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Evaluation of long- and short-handled hand hoes for land preparation, developed in a participatory manner among women vegetable farmers in The Gambia

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A B S T R A C T

Objective: This study evaluated land preparation interventions (new short- and long-handled hoes), developed in a participatory manner with women vegetable farmers in West Africa, and identified indicators of long-term adoption of these interventions.
Methods: Subjects ($n = 48$) engaged in timed trials, alternating between using an intervention tool and their traditional hand hoe to till specified plots of land. Heart rates were measured and subjects reported the relative ergonomic comfort and safeness of the tool after each trial. Follow-up interviews and focus groups were held one, two, and three months after the trials.
Results: Compared to the traditional hoe, the new long-handled hoe required 22% less time ($p = 0.01$), while the new short hoe took 20% more time ($p = 0.05$) to till the standard plots in this study. Two months after the initial trials, 94% of subjects preferred the new hoes over the traditional hoe. Most subjects (75%) preferred the new short hoe over the new long hoe and thought it was faster (81%), despite measurements to the contrary.
Conclusions: While the new long-handled hoe performed better in the timed trials in this study, most subjects preferred the new short-handled hoe. Subjects should be sensitized on the benefits of the long-handled hoe.

1. Introduction

While modern mechanized agriculture has eliminated much of the manual work in many sectors, vegetable production throughout the world still involves hazardous repetitive manual labor (Fathallah et al., 2008). This type of labor presents multiple physical risk factors for musculoskeletal discomfort and injuries (Fathallah et al., 2008; Janowitz et al., 2000).

Local vegetable production is a very important activity in most low and middle income countries such as The Gambia, a small West African country. In The Gambia, 42% of the total working population is involved in vegetable production, most of whom are women with limited education or financial resources (Carney, 1998; Culp et al., 2007). Women in this country (as in much of Africa) are seldom introduced to new tools to use in farming operations; most of their work tools and methods have been used for generations (Rogan and O'Neill, 1993). When asked about high-risk vegetable production duties, they identified land preparation as the most injury-prone task in the garden, requiring long hours of heavy physical labor and leading to musculoskeletal pain (Kuye et al., 2006; Nag and Nag, 2004; Vanderwal, 2009).

In land preparation, women typically use hoes that are short-handled and have a narrow angle (~60° between the blade and handle; see Fig. 1), which require the women to work in a bent position (Fig. 2), which has been demonstrated to lead to musculoskeletal pain (Fathallah et al., 2008). Therefore, this study was intended to evaluate different designs of land preparation tools that the research team determined could decrease discomfort and injury, and increase work productivity.

A limited number of studies have evaluated the use of different hand hoes in land preparation (Rogan and O'Neill, 1993). Some studies in the USA have successfully utilized a participatory research approach with farmers to assist in developing and selecting the tools to be evaluated (Baron et al., 2001; Earle-Richardson et al., 2005; Rivilis et al., 2008). This method has been used less with farmers in developing countries (Egharevba and Iweze, 2004; Kaul, 1993;

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Fig. 1. Traditional hoe tested in the study.

O'Neill, 2000). The few existing studies evaluating the use of hand hoes in developing countries have included small samples,often only males (Badiger et al., 2006; Nwuba and Kaul, 1986; Tewari, 1991) and few studies evaluated worker musculoskeletal discomfort, injury risks, or long-term worker acceptability and use (O'Neill, 2000).

Based on prior experience in intervention studies, we used a mixed-methods community participatory research approach (Creswell et al., 2003) in which subjects agreed to test a new short-handled and a new long-handled hoe for land preparation. Quantitative methods were used to describe worker productivity, discomfort and injury risk, as well as some indicators of the workers' long-term acceptance of the interventions. Qualitative individual interviews, focus groups, and observations were conducted to complement the quantitative data, in order to identify enabling factors and barriers to long-term adoption of the interventions.

2. Methods

2.1. Setting

This study was conducted in a women's vegetable garden located outside a small village in The Gambia, West Africa. The garden was established and is overseen by a local non-governmental organization (NGO), which willingly cooperated with the research team in implementing this study.

Fig. 2. Subject using a traditional hoe during the timed trials.

2.2. Subjects

Forty-eight (48) of the 212 women who each work in their own plot in the garden were randomly selected to participate in the study. The project team introduced the study and administered informed consent in the local language of Mandinka, as approved by The Gambia Human Ethics Committee (SCC/EC #1123) and the University of Iowa Institutional Review Board (IRB ID# 200808704). All selected women consented to participate in the study. The research team provided the subjects with a small monetary gift for their participation, which was not made known to the participants until the end of the study. Subject demographic data, including height, weight, age, and years of garden experience were collected at the beginning of the study through individual interviews.

2.3. Development of the interventions to be evaluated

After consenting, a participatory focus group, key informant (work group leaders) interviews, and observation of women during work identified land preparation as an intervention task. The various gardening tasks, as well as the pain and challenges of each task, were discussed and observed. The most painful, injury-prone, or time-consuming tasks, as well as those amenable to intervention, were selected for the study. Weeding was also noted to be a time-consuming and painful task, but the research team considered that it would be difficult to accurately evaluate the differences between weeding interventions, as the conditions of weeding vary greatly, depending on the species and density of plants, weed type and density, soil moisture level, and other considerations (Vanderwal, 2009).

A second focus group (held one week after the first) and key informant interviews were held to identify the interventions to be tested for the task of land preparation. Subjects provided feedback on 14 different designs of long (8)- and short-handled (6) hand hoes that the research team determined were likely to improve worker health, safety, and productivity. The long-handled hoe models had various designs and sizes of cutting head (some triangular, some with flat cutting edge and some with rounded cutting edge), but only the model hoe selected had a 2-sided head. Three of the short-handled hoes had 2-sided heads of varying designs and two of the hoes with 1-sided heads had 3 digging tines. Subjects were also encouraged to generate ideas of other low-cost and locally-reproducible interventions to improve land preparation.

Subjects identified two new tools from the models presented to evaluate: a short-handled and a long-handled hoe (Fig. 3; Vanderwal, 2009). Subjects considered that these new hoes were stronger and had a larger cutting surface than their traditional hoes, which should reduce the amount of time needed to till the land and improve worker satisfaction. Subjects also thought that the two sides of the tilling head of the intervention hoes would be more versatile than the one-sided head of their traditional hoes. The intervention tools selected also both had a different angle between the handle and the blade, which alters the working angle of the back and arms. The long-handled hoe had 90° angle and a straight blade. The short-handled hoe was also set at a 90° angle but had a slightly curved blade, similar to the circumference of the swinging motion when used. The traditional hoes had a sharper angle between the handle and the blade, which requires a more upward pulling motion of the soil. The research team agreed the new designs should improve working posture of the back and the arms,

Fig. 3. Intervention hoes tested in the study. The model hoes are on the outside, with the locally-manufactured short- and long-handled hoes in the center. Note that the handle of the model long-handled hoe had to be cut for shipping from the US.

as well as the degree of pulling of the soil necessary, thus reducing musculoskeletal pain and improving work efficiency.

The Gambian National Agricultural Research Institute engineering unit was contracted to manufacture 12 copies of both hoes to be used in the study, at a cost of approximately US$6 per hoe. Due to the local conditions under which the tools were produced, the replicated tools used in the study were slightly different (and heavier) than the models they were based upon, and also had some variation within each type of replicated tool (see Table 1). Participants were instructed on the proper use of the hoes before study measurement began.

2.4. Data collection methods

2.4.1. Preparation for and timing of data collection

Areas of the garden that required land preparation were identified for each subject, and then divided into 4 equal plots for each subject to use in the trials. The plots for the different subjects ranged in size from 5 to 8 m^2 due to the differing amounts of space available in each subject's land area. However, great care was taken to ensure that the 4 plots for each subject were the same size, as well as the same level of weediness, moisture content, soil type/compaction, and generally equal in terms of ease/difficulty of land preparation.

Subjects were randomly assigned to either begin with their traditional land preparation method or with one of the intervention methods (new short- or long-handled hoe), and alternated between the traditional and intervention method in subsequent trials, using both methods two times. Subjects were randomized to use either the new short- or new long-handled hoe throughout the trials. Data were collected after each trial.

All data collection instruments were developed in English and translated to the local language of Mandinka with extensive input from local research team members. Gambia College School of Public Health students were extensively trained to collect physiological data and conduct interviews (in Mandinka). The interviewers also observed the subjects throughout each trial to monitor their working conditions, and to ensure that subjects tilled each plot to the same depth with the same quality of tillage.

Environmental data (air temperature and humidity) were collected every hour during the trials, using a portable weather station (Oregon Scientific, WMR 968). Soil temperature was recorded in each plot immediately before the subject tilled that plot.

In January and March, 2009, follow-up focus group discussions were held with twelve different randomly-selected subjects to gain feedback on their perceptions and experiences with the hoes since the initial trials. Follow-up individual interviews were conducted with all subjects in February 2009.

2.4.2. Measurement of length and effort of trials

After the subjects prepared the specified land area in each trial, interviewers recorded the time required, as well as the average and maximum heart rate of the subject, using a heart rate monitor with chest strap (Reebok Precision Trainer XT).

2.4.3. Recording of discomfort and injuries

Subjects were then asked to report their level of comfort or discomfort (on a 5 point scale) in each of four body regions (neck/shoulders, arms, lower back, legs), as well as any injuries or injury near misses in that trial. Subjects were asked to point to their level of comfort or discomfort on a validated psychometric scale consisting of a series of 5 faces (Peterson, 2000). The 5 faces ranged from very comfortable (happy – on the left of the scale) to very uncomfortable (unhappy – on the right). To determine injury near misses, subjects were asked the following question: "*While using this method, did you ever feel that you were very close to having an injury, but one did not actually occur?*"

2.4.4. Rating the acceptability of tools

In the follow-up focus groups, subjects discussed their perceptions of the hand hoes, any injuries or near misses incurred in land

Table 1
Average specifications – mean and (range) – of hoes used in the study.

Characteristic	Traditional hoe[a]	Model long hoe[b]	Long hoe used in study	Short hoe used in study	Model short hoe
Weight of hoe (grams)	530 (450–600)	1200	1000 (970–1030)	600 (580–620)	500
Length of handle (cm)	48 (40–58)	145	141 (139–143)	49 (47–52)	45
Length of blade – from handle insertion to flat cutting edge (cm)	17.5 (16–20)	20	19 (18.4–19.5)	18 (17.5–18.5)	19
Blade width – flat cutting edge (cm)	7 (4–10)	10	10.5 (10.1–10.9)	10 (9.4–10.5)	9.5
Circumference of handle (cm)	9.5 (8.2–10.8)	9.4	11 (10.1–11.7)	11 (10.0–11.7)	8.5
Angle of blade (compared to handle)	60° (50°–70°)	90° (straight)	90° (straight)	90° (curved)	90° (curved)
Number of prongs on end of head opposite flat cutting edge	(flat cutting head only)	2	2	1	1

[a] The traditional hoes used in the study varied greatly, as each subject used their own hoe, made by different local blacksmiths.
[b] Note that the model long-handled hoe had a metal tube to join the handle back together, which weighed about 200 g alone.

preparation since the initial trials, and others' reaction to their use of the new hoes. In the two-month follow-up individual interviews, each subject was asked to report the amount of time they have been using the new hoes, any injuries or near misses incurred since the initial trials, and their perceptions of which hoes were safer, easier, faster, and which they preferred to use. Subjects were asked to compare the traditional hoes to the new hoes, as well as the new long-handled to the new short-handled hoe. Subjects were also encouraged to provide qualitative feedback on the rationale for their preferences and their suggestions to improve the hoes.

The Principal Investigator (PI) also observed the subjects 15 times (~on a weekly basis), for at least 2 h per observation, from October 2008 to March 2009, documenting observed activities and behaviors on an open-ended form.

2.5. Data analysis

2.5.1. Statistical analysis of quantitative data

Generalized Estimating Equations (GEE) methods were used to account for the longitudinal repeated measures design to account for clustering by individual and variability over time. Mean times for land preparation, average heart rates, and maximum heart rates were compared for each land preparation method in the repeated trials (control and intervention methods were each used twice) using GEE with the following model statements: subject = person id, dist = normal, link = identity, and type = ind (SAS Institute Inc, 2008; Zeger and Laing, 1986). Discomfort and injury near miss results from the trials were dichotomized and land preparation methods were compared through odds ratios calculated using the logit link function in GEE models. Independent variables that were significant covariates in previous studies or were significant at the $p < 0.05$ level for at least one outcome were included in the multivariable modeling for the dichotomized outcomes. These independent variables included subject height, age, and subject weight.

Repeated comparisons were made of the same subject using either the traditional or one of the intervention methods, which was the primary independent variable of interest. All GEE analyses were conducted using PROC GENMOD in SAS Version 9.2 (SAS Institute Inc, 2009).

Chi-Square and Fisher's exact tests were used to compare the number of near misses occurring during the follow-up period for each land preparation method.

The associations of outcome responses in the two-month follow-up individual interviews and independent variables were evaluated using logistic regression analysis to identify any factors predictive for the outcome responses.

2.5.2. Analysis of qualitative data

All information obtained through qualitative data collection methods (observation, focus groups, and individual interviews) was analyzed to identify patterns and common themes, with the primary objective of discovering theory explaining subjects' attitudes and behavior regarding the hoes (Glaser and Strauss, 1967). All opinions expressed by subjects in qualitative interviews and focus groups were included in the analysis, with particular attention given to the number of subjects reporting a specific point.

3. Results

3.1. Subjects

On average, the subjects were 1.60 m tall and weighed 58.7 kg. The highest number of women (33%) was in the 60–89 age group, and most (40%) had more than 20 years garden experience.

3.2. Length and effort of land preparation trials

Subjects took an average of 295 s to till plots with the traditional hoe, which was 22% ($z = -2.45$, $p = 0.01$) longer than the 231 s required for the new long-handled hoe and 20% less than the 353 ($z = 1.93$, $p = 0.05$) seconds required with the new short hoe (Table 2). Compared to using the new short hoe, the new long hoe took 35% less time ($z = 5.01$, $p < 0.01$).

Subjects worked to about the same average heart rate for all methods, but worked to a 5% lower maximum heart rate ($z = -2.43$, $p = 0.02$) when using the new short hoe, compared to the traditional hoe.

3.3. Discomfort and injuries

Compared to the traditional hoe, using the new long hoe during the trials reduced the odds of subjects reporting discomfort in the lower back, hips and legs, and also of reporting an injury near miss (Table 3). Using the new long hoe also reduced the odds of reported neck and shoulder discomfort, and arm and hand discomfort, but it was not significant in either the univariate or adjusted models. The odds of subjects reporting arm and hand discomfort was significantly greater with the new short hoe, compared to the traditional hoe. Compared to use of the new short hoe, the new long hoe significantly reduced the odds of reporting discomfort in all body regions, as well as injury near misses. Researchers also observed that use of the new long hoe enabled subjects to work with a more upright posture than with either the traditional or new short hoe.

The estimates and confidence intervals changed very little from the univariate to the multivariable adjusted models. The time required for the trial, as well as soil and environmental conditions during the trials (temperature and humidity) were not significant predictors of discomfort in any body region. The consecutive trial number (1, 2, 3 or 4) was also not a significant predictor of any outcome in this study, which indicates that there was no effect of a "learning curve" for the subjects, or tiredness when advancing from the first plot to the last.

No injuries were reported with any hoe in the trials or in the two months after the trials. Subjects reported injury near misses in 40 trials, with the fewest ($n = 4$) when using the new long hoe,

Table 2
Values of continuous outcomes by each method used in the land preparation trial.

	Mean values, *Standard deviation* by method used			*p*-values of comparison[a]		
	New long	New short	Traditional	New Long vs. traditional	New Short vs. traditional	New Long vs. new short
Time required (seconds)	231.4, *136.2*	353.1, *189.6*	295.4, *186.0*	**0.01**	**0.05**	**<0.01**
Average Heart Rate (bpm)	129.5, *13.9*	127.5, *14.2*	130.0, *12.7*	0.86	0.37	0.69
Maximum Heart Rate (bpm)	143.3, *15.4*	136.3, *12.9*	143.4, *13.0*	0.97	**0.02**	0.15

bpm = beats per minute. Bold font indicates statistically significant difference.
[a] GEE was used to calculate *p*-values.

Table 3
Association of intervention method with discomfort and injury outcomes.

Outcome	Intervention method	N=	% discomfort[b]	Unadjusted values			Adjusted values[a]		
				Odds ratio	Lower CL	Upper CL	Odds ratio	Lower CL	Upper CL
Neck and shoulder discomfort	New long	43	26%	0.44	0.19	1.05	0.46	0.19	1.13
	New short	53	51%	1.34	0.73	2.46	1.29	0.69	2.43
	Traditional reference	94	44%	–	–	–	–	–	–
Arm and hand discomfort	New long	43	23%	0.45	0.19	1.03	0.49	0.20	1.20
	New short	53	57%	**1.92**	**1.12**	**3.31**	**1.88**	**1.07**	**3.28**
	Traditional reference	94	40%	–	–	–	–	–	–
Lower back discomfort[c]	New long	43	16%	**0.19**	**0.07**	**0.50**	**0.20**	**0.07**	**0.56**
	New short	53	45%	0.79	0.46	1.36	0.76	0.44	1.31
	Traditional reference	94	51%	–	–	–	–	–	–
Hip and leg discomfort[c]	New long	43	14%	**0.22**	**0.08**	**0.63**	**0.21**	**0.07**	**0.63**
	New short	53	36%	0.75	0.42	1.35	0.69	0.38	1.26
	Traditional reference	94	43%	–	–	–	–	–	–
Injury near miss	New long	43	9%	**0.33**	**0.13**	**0.83**	**0.33**	**0.13**	**0.84**
	New short	53	26%	1.19	0.70	2.03	1.10	0.59	2.04
	Traditional reference	94	23%	–	–	–	–	–	–

Bold font indicates statistically significant difference.
[a] All values were adjusted for age and height.
[b] Indicates the % of trials for that method where subjects reported discomfort (first or second face on 5-face scale). For the injury near miss outcome, indicates the % of trials reporting an injury near miss.
[c] Outcomes were also adjusted for weight, in addition to age and height.

although there was no significant difference between methods (Table 3).

In the two months after the initial trials, only one (1) subject reported an injury near miss when using the new long hoe, significantly less than the eight (8) near misses reported with the traditional hoe (Fisher's exact test $p = 0.03$). Three (3) subjects reported a near miss when using the new short hoe, which was not significantly different than with the traditional hoe (Fisher's exact test $p = 0.19$).

3.4. Acceptability of the intervention tools

Two months after the initial trials, 25% of subjects reported that they had not used the new long hoes at all since the initial trials, 20 of 48 subjects reported that they had used the new long hoes 25% of their time, and 11 subjects reported using them 75% of their time in land preparation. In contrast, most (34 of 48) subjects reported using the new short hoes $\geq$75% of their time in land preparation since the original trials, with 9 subjects using the new short hoes $\leq$25% of their time in land preparation.

Compared to traditional land preparation methods, nearly all subjects indicated that they felt both the new long and new short hoes were safer (81%), easier (94%), faster (92%), and were preferred (94%) (combining "definitely" and "probably" categories – Table 4).

When comparing the new short to new long-handled hoes, more subjects indicated that they thought ("definitely" or "probably") that the short-handled hoe was safer (63%), easier (80%), faster (81%), and preferred (75%) (Table 5). However, some subjects did feel ("definitely" or "probably") that the long-handled hoe was safer (27%), easier (15%), faster (16%), and preferred (19%).

From the qualitative data, various barriers and enabling factors to long-term acceptability of the hoes were identified, summarized in Table 6.

4. Discussion

Subject acceptance of an intervention is influenced by a number of factors, and may not be directly related to its demonstrated productivity or health benefits (FAO/IFAD, 1998; Fathallah et al., 2008; O'Neill, 2000). Although the long-handled hoe presented indicators of being more efficient and improving safety and comfort in the trials, the new short-handled hoe was preferred by more subjects.

In this study, use of the long-handled hoe reduced the time required to prepare a specified area of land, without increasing the effort required (heart rate) compared to the traditional or new short hoe, thus improving worker productivity. However, subjects reduced their maximum heart rate with the new short-handled hoe

Table 4
Subject perception of new (both long and short-handled hoes) compared to traditional land preparation method, two months after initial trials.

	Frequency of persons reporting					
	Definitely traditional	Probably traditional	Both the same	Probably new	Definitely new	Total
Safer	1 (2%)	0 (0%)	8 (17%)	14 (29%)	25 (52%)	48
Easier	2 (4%)	1 (2%)	0 (0%)	14 (29%)	31 (65%)	48
Faster	2 (4%)	0 (0%)	2 (4%)	11 (23%)	33 (69%)	48
Prefer	2 (4%)	1 (2%)	0 (0%)	12 (25%)	33 (69%)	48
Total	7 (4%)	2 (1%)	10 (5%)	51 (27%)	122 (64%)	192

Table 5
Subject perception of new long-handled compared to new short-handled hoes for land preparation, two months after initial trials.

	Frequency of persons reporting					
	Definitely short-handled	Probably short-handled	Both the same	Probably long-handled	Definitely long-handled	Total
Safer	22 (46%)	8 (17%)	5 (10%)	2 (4%)	11 (23%)	48
Easier	30 (63%)	8 (17%)	3 (6%)	1 (2%)	6 (13%)	48
Faster	34 (71%)	5 (10%)	1 (2%)	3 (6%)	5 (10%)	48
Prefer	25 (52%)	11 (23%)	3 (6%)	1 (2%)	8 (17%)	48
Total	111 (58%)	32 (17%)	12 (6%)	7 (4%)	30 (16%)	192

Table 6
Summary of themes in qualitative findings.

	Intervention hoes (vs. traditional hoes)	New long-handled hoe (vs. new short-handled hoe)
Barriers	– Increased weight of the new hoes – Lack of familiarity – Unavailability of intervention hoes	– Lack of familiarity – Long-handled considered less versatile (for weeding) – Perceived to be slower – Handle breakage
Enabling Factors	– Less discomfort when using – Increased productivity – Strength and durability – Improved safety – Novelty – Approval of men and other villagers	– Less discomfort when using – Improved safety – Quality of tillage – Novelty – Increased work efficiency

compared to the traditional hoe ($p = 0.02$) and the new long-handled hoe ($p = 0.15$), possibly due to the greater arm and hand discomfort, thus also increasing the amount of time required to till the same area of land. The improved efficiency with a long-handled hoe is consistent with other studies (Badiger et al., 2006; Nwuba and Kaul, 1986; Chatizwa, 1997). This and other studies have also demonstrated that a longer hoe handle reduces back pain as the workers can work in a more upright posture than with a short-handled hoe (Chatizwa, 1997; Ramahi and Fathallah, 2006). Improved working posture can have a significant impact on primary and particularly secondary prevention of low-back pain (Fathallah et al., 2008). In fact, the state of California (USA) banned the use of short-handled hoes (<1.2 m length) in labor-intensive agriculture in 1975 because of pain and other worker welfare issues associated with their use (CDIR, 2005).

Despite the measured benefits in this study, after two months, only a few subjects (19%) indicated their preference for the long-handled hoe over the new short-handled hoe. As described in the theory of diffusion of innovations (Rogers, 2003), those subjects are likely the innovators and early adopters in the group. We examined the available quantitative variables but found no significant differences between these innovators and early adopters compared to those who preferred the new short-handled hoe. Characteristics of these innovators could be further explored.

Despite their preference for the short-handled hoe, most subjects (94%) reported that they preferred the intervention hoes in general over their traditional hoe. The enabling factors identified for the long-handled and the intervention hoes in general were similar; both are seen to exhibit a number of benefits including improved safety, comfort, and efficiency. However, a number of barriers apparently kept many subjects from fully accepting the long-handled hoe.

Familiarity is a key factor impacting acceptance of an intervention (Rogers, 2003). Most farmers in developing countries have been using short-handled hoes in a stooped posture for land preparation for generations (FAO/IFAD, 1998), so are more comfortable and likely feel more productive when using a short-handled hoe. Further, in many developing countries, there is a negative perception of people conducting land preparation with an upright posture, including that they are "lazy" (FAO/IFAD, 1998). Therefore, despite the improved worker comfort possible with an upright working posture, increased sensitization efforts are required for farmers to change their working posture by using a long-handled hoe. It should also be noted that in addition to the difference in handle length, the long-handled hoe was also heavier than the new short-handled hoe and has a different blade design (see Table 1). The new short hoe has a different design than the traditional hoe, and was also heavier, likely explaining the increased discomfort and reduced productivity. The impact of these differences in weight and design should be further explored in future studies.

Subjects perceived that the long-handled hoe was less versatile than the short-handled hoe, which also reduced its acceptability. Subjects felt that the long-handled hoes were useful mainly in land preparation, occurring primarily in a 2-week period early in the growing season (which took place at the beginning of the study). Short-handled hoes, on the other hand, were considered more accurate and efficient in weeding (which is done year-round), and more useful in preparing hard, dry ground. Even though all questions in the study explicitly referred to land preparation, rather than weeding, subjects may have reported on their overall hoe use preferences, rather than only considering land preparation.

Many subjects perceived the new short-handled hoe to be faster than the long-handled hoe, despite the opposite results in the trials. One subject noted that a larger working area can be reached from one standing location with the long-handled hoe, reducing the need for subjects to move their body in the plot to till more ground. Therefore, subjects may feel like they are working more slowly with the long-handled hoe because they are not moving their body around as much or as fast to complete the same amount of work, compared to using a short-handled hoe.

The subjects are accustomed to lifting their short-handled hoes above horizontal before swinging downward, particularly when the soil is dry and hard. They did the same with the long-handled hoe, even though the research team demonstrated that this is not necessary to get adequate tillage and is also inefficient. This high lifting may have contributed to the soft wood handles (purchased from local market) on three long-handled hoes breaking during the initial trial (compared to one short-handled hoe breaking). Some subjects likely remembered this fact, and even though the hoes were repaired, subjects may have considered the long-handled hoes more negatively because they were afraid the handle would break. Thus, effective diffusion of new methods may require a learning period, and continued improvements in tools and methods.

Great efforts were made by the research team to achieve a truly participative and collaborative research process, which we feel enabled us to gain unbiased feedback from the participants (Fathallah et al., 2008; Faucett et al., 2007; Rogers, 2003). This is evidenced by many participants telling us they did not like the new long-handled hoe, but did like the new short-handled hoe. Use of Gambian student interviewers was particularly beneficial as the local students were perceived as independent and non-threatening.

The roles and relationships of men and women in Gambian culture were important in this study. In studies in other African countries (FAO/IFAD, 1998), disapproval by their husbands of an upright working posture when using a long-handled hoe would cause the woman to not use that hoe. In our study, men did not disapprove of the long-handled hoes, possibly because they are typically not involved in vegetable production, so would not be as concerned as in a crop typically cultivated by men. Also, the garden is in a place where few people pass by, so fewer people will see the subjects' working posture.

Studies conducted in other countries in Africa have emphasized that men are typically responsible for making tools, but that they need to be more attentive to the needs and requests of women (Egharevba and Iweze, 2004; FAO/IFAD, 1998). The same was true in our study. The government agricultural machinist (a male) that replicated the tools absolutely insisted that the tools should be made of metal heavier than in the model hoes the women picked to test, so they would be stronger and less likely to break. Because the Project Investigator (PI) had arrived in The Gambia only a few weeks before working with the machinist, she did not feel comfortable further insisting that the tools should be lighter. This could also be explained by the tool manufacturers' desire to ensure that the tool will be strong and not break, as a broken tool could give them a bad reputation.

Other studies have shown that lighter tools reduce energy consumption (Kaul and Ali, 1992; Ramana and Ananthakrishnan, 2002) and the subjects in our study re-iterated many times that they preferred the lighter-weight model tools. However, later in the follow-up period, some women did say that they had grown accustomed to the heavier replicated tools and realized their benefits.

This study identifies numerous areas for further research. Studies could be conducted on any of the following: a) differing weights of hoes; b) longer follow-up periods, including the entire land preparation season; c) larger plots for timed trials; d) more sensitization on the use of the long-handled hoe; e) optimal width, shape and curvature/angle of the metal heads for the long and short-handled hoes; f) varying lengths of handles for subjects with different statures; g) optimal handle materials (stronger wood); and h) having one of each intervention tool available to each subject.

In addition, the reasons that the new short-handled hoe was more accepted than the new long-handled hoe could be tested in future studies by using short- and long-handled hoes that are more similar in design and weight (with stronger handles), with only the handle length differing between the two types of hoes. The hoes could then be re-evaluated over a longer time period, including in-depth interviews with the subjects asking their rationale for their preferences.

The information on the barriers and enabling factors essential for long-term adoption of the interventions can be used to help identify related interventions that could be successfully implemented in other settings and in the future. This information will be disseminated to NGOs, United Nations agencies, governments, and others involved in introducing interventions in the horticulture sub-sector worldwide, as some of the information could also be applicable in migrant worker populations in developed countries. Further research on the areas listed in the previous paragraph should help improve the long-term effectiveness of such interventions to improve the lives of those working in labor-intensive agriculture worldwide.

Our study has limitations. The time of the trials in which the subjects used each hoe was shorter than desired, a concern cited by other researchers in similar studies (Nwuba and Kaul, 1986). We attempted to have longer trials (by having larger areas of land to prepare), but there was limited unprepared land available and it was difficult to convince the subjects to prepare larger areas of land, particularly as each subject conducted four trials each. Some of the subjects were not accustomed to long periods of uninterrupted work, and it would have been very difficult for them to complete four trials of longer length. We recognize that in future studies, using a longer working period would increase the reliability of the various outcome measures, but feel that the results of this study were a good indicator how the different hoes performed, using objective timing and heart rate measurements, as well as subjective worker feedback (including for injury near misses and discomfort scores).

Also, the interviewers were trained to use the heart rate monitors, but some interviewers' recorded heart rates had inconsistencies, so all heart rate data for some interviewers were removed from the dataset. Further, data from only one garden may limit the generalizability of the results. However, the participation rate for the randomly-selected subjects in the study was 100%, which improves its generalizability.

5. Conclusions

While the new long-handled hoe performed better in the timed trials and was cited as being more comfortable, most subjects preferred the new short-handled hoe. The specific reasons for this should be further explored and subjects should be sensitized on the benefits of the long-handled hoe. Also, compared to traditional land preparation methods, the long-handled hoe appears to have the potential to improve worker productivity, comfort, and safety. The intervention tools, particularly the new short-handled hoe, presented strong indicators of long-term acceptance.

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