategy, we surveyed the participation of caregivers at three levels.

1. Whether the participant stated that she or he had participated in the strategy.
2. Whether the participant could name additional details, which she or he would only know from participating attentively.
3. Whether the participant could show material which had been distributed during the strategy.

For Strategy 4, the items were as follows.

Example items measuring campaign participation of caregivers
Do you remember the group meeting where community members received a certificate? - Yes - No
What activities do you remember? (Open question) - Drama performed by community members - Public pledge - Shouting the slogan "Handwashing? Of course! Everybody!" - None of the previous points mentioned
Did you receive a certificate during the campaign? - Yes - No
Can you show it to me? - Participant shows certificate - Participant does not show certificate

To measure the campaign participation of children, we used similar questions. However, the presence of campaign material was not surveyed individually for each child but for each classroom.

We used four items to measure how the participant perceived the campaign, two items each for group meetings and household visits. The items for the group meetings were as follows.

Example items measuring campaign perception of caregivers
How did you like the group meetings? - Did not like at all - Liked a little - Quite liked - Liked a lot - Liked very much
How convincing did you find the group meetings? - Not convincing at all - A little convincing - Quite convincing - Very convincing - Extremely convincing

Conduct follow-up survey

Since coordination with the local authorities, recruitment of the implementing partner, and campaign preparation had taken longer than expected, our project was far behind schedule when the campaign was implemented. Consequently, we decided to start the evaluation survey just six weeks after the end of the interventions. This means that the campaign evaluation presented in this chapter is limited to short-term effects. Measuring long-term effects 6 or 12 months after campaign implementation would be necessary to determine whether the campaign achieved sustainable behavior change. However, the procedure described in this chapter can be applied to any evaluation irrespective of timing.

We wanted to conduct the follow-up survey with exactly the same participants that we had surveyed during the baseline. To track caregivers, we had recorded their names, names of heads of households, addresses, and mobile phone numbers. The supervisors of the survey called all households two weeks before the start of the data collection to update the address and, if possible, confirm availability during the survey period. Data collectors visited the households one day prior to the scheduled survey date to make an appointment for the next day. In many cases, respondents were not available on the scheduled day, and many revisits were necessary to collect data from as many respondents as possible. We found 422 of the initial 600 participants.

To track children, we had recorded their names, ages, and expected grades at the time of follow-up. We first called and then visited each school prior to the dates of data collection to schedule the data collection without interfering with other school activities. On these prior visits, we distributed the lists of all children to be interviewed to the school staff. In most schools, school staff assisted greatly in locating the children for interviews. However, a substantial number of children had transferred to other primary schools or dropped out. In addition, students who had been in Grade 6 at baseline had already transferred to secondary schools. Consequently, we only found 285 of the original 600 children.

Step 4.4 Estimate efficacy of the behavior change strategies

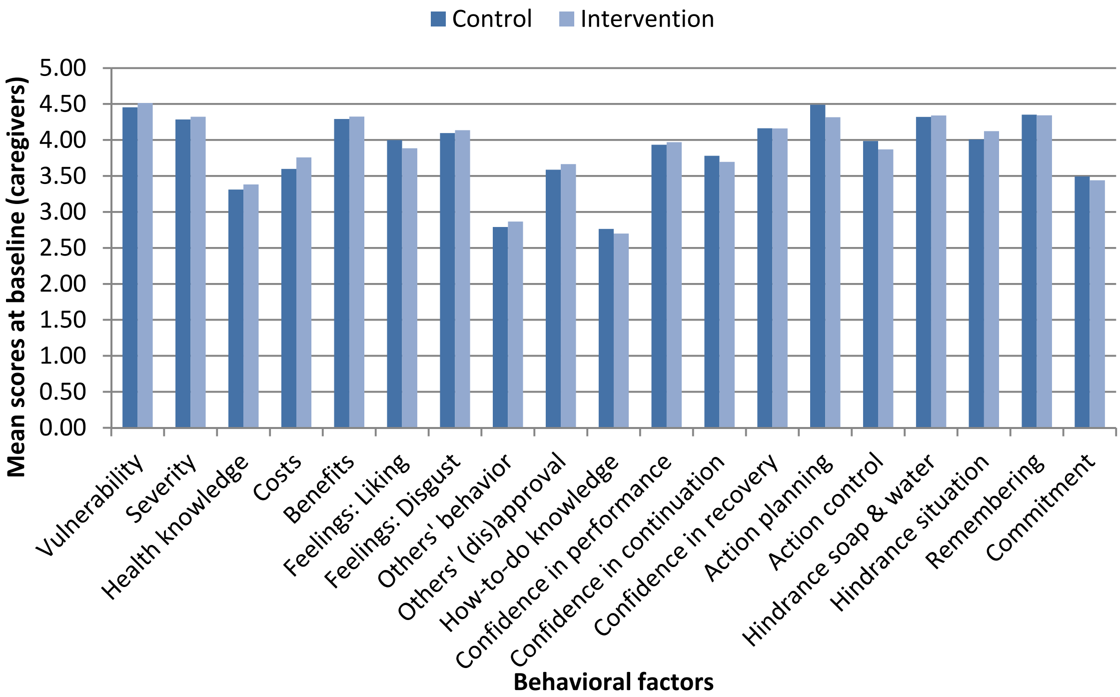
Key actions

Enter, clean and process the data

The follow-up data were cleaned and processed in exactly the same way as the baseline data.

Calculate mean scores at baseline and at follow-up separately for the control and the intervention group(s)

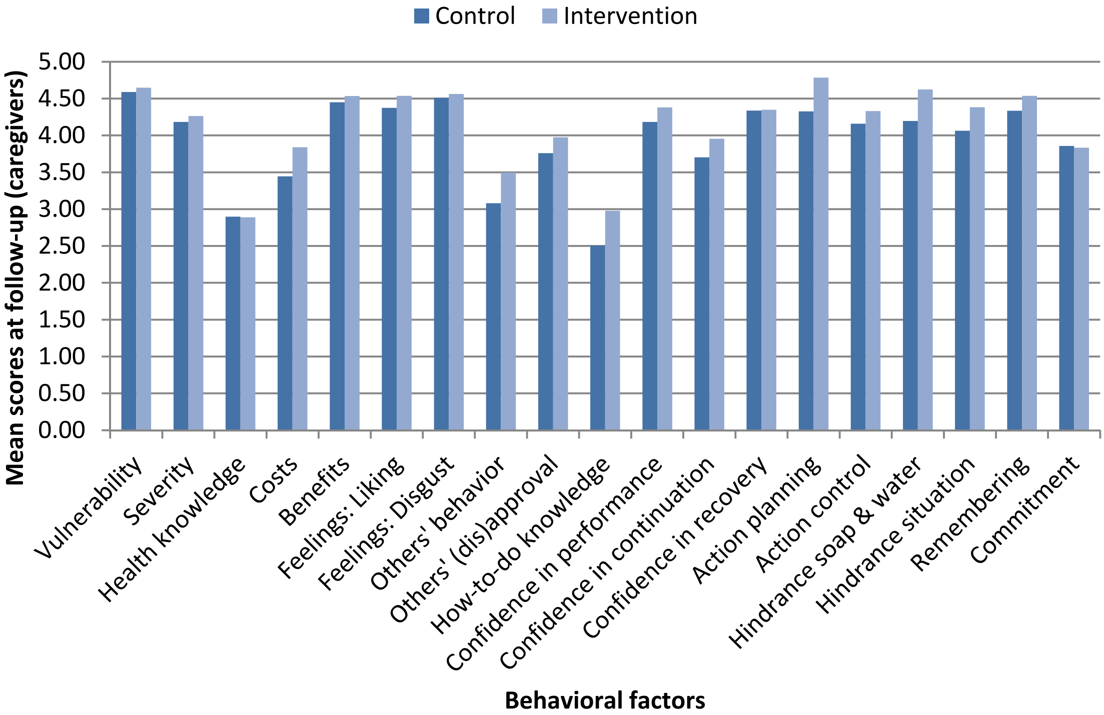
The mean scores of psychosocial factors of caregivers for the control and intervention groups **at baseline** are displayed below.



The fact that there were only marginal differences at baseline shows that both groups had similar starting conditions before the intervention. The share of self-reported doers was also quite similar in the control (12%) and intervention groups (7%). For observed behavior, handwashing rates were at 1% in the control group and at 3% in the intervention group at baseline.

With the children, baseline values of behavior and behavioral factors did not differ between control and intervention groups either. Observed handwashing with soap after using the toilet amounted to 4% in intervention schools and 1% in control schools. Observed food-related handwashing, measured as handwashing with soap before going to lunch, was 0% in both control and intervention schools, because handwashing facilities were not present. Differences with regard to behavioral factors were minimal.

The mean scores for behavioral factors of caregivers for the control and intervention group **at follow-up** are displayed in the next graph.

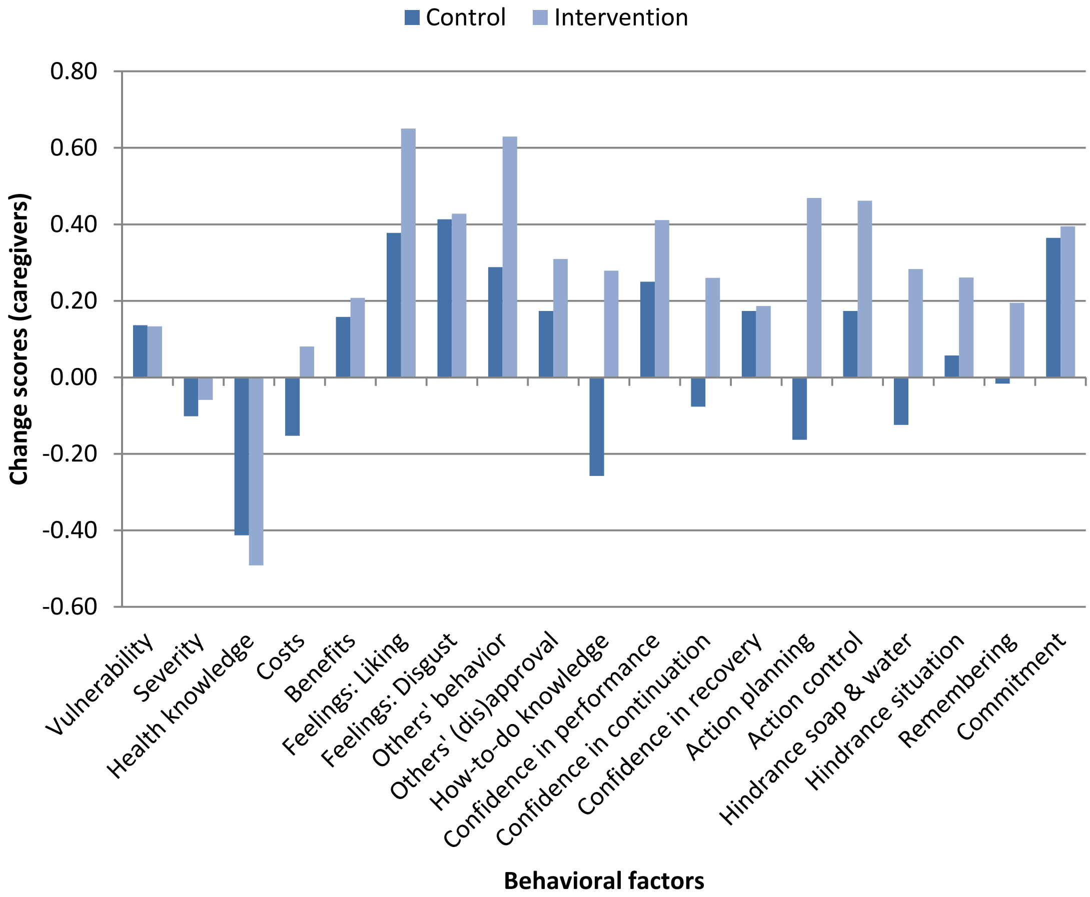


We can now see that, at follow-up, some behavioral factors differed between control and intervention groups. This is a first indication that our intervention affected the mindsets of the participants, which we discuss further below. For self-reported handwashing behavior, 24% of caregivers were classified as doers in the control group, while there were 34% doers in the intervention group. In the control group, we observed handwashing rates of 5% at follow-up, and in the intervention group, we observed 28% handwashing with soap at follow-up.

Stool-related handwashing among children remained as low as at baseline in both control and intervention schools. Spot checks revealed that handwashing facilities for stool-related handwashing did not work in either control or intervention schools. The failure of the campaign to increase stool-related handwashing thus could be attributed to the fact that handwashing facilities for stool-related handwashing had not been repaired as planned. In contrast, handwashing facilities for food-related handwashing were present in 74% of classrooms in intervention schools and not present in any control school. In 62% of classrooms in intervention schools, handwashing stations contained water, and in 55% of classrooms, soap was present. In classrooms where soap and water were present, the frequency of handwashing with soap before lunch breaks was observed to be 42%. This corresponds to an overall food-related handwashing rate of 23% in intervention schools.

Calculate change scores from baseline to follow-up separately for the control and the intervention group(s)

We then wanted to see more clearly how the behavioral factors and behavior itself changed over the period of the intervention in both the control and intervention groups. The graph below shows change scores of caregivers' behavioral factors for the control and intervention group. The change scores of the control group can be interpreted as the changes which would have occurred in the study population in any case, even without any intervention. Seasonal differences, for example, might cause such changes. In addition, the baseline survey might have affected such changes. In contrast, the changes in the intervention group show the general changes in the population plus the changes which were triggered by our intervention.

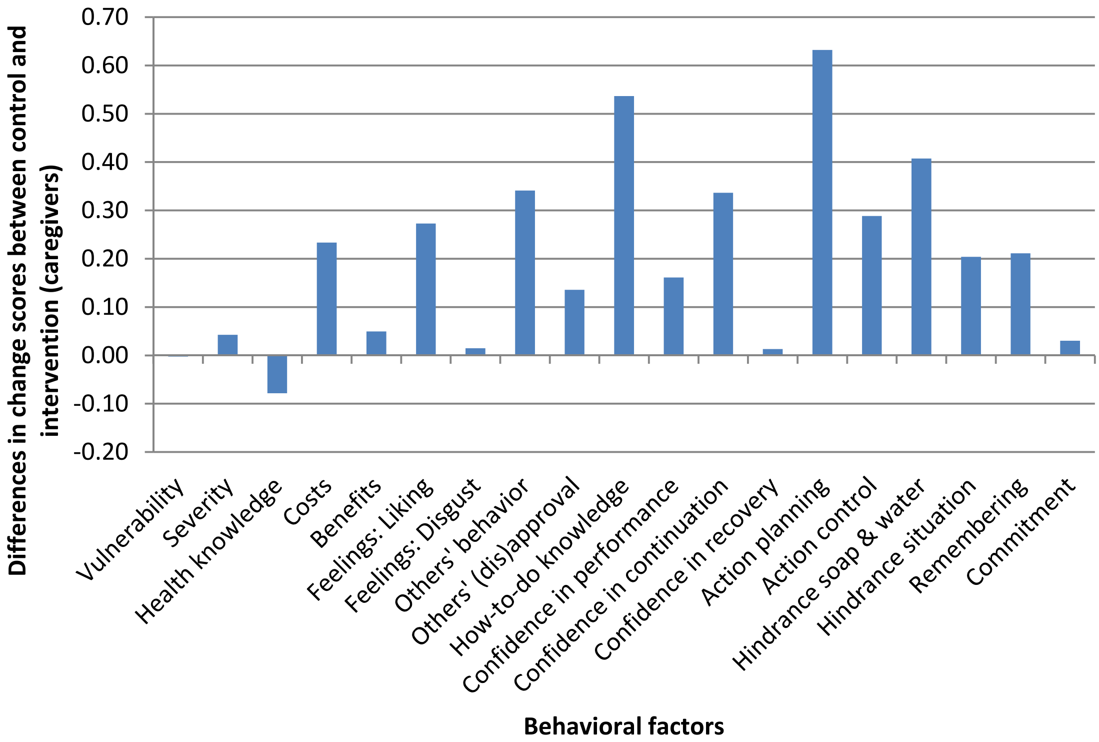


The graph displaying change scores of behavioral factors shows us that the largest changes over time occurred in the intervention group. For example, it shows that participants of the intervention liked handwashing with soap better after the intervention than before. In addition, participants perceived others to wash hands more frequently after the intervention than before. The graph also shows that some factors changed in participants of both the intervention and control groups in a similar way (e.g. *Commitment*), while for other factors (e.g. *Others' behavior*) the changes were of different magnitudes. For some factors, (e.g. *How-to-do knowledge*), changes even occurred in opposite directions. This means that participants of the intervention had a greater knowledge of when and how to wash hands after the intervention, while control households' knowledge had actually decreased between baseline and follow-up. We wanted to explore these group differences further, which brings us to the next key action.

The change scores of children's behavioral factors (not reported) were within a similar range.

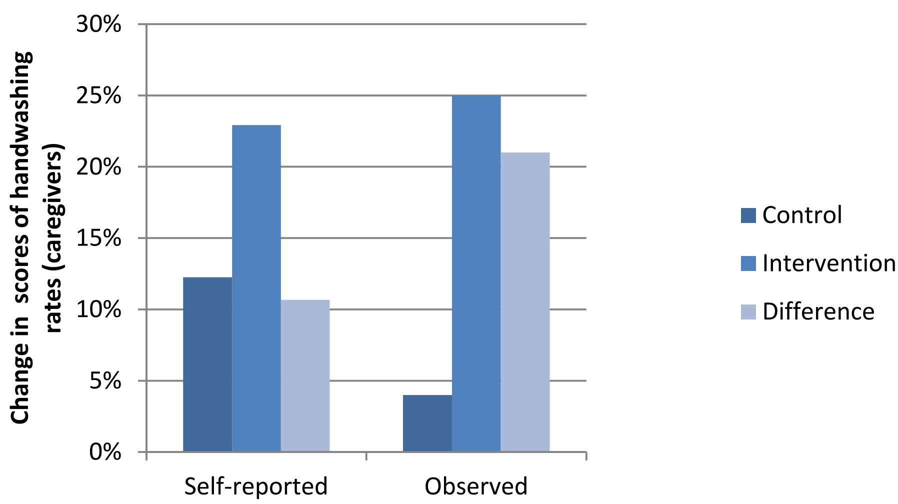
Compare change scores between control and intervention group(s)

In this last step, we aimed to find out which of the changes that we observed in the intervention group during the previous step were actually induced by our intervention. To do this, we compared the change scores between the control and the intervention groups by subtracting the scores of the control group from the scores of the intervention group. In other words, we subtracted the general changes which had happened in the population independently of our intervention (which we measured in the control group) from the aggregation of general changes plus changes which were induced by our intervention (measured together in the intervention group). This left us only with the changes that had actually been induced by our intervention. The results for caregivers are displayed below.



We can see that our campaign induced the strongest changes in *Action planning* and *How-to-do knowledge*. This means that it made participants more knowledgeable of when and how to wash hands with soap and supported them in specifying when, where, and how to actually do so during their daily lives. Further, participants perceived lack of soap and water as a greater barrier. At the first sight, this finding seems counterintuitive. However, we think that participants intended to wash hands more often, and became more aware of a lack of soap and water as a result. We can also see that participants were more confident in being able to continue washing hands with soap and water even if circumstances were difficult and liked washing hands with soap and water better than their peers in the control group.

Coming to the behavioral outcomes, self-reported and observed handwashing behavior of caregivers changed over time, as displayed in the graph below.



In the intervention group, the number of self-reported doers increased by 23%, compared to 12% in the control. Observed handwashing rates increased by 25% in the intervention group and 4% in the control group. This means that a 21% increase in observed handwashing rates can be directly attributed to the campaign, while 4% are attributed to a general change in the population.

With regard to the campaign's effects on children's behavior, no effects on stool-related handwashing were observed, since handwashing facilities at toilets had not been repaired as planned. Change scores of food-related handwashing for children in the intervention group were equal to the follow-up values (23%), because baseline values amounted to 0%. In addition, the difference in change scores between control and intervention groups amounted to 23%, because food-related handwashing in the control was 0% at both baseline and follow-up due to the lack of handwashing facilities. Consequently, the entire behavior change in food-related handwashing in schools can be attributed to the campaign.

Conclusions

This cases study showed how we applied Mosler and Contzen's practical guide, *Systematic Behavior Change in Water Sanitation and Hygiene,* to our project promoting handwashing in Harare, Zimbabwe. The aims of our campaign were to achieve substantial behavior change by systematically changing the participants' mindsets and to perform a quantitative evaluation of campaign effects.

In applying the first three phases of *Systematic Behavior Change*, we designed a handwashing campaign that was tailored to the specific characteristics of primary school children and their caregivers in Harare. In applying Phase 4 and performing a before-after control (BAC) trial, we provided unambiguous quantitative evidence on the effects that our campaign achieved on observed behavior.

The campaign successfully changed the handwashing behavior of both primary caregivers and school children. The fact that only part of the protocols was correctly implemented in the campaign suggests that effects of complete implementation would probably be stronger. Evaluation of long-term effects would be the next step to find out how sustainable the behavior change was.

We conclude that applying the practical guide *Systematic Behavior Change in Water Sanitation and Hygiene* led to an innovative campaign that produced tangible effects. Our aim was to illustrate the practical use of *Systematic Behavior Change* by describing the concrete application of each step; we hope to encourage practitioners to use it too.