Research Paper

Backpack use as an alternative water transport method in Kisumu, Kenya

Sunkyung Kim, Kathryn Curran, Li Deng, Aloyce Odhiambo, Jared Oremo, Ronald Otieno, Richard Omore, Thomas Handzel and Robert Quick

ABSTRACT

In developing countries, most households transport water from distant sources, placing physical burdens on women and children, who commonly carry water on their heads. A lightweight backpack was developed to alleviate physical stress from water carriage and provide a safe storage container. In 2015, we conducted a baseline survey among 251 Kenyan households with children <5 years old, distributed one backpack per household, and made 6 monthly home visits to ask about backpack use. At baseline, the median reported water collection time was 40 minutes/round trip; 80% of households reported collecting water daily (median 3 times/day). At follow-up visits, respondents reported backpack use to carry water ranged from 4% to 20% in the previous day; reported backpack use for water storage in the previous day ranged from 31% to 67%. Pain from water carriage was reported at 9% of all follow-up visits. The odds of backpack use in the past day to collect water were lower during rainy season (OR: 0.3, 95% CI: 0.2–0.3) and not associated with reported pain (OR: 1.7, 95% CI: 0.9–3.3). Our study suggests that participants preferred using the backpacks for storage rather than transport of water. Further dissemination of the backpacks is not recommended because of modest use for transport.

Key words | backpack, Kenya, musculoskeletal pain, water storage, water transport

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HIGHLIGHTS

- A backpack for water carriage which was already distributed to several poor countries has not been objectively evaluated.
- Backpack use for water transport was modest in Kenya.
- This study suggests that participants preferred using the backpacks for storage rather than transport of water.

INTRODUCTION

In developing countries, water is often collected by women and children using a variety of methods (Ferguson 1986; Page 1995; Geere *et al.* 2010a), walking an average of 6 km, and hauling an average total of 18 kg of water every day (World Vision 2020). Many communities in western Kenya do not have household or community taps available and residents must leave their household premises to collect water. According to the 2014 Kenya Demographic and Health Survey (KDHS), nearly 60% of households do not have an onsite water source, and residents of 40% of rural households have to walk more than 30 min to obtain their drinking water, carrying water most often on the head (KDHS 2014).

With a volume of 20 liter, a typical jerrycan or bucket used to carry water weighs over 20 kg when filled. The

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weight of the loads and the repetitive stress placed on the spine by carrying water on the head have been shown to result in back and neck pain and radiographic changes in the spine (Levy 1968; Jumah & Nyame 1994; Jäger *et al.* 1997; Geere *et al.* 2010b). In addition, open containers or buckets can be easily contaminated if dirty hands, cups, or other items contact the water. Jerrycans, with a narrow opening, reduce this type of contamination, but are difficult to clean because they have a narrow opening.

Habitat for Humanity International (HFHI) and Greif International, an industrial packaging company (Delaware, OH), have collaborated to develop a lightweight backpack for water collection and storage called 'PackH2O' (https://www.partnersforcare.org/packh2o/). PackH2O is seven times lighter than a typical jerrycan, has a removable plastic liner that can be cleaned, and employs a spigot to readily dispense water stored in the backpack (Figure 1). In a preliminary pilot evaluation of the PackH2O, Greif International reported that the product eased transport and shortened water collection time over traditional water collection and storage tools (PIH ZL 2012). However, at the time of this study, there had been no independent evaluations of the PackH2O (Martinsen *et al.* 2019). Since 2012, over 225,000 backpacks have been distributed around the world, and as of 2018, almost 50,000 PackH2O backpacks had been deployed throughout Kenya with no published evaluations (Noland 2018). This level of investment merits justification by evaluations of use and acceptability of the backpacks as well as an assessment of stored water quality, if they are commonly used for storage.

With the assistance of HFHI, the Safe Water and AIDS Project (SWAP), a Kenyan non-governmental organization, distributed PackH2O backpacks (hereafter referred to as backpack) to rural households in western Kenya and assessed the utility and acceptability of the backpacks as a means of collecting and storing drinking water, and their effectiveness in reducing musculoskeletal pain.

METHODS

Study sites

We selected a convenience sample of eight rural villages (Kakiki, Kagoo B, Kamwanda West, Kandhere, Karabuok North, Karabouk South, Koulu B, Thim) in Kisumu County, Kenya, where a previous study suggested that the populations had to travel to collect water from their main water sources, which included Lake Victoria, rivers, earth-pans (manmade ponds), and boreholes, and store the water in their homes (KDHS 2014).

Sample size calculation

We calculated the approximate sample size of 200 households using the assumption that 50% of the households would use

Figure 1 | Backpack and a woman carrying backpack as an alternative water transport method in Kisumu in Kenya, 2015.

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the backpack, with a precision of 7% and a confidence level at 95%. Assuming a loss to follow-up of 25%, we attempted to enroll a sample of approximately 250 households.

Study design and data collection

This study utilized an experimental, longitudinal, and quantitative design. We obtained rosters of 438 total households in 8 villages from village elders. Eligible participants for the study included female heads of household or child caretakers ≥18 years old, with at least one child <5 years old. In December 2014, enumerators visited households until the desired sample size was reached to collect baseline data, including demographic and socioeconomic characteristics; water sources; water collection, storage, and treatment practices; and musculoskeletal pain related to water carriage. Stored drinking water was also tested for the presence of free chlorine residuals (FCR) using the *N*,*N* diethyl 1–4 phenylenediamine sulfate (DPD) method (Hach Co., Loveland, CO, USA). Enumerators obtained household coordinates using mobile devices with Geographic Positioning System (GPS) capabilities and GPS coordinates from water sources from a pre-selected random sample of 45 households to calculate a proxy for distance between home and water source. In January 2015, one backpack per household and training about proper backpack use were provided to each enrolled participant at group information sessions in each village. From January to June 2015, monthly follow-up home visits were made over a 6-month period by trained enumerators and community health workers, and the participants were asked about their backpack use and physical pain from water carriage during the same period, with the pain location categorized into a priori list of body regions (Supplemental Table 1). The English survey questionnaire was pre-translated to correspond to participants' native language (Dholuo) and administered at baseline and follow-up by enumerators fluent in Dholuo.

Data analysis

Survey instruments were programmed on personal digital assistants (PDA) using *Visual CE* software version 10.0 (Syware, Cambridge, MA, USA) and analyses were performed using *SAS version 9.4* (Cary, NC, USA). The associations between reported backpack use for carrying water (as a dependent variable) and selected characteristics (as independent variables) were examined using multivariable logistic regression where the unit of analysis was the household. Analyses were conducted separately for reported use in the past month and previous day. The characteristics considered in the analysis were reported pain (yes or no), age group (<24, 24–35, and >35 years), education (<primary, ≥primary), body mass index (BMI), rainy season (yes for April or May, and no), and walking time from water source to home (≤10, 11–30, >30 min). BMI was calculated from reported height and weight by respondents, and then categorized into underweight (<18.5 kg/m^2), normal weight (18.5 to <25 kg/m^2), and overweight or obese (≥25 kg/m^2) to explore whether the size of each participant is a determinant of backpack use. Potential correlations from clustered data structure (repeated monthly reports < households < villages) were considered using the Generalized Estimating Equation approach. We note that reports of musculoskeletal pain (at the same period as water carriage) from carrying water were collected during rounds 1–5, but round 6 data were missing and excluded in the analysis. To examine the impact of this exclusion to the results, we also conducted a sensitivity analysis including all six rounds of data without the pain variable.

Ethical considerations

The Kenya Medical Research Institute Ethical Review Committee (protocol number 2788) and CDC Institutional Review Board (protocol number 6583) approved the study protocol. We obtained written informed consent from all participants.

RESULTS AND DISCUSSION

Sample characteristics at baseline

Of 438 households in village rosters (Table 1), 13 were empty during the baseline home visits, 64 could not be

Table 1 | The number of total households, total households with children <5 years old, and households with children <5 years old sampled at baseline, by village, Kisumu County, Kenya, 2014–2015

Village	Total households	Households with children <5yo in villages		Households with children <5yo in sample	
		N	%	*n*	%
Kakiki	171	67	39	42	63
Kagoo B	235	89	38	47	53
Kamwanda West	125	52	42	33	63
Kandhere	68	35	51	18	51
Karabuok North	94	45	48	26	58
Karabuok South	128	59	46	35	59
Koulu B	216	56	26	35	63
Thim	94	35	37	15	43
Total	1,131	438	39	251	57

found, 24 did not transport or store water, 22 had no children <5 years old, and 51 were excluded for other reasons (e.g., died, duplicate entries, separated/divorced). Of the remaining 264 households that were eligible for inclusion in the study, 13 refused to participate, which left a total of 251 enrolled in the 8 villages for the baseline survey. The median age of respondents was 26 years (interquartile range or IQR: 22–32 years), 63% finished at least primary school, and 95% had electricity at home (Table 2). The homes of 78% of respondents had an earthen floor and 81% had mud walls. For BMI categorization, 18% were underweight and 17% were overweight or obese. Thirty-six percent of households reported drinking water from an improved source (borehole, rain catchment, covered well, or piped water) and 27% used an improved water storage container (plastic jerrycan or ceramic filter). Approximately half of respondents (54%) reported treating their water, and of these, 43% said they used a chlorine product. Water treatment was confirmed in 1% of households through chlorine residual testing at baseline.

Table 2 | Baseline characteristics of participants, Kisumu in Kenya, 2014–2015, $N = 251$

	Participants, *N* (%) or median [IQR]
Age in years, median [IQR]	26 [22–32]
<24	84 (33)
24–35	131 (52)
>35	36 (14)
Education: ≥primary	159 (63)
BMI, kg/m^2	
Underweight (<18.5)	46 (18)
Normal weight (18.5 to <25)	162 (65)
Overweight or obese (25+)	43 (17)
Have electricity in the house	238 (95)
Observed main material for floor	
Thatch	197 (78)
Wood	52 (21)
Other	2 (1)
Observed main material for roof	
Thatch	25 (10)
Iron sheet/tile/asbestos sheets	225 (90)
Other	1 (0)
Observed main material for wall	
Dung/mud	202 (81)
Metal/cement/cement/plaster/bricks/blocks/stones	48 (19)
Other	1 (0)
BMI, kg/m^2	
Underweight (<18.5)	46 (18)
Normal weight (18.5 to <25)	162 (65)
Overweight or obese (25+)	43 (17)
Improved drinking water source[a]	91 (36)
Improved drinking water container[b]	69 (27)
Treat drinking water?	135 (54)
→ If yes, what do you do to it? select all that apply	
Chlorination	107 (43)
Filter or boil	27 (11)
Other	15 (6)
Observed container lid	210 (84)
Observed latrine	131 (52)
Confirmed chlorination	3 (1)

[a]Borehole, rain catchment, covered well, or piped water.
[b]Plastic jerrycan or ceramic filter.

Drinking water collection and physical pain from carrying water at baseline

At baseline, about one-third (32%) of respondents said they used plastic jerrycans and the rest used buckets (or bucket-like) containers to collect water, and 99% carried water on their heads (Table 3). The median reported time to collect water (per round trip) was 40 min (IQR: 30–60 min). Eighty percent of respondents reported collecting water every day and, of these, 85% said they collected water at least three times per day. A majority of respondents (91%) said they have had pain from carrying water at some time during their life, with the most frequently reported locations including chest (46%), head (43%), and neck (36%). These were also the most commonly reported locations for pain during the past 2 weeks. The median distance from home to water source calculated from GPS coordinate data of 44 households was 415 m (IQR: 228–688 m) (data not shown).

Backpack use and pain for water carriage at follow-up

Among 251 respondents, we distributed backpacks to a subset of 239 women in January 2015 (three refused to participate and nine were away at the time of distribution). Among 239 participants, a total of 1,334 follow-up home visits were made, with a median of 223 monthly visits ranging from 216 to 228 visits. In nearly two-thirds of these visits (62%), respondents said they collected water with the backpack in the past month and 13% said they used the backpack for water collection in the past day (Table 4). The monthly rate of reported use of the backpack for water collection during the previous month varied from 37 to 85%, and from 4 to 20% for the previous day (Figure 2). Respondents reported even storing water in the backpack over the past month during 83% of home visits, and either today or during the previous day at 64% of visits (Table 4). Water was observed in the backpack at 48% of home visits, which varied by month from 31 to 67% (Figure 2). Pain from carrying water was reported at only 9% of all home visits (Table 4). Among backpack users, reported pain ranged from 6 to 19% in the previous month and 0 to 19% in the previous day (Figure 3). Among

Table 3 | Drinking water collection and pain reported from carrying water at baseline, Kisumu, in Kenya, 2014–2015, $N = 251$

	Participants, *N* (%) or median [IQR]
Type of water container to collect and carry home	
Plastic jerrycan	80 (32)
Buckets	171 (68)
How do you carry water to home? Select all that apply	
Head	249 (99)
Hands	11 (4)
Back	1 (0.4)
Time to collect water (round trip), min	40 [30–60]
Time from home to water source	15 [10–25]
Time from water source to home	25 [10–35]
No. of trips to collect water per week	
Every day	200 (80)
Other	51 (20)
→ If every day, no. of trips to collect water per day	
<3	31 (15)
≥3	169 (85)
Any pain from carrying water in lifetime	227 (91)
→ If yes, location of the pain	
Head	136 (54)
Neck	90 (36)
Shoulder	17 (7)
Upper back	41 (16)
Lower back	52 (21)
Chest	115 (46)
Ribs	14 (6)
Knee	25 (10)
Any pain from carrying water <2 week	133 (55)
→ If yes, location of the pain	
Head	69 (27)
Neck	50 (20)
Shoulder	11 (4)
Upper back	18 (7)
Lower back	32 (13)
Chest	48 (19)
Ribs	15 (6)
Knee	17 (7)

Table 4 | Monthly reports for backpack (BP) use and pain from carrying water during follow-up home visits, Kisumu in Kenya, 2014–2015, $N = 1,334$ visits

	Visits, N/total (%)
Water collection	
Collect water with BP in the past month	753/1,205 (62)
Did you collect with BP yesterday?	160/1,205 (21)
How often use BP to collect water	
Everyday	58/1,333 (4)
Other	1,275/1,333 (96)
Water storage	
Ever store water in BP	1,104/1,334 (83)
→ Stored water in BP today or yesterday	701/1,103 (64)
→ How often use BP to store water	
Everyday	354/1,104 (32)
Other	750/1,104 (68)
Observed water in BP	574/1,201 (48)
Pain from carrying water	
Any pain in the past month from carrying water	101/1,109 (9)
→ If yes, location of pain	
Head	8/101 (8)
Neck	14/101 (14)
Shoulder	44/101 (44)
Upper back	17/101 (17)
Lower back	27/101 (27)
Chest	33/101 (33)
Ribs	2/101 (2)
Knee	2/101 (2)
What do you like most about the BP? Select all	
Good for water storage	796/1,334 (60)
More comfortable to carry	558/1,334 (42)
Convenient to use	188/1,334 (14)
What do you like least about the BP? Select all	
Too heavy	164/1,334 (12)
Causes pain	52/1,334 (4)
Uncomfortable	48/1,334 (4)
It broke	12/1,334 (1)
Maintenance of BP	
Do you clean inside of BP?	1,124/1,334 (84)
If yes, how often?	
Every time I collect water	186/1,124 (17)
Other	938/1,124 (83)

backpack non-users, reported pain ranged from 1 to 33% in the past month and 5 to 22% in the past day. Respondents reported pain most frequently in the shoulder (44%), upper/lower back (44%) and neck (14%).

Preferences and challenges with backpacks

At monthly home visits, 60% of participants reported they liked the backpacks for water storage, 42% said they were comfortable for carrying water, and 14% stated that their favorite feature of the backpacks was convenience (Table 4). A few challenges were also reported as hindering backpack use, including too heavy (12%), causes pain (4%), uncomfortable to use (4%), and breakage (1%). During 84% of home visits, respondents reported cleaning the inside of backpacks; of these, 17% said they cleaned the backpack every time water was collected.

Backpack use for water carriage models

The odds of reported backpack use to carry water in the past month were higher in those who had ≥primary school education (odds ratio or OR: 1.6, 95% confidence interval or CI: 1.04–2.3) and who were in the underweight BMI category compared with normal BMI (OR: 1.7, 95% CI: 1.1–2.9) (Table 5). The odds of backpack use to carry water were lower in the rainy season than in the dry season (OR: 0.3, 95% CI: 0.2–0.3). There were no significant associations between backpack use and reported pain in the past month, respondent age group, or time from water source to home. Similar patterns were observed in the analysis of reported backpack use to carry water in the previous day, with consistently lower odds of backpack use during the rainy season than the dry season (OR: 0.3, 95% CI: 0.2–0.4). In the sensitivity analysis using all data from all six rounds and excluding missing pain data from the sixth round, the results did not change appreciably (Supplemental Table 2).

Discussion

Results of this evaluation suggested that the uptake of backpack for water collection and transport among participants in western Kenya was modest. Backpack use for water storage was more common than for water transport and increased during the rainy season, likely because the backpack fit the

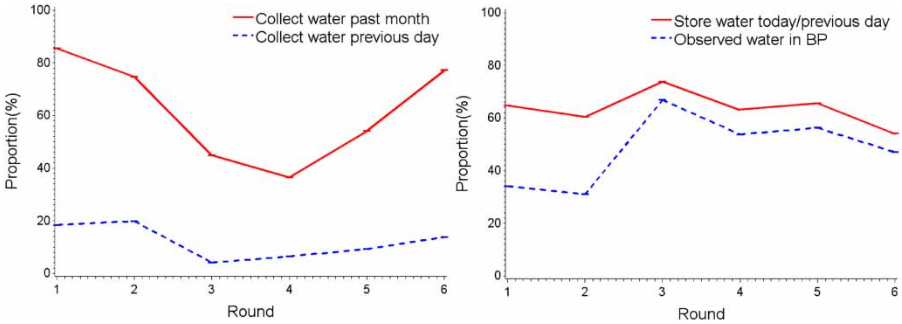

Figure 2 | Monthly reported backpack use to collect water past month or previous day (left) and to store water today/previous day and observed water in the backpack (BP) (right).

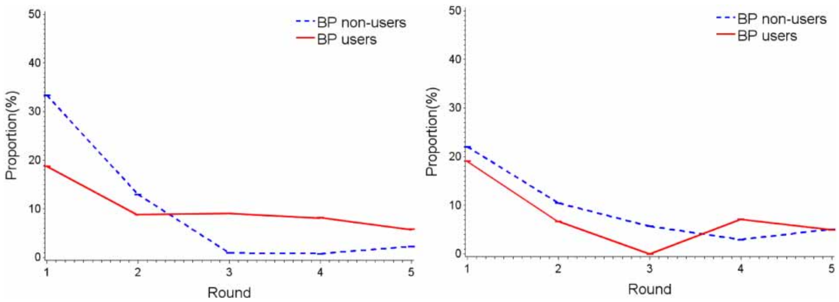

Figure 3 | Monthly reported pain from carrying water by backpack (BP) use past month (left) and previous day (right).

Table 5 | The odds ratios (OR) of reported backpack use in past month or previous day to carry water, Kisumu in Kenya, 2014–2015

	Past month OR (95% CI)	*P*-value	Previous day OR (95% CI)	*P*-value
Pain from carrying water past month	1.7 (0.9, 3.3)	0.117	0.9 (0.5, 1.7)	0.740
Age group, years				
<24	Ref	–	Ref	–
24–35	0.8 (0.5, 1.3)	0.438	0.7 (0.4, 1.1)	0.083
>35	1.1 (0.6, 1.9)	0.826	1.0 (0.5, 1.9)	0.910
Education level attained				
<Primary	Ref	–	Ref	–
≥Primary	**1.6 (1.04, 2.3)**	**0.030**	1.5 (0.9, 2.3)	0.112
BMI, kg/m^2				
Normal weight	Ref	–	Ref	–
Underweight	**1.7 (1.1, 2.9)**	**0.030**	1.3 (0.7, 2.3)	0.407
Overweight or obese	1.1 (0.6, 2.0)	0.658	1.1 (0.6, 2.0)	0.765
Rainy season*				
No	Ref	–	Ref	–
Yes	**0.3 (0.2, 0.3)**	**< 0.001**	**0.3 (0.2, 0.4)**	**< 0.001**
Time from water source to home, min				
≤10	Ref	–	Ref	–
11–30	1.0 (0.6, 1.6)	0.929	1.0 (0.6, 1.8)	0.945
>30	1.0 (0.6, 1.7)	0.933	1.0 (0.5, 1.8)	0.903

*April or May.

local water storage strategy of filling as many containers as possible when it rains. The finding of low use for water transport was consistent with a recent evaluation of the same backpack conducted in rural Haiti which showed the overall modest acceptance of backpack with decreasing use over a 6-month period (Martinsen *et al.* 2019).

Water transport

Devising a container for carrying water on the back reflects an interest that has been raised in recent years (WHO 2007, 2017). Despite the apparent musculoskeletal stress of water carriage and scientific evidence of chronic health problems from this practice (Levy 1968; Jumah & Nyame 1994; Jäger *et al.* 1997; Geere *et al.* 2010b), no large-scale epidemiological studies were found which had used a scientifically appropriate study design to analyze the association between water carrying and objective indicators of effects on physical health (Evans *et al.* 2013). A few studies have compared several types of containers that reduce physical pain, but no designs have been widely disseminated (Geere *et al.* 2010b; Martinsen *et al.* 2019). In a study conducted on Xhosa women of South Africa, the participants reported they can carry greater loads on the back than on the head and said that back-loading was generally more comfortable (Lloyd *et al.* 2010). Conversely, several studies have reported that back-loading led to more areas of pain and discomfort than head-loading using buckets and jerrycans (Noland 2018; Martinsen *et al.* 2019). Although fewer women had complaints (heavy, difficult to use straps, pain, difficulty cleaning) than positive comments (storage, comfort, convenience) about the backpack in this study, the duration of data collection may have been insufficient, the distance to water sources not far enough (<500 m on average), and the use of backpacks too limited to meaningfully evaluate acute and chronic pain associated with backpack use. Furthermore, because the backpacks were neither fitted to the women nor ergonomically designed, it is possible that musculoskeletal problems could have developed over time (Geere *et al.* 2018). An additional possibility is that the use of the head for carrying water was an ingrained habit that served as a barrier to changing this longstanding practice. This possible explanation is consistent with a study by Schilling *et al.* that found that poverty, low educational levels, and ingrained habits were a barrier for rural residents to adapt to new health interventions (Schilling *et al.* 2013). Behavior change interventions that employ social norms can help overcome barriers to change and sustain new behaviors (Yamin *et al.* 2019), particularly if the new behaviors have advantages that facilitate diffusion of innovative practices or technologies into populations (Rogers 1983).

Water storage

Although the results of this study did not clearly answer the question of the acceptability of the backpack for water carriage in western Kenya, many study participants appeared to have little motivation to use the backpack for water transport during the rainy season because they preferred its use for rainwater collection. The highest level of reported use of the backpacks for water storage in the previous day occurred during the rainy season. Participants indicated that, by providing an additional water storage container with the added advantages of a wide opening for rain capture and easy cleaning, as well as a spigot for water removal, the backpack serves the household need for water storage.

The unexpected preference for storage over transport of water raised several questions regarding the utility of the backpack. Acceptable water containers are accessible in western Kenya and have been tested for their ability to maintain water quality (Ogutu *et al.* 2001; Murphy *et al.* 2016). Unless the backpacks offered advantages in storage over effective, less expensive alternatives, it would be difficult to justify using scarce resources to make them widely available if they were not commonly used for their original purpose of water transport.

Evaluating the relative hygienic advantages and durability of the plastic liner would be important because of its role in maintaining water quality (Mellor *et al.* 2013). During this study, a majority of participants did report during home visits that they cleaned the inside of the backpacks (84%) and, at the end of the study, nearly all participants (93%) reported cleaning the plastic liners. Whether these hygienic practices were accompanied by treatment of water from potentially contaminated sources would be an important evaluation question.

Limitations

This study was subject to several limitations. First, because we selected a convenience sample of eight rural villages in one district, our study findings may not be generalizable to the Kenyan population. Second, the 6-month study follow-up period was relatively short and limited our ability to assess further attrition in use through discomfort or breakage. Although the backpacks did appear to be durable with only two reports of breakage, a follow-up at 1 year would enhance the assessment of durability, as well as continued acceptability of the backpacks. Third, courtesy bias may have inflated apparent backpack use: reported water storage in the backpack today/previous day was reported to be 64% compared with a confirmed rate of 48% (observed water in backpack) during home visits (Glick 2009).

Conclusions and recommendations

In conclusion, we observed that the acceptability of backpack use was modest for water collection and transport but somewhat higher for water storage. Participants decreasingly reported physical pain over the study period, but its link to backpack use remains unclear. At this time, we do not recommend dissemination of the backpacks because of their modest use for water transport. Further evaluation of promotion, use, and effectiveness of alternative water transport interventions to minimize the potential health effects of head-loading is needed because water fetching is a practice that will continue, of necessity, for some time.

COMPETING INTERESTS

The authors declare no conflicts of interest.

DISCLAIMER

The contents of this paper are solely the responsibility of the authors and do not necessarily reflect the official views of the Centers for Disease Control and Prevention (CDC).

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

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