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Does the Implementation of Hardware Need Software? A Longitudinal Study on Fluoride-Removal Filter Use in Ethiopia

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S *Supporting Information*

ABSTRACT: Evidence suggests that the effectiveness of technology designed to provide safe and healthy water is dependent on the degree of its use. In addition to providing safe water "hardware" (i.e., new infrastructure or equipment) to populations at risk, it might be necessary to also provide suitable "software" programs (behavior change strategies) to support use. A longitudinal survey was conducted in rural Ethiopia following the distribution of fluoride-removal household filters. Three intervention groups were evaluated. Group 1 only received the hardware, i.e., the fluoride-removal filter. Groups 2 and 3 also received software in the form of two evidence-based psychological interventions: a planning and social prompts intervention and an educational workshop with pledging. Group 2 received both software interventions, and Group 3 only received the educational workshop. The effects of the hardware and software on behavior and thus filter use were analyzed along with specific psychological factors. The results showed that the provision of the hardware alone (the fluoride-removal filter) was not enough to ensure sufficient use of the equipment. The addition of a software component in the form of psychological interventions increased filter use up to 80%. An increase in filter use was measured following each intervention resulting in the health-risk being minimized. We conclude that it is necessary that the implementation of hardware of this nature is accompanied by evidence-based intervention software.

INTRODUCTION

In developing countries, considerable funds have been allocated to providing water and sanitation facilities, e.g., drinking water disinfection technologies, improved toilets, and hand washing stands. However, practitioners have increasingly realized that it is not enough to provide "hardware" (i.e., new infrastructure or equipment) to solve these problems as this will have no health benefit if the new infrastructure is used improperly or not at all.[1] The challenge comes from the need for beneficiaries to switch from the old behavior of not using the hardware to a new behavior of using it continuously. They need to undergo behavior change. The solution might be the provision of a form of "software" (e.g., behavior change intervention) to accompany the hardware. The right software would need to enhance the necessary behavior change. In order for behavior change to occur, attitudes and perceptions must also change.

Various models have described behavior change and the different behavioral factors that determine whether it occurs.[2] The risk, attitude, norms, abilities, self-regulation (RANAS) model,[3] which was developed to explain behavior change in developing countries in the water, sanitation, and hygiene (WASH) sector, groups determinants of behavior derived from several established health models into five blocks. These psychological factors include all the possible drivers of health behavioral change. Risk factors are divided into perceived vulnerability (a person's subjective perception of his or her risk of contracting a disease) and perceived severity (a person's perception of the seriousness of the consequences of contracting a disease). Additionally, an individual should have an understanding (factual knowledge) of how he or she could be affected by a disease as a result of environmental conditions. Attitudinal factors include cost/benefit (e.g., how time-consuming is the behavior?) and affective evaluations (e.g., the taste and temperature of the treated drinking water). Normative factors comprise the descriptive norm (i.e., perceptions of those behaviors that are typically performed by others) and the injunctive norm (i.e., perceptions of those behaviors that are typically approved or disapproved of by important others). Ability factors characterize self-efficacy (i.e., a belief in one's capabilities to organize and take appropriate actions) and the action knowledge (i.e., knowing how to perform the behavior). Finally, self-regulation factors refer to aspects of putting a behavior into practice and maintaining it. Coping planning includes arrangements plans to cope with barriers that arise to the desired behavior change that may arise. The individual also has to be committed to the new behavior and to remember it at critical moments. A more detailed description of the behavioral factors is given in Mosler.[3]

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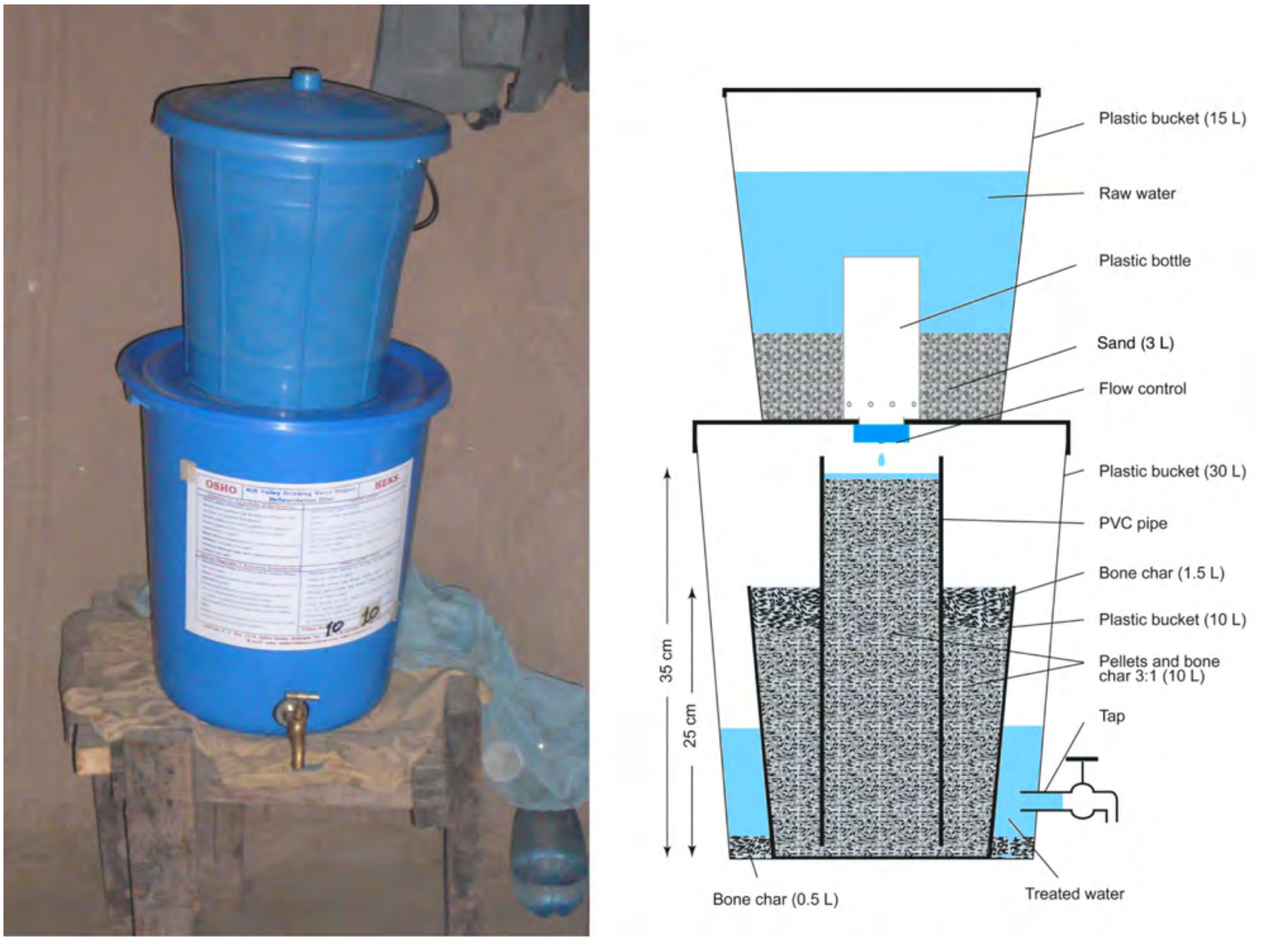

Figure 1. Fluoride removal household filter in the main house of a rural family in the Ethiopian Rift Valley (Images by Lars Osterwalder, Eawag).

The model implies that these various factors need to favor the new behavior for a person to adopt the new behavior. By conducting an initial survey, it can be revealed whether or not this is the case. If one or more factors do not favor the new behavior, an intervention aiming at these factors may be necessary to establish the new behavior. In this case, an evidence-based intervention would take the form of software specifically adapted to the hardware.

The present study evaluated the effects of the provision of hardware (fluoride-removal filters) solely and the effects of the provision of hardware with supporting software, in the form of two evidence-based psychological interventions. The effects on specific psychological factors and on behavior change were analyzed. A one-year longitudinal study was undertaken in two rural villages in the Northern Rift Valley, Ethiopia. The region has a water fluoride problem, with fluoride concentrations much higher than the 1.5 mg/L guideline set by the World Health Organization[4] (WHO) for water sources.[5] This can lead to a number of health problems, including dental fluorosis, characterized by brown patches on the teeth, and skeletal fluorosis, with joint pain, limited joint movement, and deformation of bones. This may eventually become crippling. In order to prevent the symptoms of fluorosis, fluoride-removal filters were distributed by the nongovernmental Oromo Self Help Organization (OSHO).

In the present study, the filters act as the hardware. We analyzed the effects of the acquisition of hardware on commitment and on behavior change with regard to use of the filter. The essential question was whether there would be sufficient behavior change to bring the effective fluoride exposure level down to somewhere near the recommended guideline of 1.5 mg/L.

The evidence-based software (i.e., two psychological interventions) was chosen after analyzing an initial survey. Based on the RANAS model guidelines, the results of the initial survey suggested two behavior change interventions. The first intervention was a planning and social prompts comprising a reminder and a plan about when in the course of daily activities the filter should be filled; one household member had the task of reminding the responsible person. This intervention was meant to increase the RANAS factors of habit and remembering.

As planning can influence habits, an individual plan describing when to fill the filter during the course of the day was worked out.[3] Prompts are assumed to have a positive influence on self-regulation factors, particularly with regard to remembering to perform the target behavior.[6] There is considerable research-based evidence supporting the suggestion that prompts are capable of inducing behavior change.[7] This first intervention targeted habit in the planning part, remembering by the prompt, and then behavior via the changes in habit and remembering. It was designed as suggested by the RANAS model to directly target the factors that were found not be in favor of the behavior in the initial survey.

Group	Filter distribution	Survey	Intervention	Survey	Intervention	Survey
Group 1 ($n = 32$)[a]	April 2010	Baseline T1 in September 2010	None	Survey T2 in February 2011	None	Survey T3 in May 2011
Group 2 ($n = 27$)[b]	May 2007		Planning and social prompt		Educational workshop and pledging	
Group 3 ($n = 19$)[c]			None			

Figure 2. Groups and interventions overview. [a]Two households could not be interviewed in survey T3. [b]Two households could not be interviewed in survey T1 and one in survey T3. [c]Four households could not be interviewed in survey T1 and three in survey T3.

The second evidence-based intervention was an educational workshop with pledging (public commitment). This intervention was designed according to the RANAS model to target knowledge, commitment, and interpersonal communication. The educational workshop was designed to increase knowledge. Personal commitment can be increased by pledging because people generally want to be seen as consistent.[8] The educational workshop should increase the frequency of interpersonal communication, as various studies have confirmed the importance of interpersonal communication in health behavior change.[9]

The overall effect of the second intervention should show an increase in individual knowledge due to the educational workshop, more frequent interpersonal communication through the public gathering, and a heightening of commitment from the act of pledging. According to the RANAS model these changes in knowledge, interpersonal communication, and commitment should lead to an increase in the desired behavior.[3]

This study has one research question and two hypotheses. The research question is as follows:

• How does the provision of the fluoride-removal filter (hardware) affect behavior change regarding filter use and commitment to its use? What are the effects on the health risk exposure?

The two hypotheses are as follows:

• Planning and social prompts intervention (software) will increase habit and remembering to use the filter. It will enhance behavior change regarding filter use. The health risks exposure will be reduced.

• An educational workshop, combined with pledging, will increase knowledge, the frequency of interpersonal communication, and commitment. It will enhance behavior change. The health risk exposure will be reduced.

■ METHODS

Research Area. The study was conducted in the northern part of the Ethiopian Rift Valley in two rural villages (Weyo Gabriel and Chalaleki 2). The project area was chosen by OSHO on the basis of accessibility and acceptance by regional leaders. The village of Weyo Gabriel was part of a pilot project in May 2007, which allowed fluoride-removal household filters to be acquired with the financial support of OSHO. Filters were acquired by 46 households in this project. In April 2010, the project continued with the distribution of more fluoride-removal household filters in the village of Chalaleki 2 and 32 households acquired filters.

Sample. The project's beneficiaries were low-income families, mostly self-sustaining farmers, who lived in simple clay huts without electricity, running water, or proper sanitation facilities. People usually fetched water either from private hand-dug wells, the nearby lake, or public water selling points, such as windmills or electric pump boreholes. Those different water sources have fluoride concentrations in excess of the recommended WHO guideline of 1.5 mg of fluoride per liter.[3] Of the interviewees, 81% were female and, on average, had attended school for 1.5 years. About 60% of the participants had not been to school at all. The average household size was six people (ranging from one to 16). The main religion was Ethiopian Orthodox (95%); the average age was 33.1 years (SD = 10.6). *t*-Tests revealed that the three study groups did not differ in terms of income, education, or household size.

The Fluoride-Removal Household Filter. The fluoride-removal household filter used in this study was designed by OSHO and the Nakuru Defluoridation Company Limited. It consists of a two-bucket system; in the upper bucket, a sand filter acts as a turbidity remover. From there, the water flows into the lower bucket, which is filled with bone-char and calcium phosphate pellets for defluoridation (Figure 1). The lifespan of the defluoridation material is about one year, depending on the intensity of use and the fluoride concentration in the water being filtered. Eight liters of water can be placed into the upper bucket and filtered within approximately half an hour. The lower bucket can serve as storage for 20 L of water. Filtered water is not completely fluoride-free; it has a fluoride concentration of approximately 0.75 mg/L. However, for simplification throughout the paper, we refer to filtered water as fluoride-free. Beneficiaries must purchase the filter units at a cost of approximately US$4.80 (heavily subsidized from an initial cost of US$48). Filter unit maintenance requires weekly rinsing of the sand in the upper bucket and yearly replacement of all filter media (50% subsidized, at a cost to the beneficiaries of $US7). Filters and defluoridation material were monitored regularly by OSHO and replacements arranged when necessary.

Procedure and Interventions. A longitudinal study was conducted to determine the effect of the interventions on fluoride-removal filter use. Three groups were compared over time. Figure 2 displays an overview of the different groups and interventions. Surveys were conducted in September 2010, February 2011, and May 2011. Interventions were carried out four weeks before the follow-up surveys, i.e., in January and April 2011. For Group 1, the 32 beneficiaries from the village of Chalaleki 2 were sampled. This group, which had recently obtained the hardware (fluoride-removal filter), did not receive any software (psychological interventions). Groups 2 and 3 included the 46 beneficiaries of the village of Weyo Gabriel where inhabitants had received fluoride-removal filters three years earlier in a pilot project. The beneficiaries of Weyo Gabriel were randomly assigned to Group 2 or Group 3. Group 2 received two different software interventions: a planning and social prompts intervention followed by an educational workshop with pledging. Group 3 only received the educational workshop intervention.

The procedure for the distribution of the filters was the same for both villages. Villagers interested in acquiring a filter could contact the OSHO to receive information about the filter and prices. A distribution day was held for all the villagers who wanted a filter. The OSHO social worker provided information about fluoride, fluorosis, and the filter.

Planning and Social Prompts. The beneficiaries of Weyo Gabriel belonging to Group 2 had a visit from a promoter in January 2011, which lasted approximately half an hour. When possible, the promoters talked to the person in the household responsible for managing the water supply. Using a personal filter-filling sheet (Figure S1), they calculated the total daily water consumption used for drinking and cooking in liters. Then they calculated how many times a day the filter should be filled in order to obtain the required amount of water. Once the required filling number was known, planning was carried out with the help of a color circle that included the typical daily events of a rural family (Figure S2). Suitable and convenient times to fill the fluoride removal filter were identified and marked on the circle. In order to set up a social prompt, the promoter asked an additional person, usually a child or another member of the household, for help. The circle and the filling times were explained to this person, who then agreed to help the responsible family member remember when to fill the filter.

Educational Workshop with Pledging. The educational workshop with pledging was held for members of Groups 2 and 3 at the beginning of April 2011. Only women were invited to the workshops, as they were the target group for the interviews. The workshop lasted approximately three hours. A well-known and influential woman from the village was appointed as workshop leader. The workshop included an informational session on fluoride, its effects on health, and the prevention of fluorosis. This was followed by an interactive group game to repeat and deepen participants' knowledge of the subject (Figures S3 and S4). At the end of the workshop, a pledging (public commitment) was performed in which all women raised their hands and said out loud that they pledged to use the filter (Figure S5).

Data Gathering and Questionnaire. Due to the high illiteracy levels of the beneficiaries, the surveys were carried out in a structured face-to-face interview format. An interview team of eight local college students, who had previously worked with the research team, was recruited. They were retrained for two days before each round of surveys to discuss and practice the questionnaire. During all the surveys, the interviewers were accompanied in the field and supervised. The questionnaires were translated into two local languages. They were subsequently revised by the interviewers during the training and then pretested in the field. Households were visited without preannouncement. During each interview, the interviewees were informed that their participation was voluntary. Even though none of the households refused to participate in the study, not all of the households were interviewed each time, as sometimes no adult member of the household was at home. This resulted in different sample sizes for the different survey rounds; in the first survey, 72 households were interviewed, in the second survey 75, and in the third 69. Beneficiaries received information on the study, and verbal informed consent was obtained at each point. The one-hour interviews were conducted with the person responsible for water management within the household. If possible, the same person was interviewed each time. All surveys were conducted during the dry season to minimize possible climatic influences. The questionnaires were designed to measure filter use, fluoride-free water consumption, and underlying psychological factors.

Dependent Variable: Filter Use. In the present study, the dependent variable was filter use measured in water filtered per person-day in liters. Participants were asked how many times a day they filled the filter. This number was multiplied by the same standard filling volume for each participant and then divided by the number of people living in the household (Figure S2).

Psychological Factors. Four psychological factors were used in the analysis: habit, remembering, commitment, and interpersonal communication. These items have been used and validated in similar field settings with regard to drinking water in Zimbabwe[10] and Bangladesh.[11]

The habit factor included three measures: "I fill the filter automatically without thinking much about it," "Filling the filter with water is something I do without consciously remembering," (the answers to these two statements were given on nine-point Likert scales [−4 = I strongly disagree, 4 = I strongly agree]), and "How much do you feel that you fill the filter as a matter of habit?" (the answer was given on a five-point Likert scale [0 = not at all a habit, 4 = a very strong habit]). For the purposes of analysis, the third item was also matched to the nine-point Likert scale.

Remembering was measured by the question: "How often do you forget to fill the filter with water?" The answer was given on a five-point scale from 0 = (almost) always to 4 = (almost) never.

"How often do you talk about the filter or fluoride-free water?" was asked to assess the frequency of interpersonal communication. The answer was given on a six-point scale (0 = never, 6 = every 1 to 3 days).

For commitment, three items were used (the answers were given on five-point Likert scales): "How important is it for you to fill the filter regularly?" (0 = not at all important, 4 = very important), "How annoyed do you feel if you forget to fill the filter?" (0 = not at all annoyed, 4 = very annoyed), and "Do you feel committed to use the filter?" (0 = not at all committed, 4 = very committed).

Knowledge about fluoride, fluorosis, and its prevention was measured with Kprim-styled multiple-choice questions.[12] Six blocks of four yes or no questions were given. In each block, one point could be earned by getting all the four answers right,

Table 1. Results of Wilcoxon Signed Rank Test Statistics in Groups 1 to 3

					Wilcoxon Signed Rank Test Statistics					
					Δ T1T2			Δ T2T3		
factor	*n*	T1 Mdn[a]	T2 Mdn[a]	T3 Mdn[a]	Z	p	r[b]	Z	p	r[b]
Behavior[c]										
Group 1	32	2.00	3.20	2.40	−3.23	0.002[d]	0.38	−2.82	0.004[d]	0.37
Group 2	27	2.26	2.67	3.09	−1.93	0.027[e]	0.27	−0.74	0.23[e]	0.10
Group 3	19	2.29	1.60	3.86	−0.53	0.60[d]	0.14	−0.19	0.028[e]	0.51
Commitment										
Group 1	32	4.00	3.83	3.67	−0.99	0.32[d]	0.13	−1.16	0.24[d]	0.15
Group 2	27	--	3.67	3.67	--	--	--	−0.89	0.18[e]	0.12
Group 3	19	4.00	4.00	3.83	−0.92	0.36[d]	0.17	−0.66	0.25[e]	0.12
Habit										
Group 2	27	3.00	3.00	--	−0.47	0.32[e]	0.19	--	--	--
Remembering										
Group 2	27	4	4	--	−1.02	0.15[e]	0.14	--	--	--
Knowledge										
Group 2	27	--	3.5	4.5	--	--	--	−2.76	0.003[e]	0.54
Group 3	19	--	3.5	5.0	--	--	--	−3.12	0.001[e]	0.78
Interpersonal Communication										
Group 2	27	--	2	4	--	--	--	−1.98	0.029[e]	0.26
Group 3	19	--	2	4	--	--	--	−1.25	0.10[e]	0.22

[a]Effect size.[15] [b]Behavior refers to filter use measured in liters filtered per person-day. [c]Significance of p is two-tailed. [d]Significance of p is one-tailed. [e]Medians (Mdn) are provided.

or 0.5 points could be earned by getting three out of four questions right. The maximum that could be achieved was thus six points.

Data Analysis. Wilcoxon's sign ranked tests were used to compare the medians of filter use and psychological factors within groups over time. Nonparametric tests were chosen instead of *t*-tests because the required assumption of normal distribution was not met. Additionally, effect sizes, calculated based on Rosenthal,[13] were calculated. Effect sizes, as opposed to significance, are used to calculate how relevant and meaningful a finding actually is, as they measure the strength of a phenomenon. They are considered small if 0.1 − <0.3, medium if 0.3 − <0.5, and large if ≥0.5.[14]

Assessment of Effective Fluoride Exposure. The WHO guideline for fluoride concentrations in drinking water is a maximum of 1.5 mg/L.[4] To assess whether a group of people were above or below this limit, we calculated the effective fluoride exposure, which is the mean of the exposure from the water consumed after having been through the filter and of the water consumed from other contaminated sources. To assess the total consumption of water per person-day we asked how many times certain drinking vessels were used during a day. We then allowed the interviewers to estimate the sizes of these cups and pots in liters. The mean consumption of all participants was then calculated to get an estimation of the total water consumption per person-day (see Supporting Information, p S2). The following equation was used to calculate the effective fluoride exposure (FE)

$$FE = P1 \times FW + P2 \times UFW$$

where P1 is the mean percentage of filtered water consumed, FW is the concentration of fluoride in filtered water, P2 is the mean percentage of untreated water consumed, and UFW is the weighted mean concentration of fluoride in unfiltered water. The value of FW is 0.75 mg/L. To calculate P1, we divided the mean of fluoride-free water consumption by the mean of total water consumption. P2 is 1 − P1. To assess UFW, we calculated the mean of the fluoride concentration of the sources used weighted by frequency of use. Several water sources are used in both villages, and fluoride concentrations of these sources were measured. According to what the participants said concerning the frequency of use of the source, the calculation of the mean was weighted (e.g., if source 1 was used twice as often as source 2, source 1 would contribute twice as much to the mean as source 2).

RESULTS

Water Consumption. The mean total water consumption calculated per person-day over all three rounds of surveys (T1, T2, and T3) was 4.55 L (SD = 2.63, N = 75). This gives an estimation of the required amount of water per person-day for drinking and cooking.

The mean consumption of fluoride-free water for all the groups increased from 2.55 L per person-day (SD = 1.66) at T1 to 3.29 L per person-day (SD = 2.29) at T2, and 3.26 L per person-day (SD = 1.82) at T3. The relatively high standard deviation should be noted. All households reported using the filter. Most households seemed to consume a mixture of filtered and unfiltered water.

Change over Time for Group 1. The median of filter use measured in liters for Group 1 (n = 32) increased from 2.00 L per person-day at T1 to 3.20 L per person-day at T2, with a medium effect size (p = 0.002, r = 0.38). From T2 to T3, there was a decline to 2.40 L per person-day, with a medium effect size (p = 0.004 r = 0.37). Commitment decreased over time, although it was statistically not significant (Table 1).

Change over Time for Group 2. The median of filter use measured in liters filtered for Group 2 (n = 27) increased from 2.26 L per person-day at before the planning and social prompts intervention (T1) to 2.67 L per person-day after the intervention (T2), with a medium effect size (p = 0.027, r = 0.27). Habit and remembering did not increase significantly.

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Filter use increased in the period from before the educational workshop (T2) to after the workshop (T3) to a median of 3.09 L per person day. However, this change was not significant. Respondents achieved more points in the knowledge section, increasing from 3.5 points out of 6 at T2 to 4.5 points out of 6 at T3, with a large effect size ($p = 0.003$, $r = 0.54$). Commitment did not change significantly; it stayed at a very high level where respondents reported to be very committed to filter use. Prior to the workshop, respondents talked about fluoride every month; after the workshop, they began to talk about fluoride every two weeks. This change was significant with a medium effect size ($p = 0.029$, $r = 0.26$) (Table 1).

Change over Time for Group 3. In Group 3 ($n = 19$), between T1 to T2, behavior decreased but was not statistically significant, and commitment remained at the same high level. Significant changes occurred only after the educational workshop: The median of consumption of fluoride-free water increased from 1.6 L per person-day at T2 to 3.86 L at T3, with a large effect size ($p = 0.028$, $r = 0.51$). Respondents achieved more points in knowledge, increasing from 3.5 point to 5 points out of 6, with a large effect size ($p = 0.001$, $r = 0.78$). Respondents were at a very high level of commitment all the time. Prior to the workshop, respondents talked about fluoride every month; after the workshop, they began to talk about fluoride every two weeks. However, this change was not significant, with a small effect size ($p = 0.10$, $r = 0.22$; Table 1).

Effective Fluoride Exposure. Effective fluoride exposures at T3 for the three groups were calculated using the mean volume of fluoride-free water consumption for each group, the total water consumption (4.55 L), and the fluoride concentrations in both treated and untreated waters, as described in the Methods section. The mean volumes of fluoride-free water consumption for Groups 1, 2, and 3 at T3 were 2.69 L, 3.52 L, and 3.96 L, respectively. The fluoride concentrations of untreated water were 9.4 mg/L, 4.6 mg/L, and 4.6 mg/L, respectively. Using a fluoride concentration of 0.75 mg/L for treated water, the effective fluoride concentrations in water for groups 1, 2, and 3 were 4.29, 1.64, and 1.25 mg/L, respectively.

DISCUSSION

The aim of the present study was to determine the effects of the provision of hardware (fluoride-removal filters) and software (evidence-based psychological interventions) on behavior change and on underlying psychological factors. Of particular interest was the question of whether psychological interventions would have an additional effect on behavior change after the fluoride-removal filters were distributed or if the distribution itself was sufficient to result in the required health benefits. We used the RANAS model as a framework to design and test the software.

The first research question concerned the changes in the behavior and commitment of Group 1, which received the fluoride-removal filter but no psychological intervention. The measure of behavior (i.e., use of the filter) increased initially. This might be explained by the requirement for beneficiaries to make a financial contribution toward the cost of the filter[8] and because adherence is often high at the beginning of a program.[15] However, over the long-term, the desired behavior declined. One year after the distribution of the fluoride-removal filter, the behavior in Group 1 was as low as it had been immediately after the distribution, namely at 2.4 L filtered per person-day. Less than 60% of the total amount of water consumed was fluoride-free. Even though fluoride exposure is reduced through the filter, there was still a mean exposure to fluoride in excess of 4 mg/L, which is more than twice the recommended guideline.[4] The beneficiaries who received no psychological interventions were still at high risk of contracting fluorosis despite owning a fluoride-removal filter. The observed decline in new healthy behavior seen here is consistent with other research. A 50% dropout rate was found in other studies.[16] Dietary changes are also often short-lived,[15] as is adherence to medication.[17]

The first intervention was the planning and social prompts intervention. It was designed according to the RANAS model and meant to increase habit and remembering, thus enhance behavior change toward filter use. As expected, filter use increased after the intervention; therefore, the planning and social prompts intervention induced behavior change. This is consistent with other studies that indicated the effectiveness of prompts.[18] Contradicting our hypotheses, no change in habit and remembering was observed. Regarding conformance with the RANAS model results are thus mixed: the evidence-based intervention was able to increase filter use. However, habit and remembering could not be increased by the interventions, possibly because of a ceiling effect.

The second intervention designed according to the RANAS model was the educational workshop, which was meant to induce behavior change toward filter use by increasing knowledge, commitment, and the frequency of interpersonal communication. Group 2, which received the workshop as a secondary intervention, showed only a small increase in filter use, which was not significantly measurable. However, following the first intervention, which was before the workshop, about 80% of the total water consumption of Group 2 was filtered water. There might be a limit to the number of people who can be reached through an intervention approach that focuses on learning and the performance of a new healthy behavior. There may also be a limit to the extent to which people are willing or able to perform new healthy behavior. Rogers[2b] suggests that about 10−20% of a community will not adapt to innovations. It is possible that Group 2 had already reached this limit after the first psychological intervention, making further behavior change after the second psychological intervention impossible.

In Group 3, whose first intervention was the workshop, there was a predicted increase in filter use. The beneficiaries filtered almost four liters of fluoride-free water per person-day, meaning that about 85% of their consumption was accounted for by filtered water. The results therefore indicate that an educational workshop with pledging is an effective way to promote behavior change. Other studies have demonstrated the importance of public commitment (pledging) to increase the use of safe water options.[19]

The results with regard to psychological factors were mixed. The workshop significantly increased the level of knowledge concerning fluoride and fluorosis for both attending groups. In addition, the frequency of interpersonal communication increased, although only marginally in Group 3. The beneficiaries talked more about fluoride and the filter after the intervention. Surprisingly, commitment was always high in both attending groups before and after the workshop. In the final survey, the two groups that received software in the form of psychological intervention achieved fluoride consumption levels below the recommended guideline level in one group and only slightly above in the other.[4]

As for the first intervention, the results of the educational workshop are mixed with respect to accordance to the RANAS model. The main aim of augmenting filter use was only achieved in one group. As predicted by the model, there is some evidence that the behavior change was caused by knowledge and interpersonal communication. However, there was no evidence for commitment.

Some limitations of the present study are worth noting. For Groups 2 and 3, three years passed between the distribution of the filter and the first survey. We do not know what happened in those three years. We do know that after the three years, filter use was rather low. We see the time lag as advantageous to the design of the study: it allows us to look at psychological intervention effects separate from effects of the novelty of the distribution of the filter, since the latter are likely to have vanished after this time.

Between the interventions and the surveys, four weeks passed. This allows us to look at midterm effects only. Future research should conduct several surveys to analyze long-term effects of interventions.

Due to the high illiteracy rates, the paper-based questionnaires had to be filled out by an interviewer. The interviewers used for the surveys were trained to reduce the risk of introducing social bias. This is an important consideration in this study, as it was not feasible to use data loggers, and we had to base our calculations of filter use, at least partly, on self-reports. In a study conducted with beneficiaries of the fluoride-removal filter in another rural Ethiopian village, Johnston, Edosa, and Osterwalder[20] compared data from data loggers with self-reports. Their results indicate that while the self-reported number of filling events closely matches the results from data loggers, the volume of water filtered is usually overestimated. Therefore, we tried to minimize bias due to self-reporting by basing the calculation of filter use on the self-reported number of filling events per day multiplied by the same standard filling volume for each participant.

The approach used in the calculation of the fluoride exposure risk should also be mentioned. In order to balance out fluctuations in measurements, we only performed this calculation on a group level rather than on an individual level. Individual values can vary; even if the mean exposure risk of a group is under the recommended level, some members may actually still be above it.

It should also be noted that the fluoride concentration in untreated water was not the same for both villages. Indeed, the fluoride concentrations were so high in Chalaleki 2 that the 80% fluoride-free water consumption level, which was reached through the use of interventions, would still have not been enough to reduce the mean overall fluoride consumption level to less than the recommended level.

Implications for Practice and Conclusion. The findings of this study indicate that it is not sufficient to merely introduce a new health-improving device to a community; it is also essential that the implementation be accompanied by evidence-based psychological interventions in order to have a positive effect on the beneficiaries' health. When no psychological interventions were given as software, the consumption of fluoride-free water dropped to less than 60%, leaving people at a high risk of contracting dental or skeletal fluorosis. Hardware provided without software was not sufficiently used to achieve risk avoidance. On a similar note, Enger et al.[21] point out that for household water treatment to be effective, the method itself needs to be efficient and users need to be compliant.

The present study gives two examples of successful software (i.e., psychological intervention designed according to the RANAS model) that can promote behavior change: the planning and social prompts intervention and the educational workshop with pledging. These interventions were capable of increasing consumption from under 50% to over 80%, reaching a level where the performed behavior had a positive impact on health. The fact that these interventions can be used to promote behavior change is an important factor to consider when upscaling the fluoride-removal filter program.

However, it is important to note that raising the consumption of fluoride-free water by 80% is only sufficient in areas with naturally occurring fluoride concentrations of less than approximately 4.5 mg/L. If concentrations are higher, filter use must also be higher.

The advantage of the social prompts used in this study, compared to more traditional prompts, is that no material costs were involved. Since budgets are often limited, this can be essential when up-scaling programs such as this. This paper provides some evidence that software, i.e., interventions, designed according to the RANAS model are effective in changing behavior. Further research is needed to provide conclusive evidence for the efficacy of predicting intervention success by measurable psychological factors. Screening communities for these psychological factors may be used to inform the choice of intervention to improve efficacy and enhance behavior change.

■ ASSOCIATED CONTENT

Supporting Information

Details and examples of the materials used in the psychological interventions and a thorough description of the assessment of total water consumption and the consumption of fluoride-free water. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

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