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ORIGINAL INVESTIGATIONS

International Mobile-Health Intervention on Physical Activity, Sitting, and Weight

The Stepathlon Cardiovascular Health Study

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ABSTRACT

BACKGROUND Although proof-of-concept for mobile health (mHealth) life-style programs targeting physical inactivity and overweight/obesity has been established in randomized trials, the feasibility and effect of a globally distributed, large-scale, mass-participation mHealth implementation has not been investigated.

OBJECTIVES The purpose of this study was to determine the effect of Stepathlon, an international, low-cost, mass-participation mHealth intervention, on physical activity, sitting, and weight.

METHODS We prospectively collected cohort data from participants completing Stepathlon, an annual 100-day global event in 2012, 2013, and 2014. Participants were organized in worksite-based teams, issued pedometers, and encouraged to increase daily steps and physical activity as part of the team-based race. The program was conducted via an interactive multiplatform application available on mobile devices and the Internet. Analysis was performed according to a pre-specified plan.

RESULTS A total of 69,219 subjects participated (481 employers, 1,481 cities, 64 countries, all populated continents, age 36 $\pm$ 9 years, 23.9% female, 8.0% high-income countries, and 92.0% lower-middle income countries). After Stepathlon completion, participants recorded improved step count (+3,519 steps/day; 95% confidence interval [CI]: 3,484 to 3,553 steps/day; $p < 0.0001$), exercise days (+0.89 days; 95% CI: 0.87 to 0.92 days; $p < 0.0001$), sitting duration (−0.74 h; 95% CI: −0.78 to −0.71 h; $p < 0.0001$) and weight (−1.45 kg; 95% CI: −1.53 to −1.38 kg; $p < 0.0001$). Improvements occurred in women and men, in all geographic regions, and in both high and lower-middle income countries, and the results were reproduced in 2012, 2013, and 2014 cohorts. Predictors of weight loss included step increase, sitting duration decrease, and increase in exercise days (all $p < 0.0001$).

CONCLUSIONS Distributed mHealth implementation of a low-cost life-style intervention is associated with short-term, reproducible, large-scale improvements in physical activity, sitting, and weight. (Effect of the Stepathlon Pedometer Program on Physical Activity, Weight and Well-Being; ACTRN12615001310550) (J Am Coll Cardiol 2016;67:2453–63) © 2016 by the American College of Cardiology Foundation.

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ABBREVIATIONS AND ACRONYMS

HIC = high-income countries

LMIC = low- and middle-income countries

mHealth = mobile health

Physical inactivity, sedentary behavior, and obesity are increasingly recognized as growing contributors to the global burden of cardiovascular disease and type 2 diabetes mellitus, in addition to their association with excess mortality (1,2). The increasing global presence of internet technology, with more than 3.2 billion users (3), and in particular the dynamic growth of mobile broadband, which now has 47% penetration (3), provides a powerful new potential pathway to enable low-cost distributed implementation of life-style interventions in diverse geographic and sociocultural settings (4,5).

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A growing body of evidence in randomized settings arising from proof-of-concept-type studies has demonstrated that mobile health (mHealth)-based life-style programs and workplace-pedometer programs may be a useful strategy to achieve modest but statistically significant improvements in physical activity, sitting, and weight (6–11). To date, such studies of mHealth and workplace life-style interventions have predominantly been conducted at a limited scale in relatively targeted populations (4,6,7), with nearly all analyses focused toward single high-income countries (4,6,12).

At the current time, however, it remains unclear whether improvements in physical activity and weight with mHealth interventions seen in randomized trials will be translated when conducted as large-scale, mass-participation programs, using "real-world" participants. The potential power of mHealth technology, however, lies in its capacity for inexpensive geographically distributed implementation. It is unclear whether mHealth technology utilization for life-style change will be feasible or efficacious when conducted internationally, including large numbers of participants from both high-income countries (HIC) and low- and middle-income countries (LMIC) (5). mHealth-based distribution of preventive health life-style strategies may be especially advantageous in LMIC settings, in the context of the rising burden of cardiovascular disease morbidity in these nations (13).

To address the global population-level burden of physical inactivity, there is a clear need to develop mass-participation interventional programs with the capacity for geographically distributed implementation. To achieve such large-scale international mass participation, it may be important that such programs utilize appropriate and accessible technologies, are attractive to consumers, and are of sufficiently low cost to enable self-financed growth.

In the current study, we sought to investigate the feasibility and efficacy of Stepathlon, a low-cost, pedometer-based, workplace physical activity and wellness program, which utilized an mHealth technology-based approach to facilitate large-scale implementation and program delivery. The program was conducted annually as a 100-day event in the years 2012 to 2014. Light-weight, low-cost, noninteractive pedometers were used as a self-monitoring and motivational tool (14), with the aim of encouraging participants to increase step counts and physical activity. Our study's objective was to determine the effect of Stepathlon participation on step counts, sitting duration, and weight.

METHODS

The study was conducted as an academic-private partnership between researchers at both Flinders University and University of Adelaide and Stepathlon Private Limited, a start-up company located in Mumbai, India. The Human Research Ethics Committee of the University of Adelaide reviewed and approved the research protocol with a low-risk waiver. Data were provided on an unrestricted basis by Stepathlon for the purposes of scientific research and were analyzed according to a pre-specified statistical analysis plan. The project was registered in the Australian and New Zealand Clinical Trials Registry (ACTRN12615001310550).

STEPATHLON PROGRAM. The Stepathlon is a 100-day international event where employees participate in a workplace-based pedometer program. The Stepathlon was conducted annually, with employee participants organized into teams of 5 individuals to provide a supportive social environment to facilitate activity. Participants were issued low-cost, light-weight pedometers to monitor daily step counts. Pedometers used in Stepathlon used 3-dimensional piezoelectric accelerometer technology to increase accuracy of step

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count recordings. The pedometers were noninteractive and did not have the capacity to communicate electronically with mobile devices or the internet. Participants were encouraged to increase incidental activity such as using stairs and avoidance of sitting. For participants who undertook other physical activity (e.g., swimming, cycling), walking step equivalents were computed from the American College of Sports Medicine Compendium of Exercises (15).

Participants were encouraged to enter daily activity into the Stepathlon web site. Interaction with the web site was conducted via a downloadable mobile device application, available on multiple platforms, or available via the internet for users without mobile broadband access. The web site was constructed to facilitate motivation and engagement of participants. The site featured personalized tools for self-monitoring, including personalized logs of exercise, physical activity, and dietary intake. Encouragement e-mails were sent daily to all participants, which included messages about physical activity and nutrition. Supplementary communications with participants were structured in a way that encouraged engagement. For example, e-mail messages were sent to participants at individual milestones, but were also triggered by team milestones. The messaging was also designed to be entertaining. For example, simple quizzes and competitions were used as a way to encourage interaction with the online interface. The web site included updated content with papers on nutrition and life-style, and featured a social network through an online community of participants, with users posting comments on participation. Interactive advice and expert guidance on life-style and physical activity was available through an online chat facility. The overall 100-day step count challenge was conducted as a race between teams of 5 participants to maximize social leveraging toward physical activity. In the race, cumulative team steps were converted to distances in kilometers, as part of a team-based race around a virtual world map. Competition occurred both between teams within the same employer and with teams outside the same employer. A leaderboard was visible in the user interface to enable participants to see team data from the top teams, but individual participant data was not shown publicly on the user interface. A series of screenshots is provided in Online Appendix 1 to show examples of the online user interface.

PROGRAM PARTICIPANTS AND DATA COLLECTION. Stepathlon program participants included adult employees of private and public sector organizations located in Asia, Europe, Africa, North America, South America, Australia, and New Zealand. Costs for employee participation were borne by the employers, with the cost of participation modest (approximately $50 per participant in India, and $60 outside of India). The data for the current study were prospectively collected via web-based physical activity and life-style survey questionnaires completed by participants before and after the 100-day Stepathlon event. Items on the questionnaire related to basic demographic information (e.g., age, sex, city, and country), as well as personal activity and life-style information. Participants were mailed pedometers and login details for the Stepathlon mobile device application/web site approximately 1 to 2 weeks prior to event commencement. The web site for baseline data collection opened in the 1 week prior to the event commencement. Baseline data collection was compulsory for entry into the Stepathlon event. Completion surveys were completed approximately 1 to 2 weeks following completion of the Stepathlon event.

STATISTICAL ANALYSIS. The pre-specified endpoints of the current study were the effect of Stepathlon on physical activity, as measured by step count change and sitting duration change, and weight in kilograms, assessed with linear regression models. Models were fitted to estimate the difference between pre- and post-intervention characteristics. For all outcomes, linear regression models were fitted with a generalized estimating equation to account for repeated measures and including interaction terms to investigate the potential effect modification by sex, age, year cohort, geographic region, and income group. If an interaction term was nonsignificant, it was dropped from the model and the main effects estimated; otherwise, separate estimates of effect of time by level of the effect modifier were obtained. Because step count is an ordinal variable (with categories consisting of 2,500-step increments, starting from <5,000 steps), it was also modelled using ordinal logistic regression as an additional sensitivity analysis; similarly, exercising days is a count variable (number of days/week) and was also modelled using log Poisson regression. Because the conclusions from these models were similar to those from the linear regression models, the latter are presented for reasons of interpretability. The relationship between weight change and other outcomes (change in step count, sitting duration, and exercise days) was explored using univariate linear regression. Statistical analysis was performed in Stata version 13 (StataCorp LP, College Station, Texas). Significance was set at 2-tailed alpha <0.05.

TABLE 1 Baseline Characteristics of Study Participants

	Noncompleting Stepathlon Participants (n = 32,657)	Completing Stepathlon Participants (n = 36,562)	Overall (n = 69,219)
Age, yrs	33.0 ± 7.9	36.9 ± 8.7	36.0 ± 8.4
Sex			
Male	24,153 (74.7)	28,320 (77.5)	52,473 (76.2)
Female	8,193 (25.3)	8,237 (22.5)	16,430 (23.9)
Weight pre-Stepathlon, kg	74.0 ± 13.6	73.5 ± 13.1	73.6 ± 13.3
Male	77.3 ± 12.3	76.0 ± 11.9	76.6 ± 12.1
Female	64.1 ± 12.6	64.6 ± 12.9	64.4 ± 12.8
Region			
East Asia and Pacific	2,171 (6.7)	3,043 (8.3)	5,214 (7.6)
Europe and Central Asia	81 (0.25)	146 (0.4)	227 (0.3)
Latin America and Caribbean	13 (0.04)	9 (0.02)	22 (0.03)
Middle East and North Africa	101 (0.3)	47 (0.1)	148 (0.2)
North America	111 (0.3)	124 (0.3)	235 (0.3)
South Asia	29,738 (91.1)	32,771 (89.6)	62,509 (91.4)
Sub-Saharan Africa	5 (0.02)	1 (0.00)	6 (0.01)
Other	437 (1.34)	421 (1.15)	858 (1.24)
Country			
India	29,699 (90.94)	32,715 (89.48)	62,414 (90.17)
Australia	1,354 (4.15)	2,105 (5.76)	3,459 (5)
New Zealand	341 (1.04)	448 (1.23)	789 (1.14)
Singapore	238 (0.73)	201 (0.55)	439 (0.63)
United States	105 (0.32)	122 (0.33)	227 (0.33)
China	96 (0.29)	87 (0.24)	183 (0.26)
Philippines	59 (0.18)	59 (0.16)	118 (0.17)
United Arab Emirates	83 (0.25)	35 (0.1)	118 (0.17)
United Kingdom	37 (0.11)	65 (0.18)	102 (0.15)
Taiwan	29 (0.09)	46 (0.13)	75 (0.11)
Hong Kong	17 (0.05)	53 (0.14)	70 (0.1)
Poland	20 (0.06)	41 (0.11)	61 (0.09)
Other	579 (1.77)	585 (1.6)	1164 (1.68)
World Bank			
High income: OECD	1,887 (5.8)	2,480 (7.8)	4,727 (6.9)
High income: non-OECD	384 (1.2)	345 (0.9)	729 (1.1)
Upper middle income	135 (0.4)	121 (0.3)	256 (0.4)
Lower middle income	29,811 (91.3)	32,833 (89.8)	62,644 (91.6)
Low income	3 (0.01)	2 (0.01)	5 (0.01)
Other	437 (1.34)	421 (1.15)	858 (1.24)

Values are mean ± SD or n (%). Baseline demographic characteristics of Stepathlon participants are shown. The distribution of Stepathlon participants is shown by sex, geographic region, and World Bank income category. Comparison is shown between Stepathlon participants who completed pre- and post-event data collection (completing Stepathlon participants) and those for whom only pre-event data collection occurred (noncompleting participants).

OECD = Organisation for Economic Co-operation and Development.

RESULTS

Over the 3 years from 2012 to 2014, 69,219 participants completed the pre-event questionnaire, and of these, 36,652 completed the post-event questionnaire (53.0% response rate). A comparison of baseline demographic and physical activity characteristics of completing and noncompleting participants is shown in **Tables 1 and 2**. Participants were recruited from 64 countries, from 481 employers, in 1,481 cities, on all continents. The largest participant countries were India (62,414 participants, 90.2%), Australia (3,459 participants, 5.0%, New Zealand (789 participants, 1.1%), and Singapore (439 participants, 0.6%) (**Table 1**). The distribution of participants by World Bank geographic region and income level is also shown (**Table 1**) (16).

EFFECT OF STEPATHLON PARTICIPATION ON STEP COUNT. The distribution of participants by step count category before and after Stepathlon completion is shown in the **Central Illustration** and **Table 3**. Overall, the step count was found to increase by +3,519 steps/day (95% confidence interval [CI]: 3,484 to 3,553 steps/day; $p < 0.0001$) (**Central Illustration**, **Figure 1A**, **Table 3**), when modeled as a continuous variable. Similar increases were found in women (+3,159 steps/day, 95% CI: 3,086 to 3,232 steps/day; $p < 0.0001$), men (+3,398 steps/day, 95% CI: 3,356 to 3440 steps/day; $p < 0.0001$), each of the year cohorts (all $p < 0.0001$) (**Figure 1A**). To confirm this conclusion, step count was modeled as a categorical variable with an ordinal logistic regression (Online Appendix 2A).

EFFECT OF STEPATHLON ON EXERCISE DAYS AND EXERCISE DURATION. Overall, there was an improvement of +0.89 exercise days/week after Stepathlon (95% CI: +0.87 to +0.92 days; $p < 0.0001$) (**Figure 1B**). Improvements in exercise days/week were seen in both women and men and in all years (**Figure 1B**, **Table 3**). Exercise duration was reported on a 2-point ordinal scale with categories of <30 or ≥30 min/day. Stepathlon completion was associated with an improvement in the odds of exercising ≥30 min/day of 1.65 (95% CI: 1.61 to 1.68; $p < 0.0001$) (Online Appendix 2B).

EFFECT OF STEPATHLON PARTICIPATION ON SITTING DURATION. Overall, there was a decrease in sitting hours post-Stepathlon participation of −0.74 h (95% CI: −0.78 to −0.71 h; $p < 0.001$) (**Central Illustration**, **Figure 1C**, **Table 3**). Similar reductions in sitting duration were seen in women, men, and each of the year cohorts (all $p < 0.0001$) (**Figure 1C**). Statistically significant reductions in sitting duration were seen in all geographic regions and across all income levels (**Figure 1C** and Online Appendix 2C).

EFFECT OF STEPATHLON PARTICIPATION ON WEIGHT. Overall, there was a reduction in weight post-Stepathlon participation of −1.45 kg (95% CI: −1.53 to −1.38 kg; $p < 0.0001$) (**Central Illustration**, **Figure 1D**). Significant reductions in weight were seen in women (−0.74 kg; 95% CI: −0.91 to −0.57 kg; $p < 0.0001$), men (−1.63 kg; 95% CI: −1.72 to −1.53 kg;

$p < 0.0001$), and in each of the year cohorts (all $p < 0.001$) (**Figure 1D** and Online Appendix 2D). Weight reduction was seen in the South Asian, East Asian, North American (all $p < 0.0001$), Middle East ($p = 0.0003$), and European regions ($p = 0.00085$) (**Figure 1D**). Weight reduction was seen in lower middle income, upper middle income, and high income Organisation for Economic Co-operation and Development and non-Organisation for Economic Co-operation and Development countries (**Figure 1D**).

PREDICTORS OF WEIGHT CHANGE. Step count increase was associated with improvement in weight (+1 category of step count increase was associated with a weight decrease of −0.23 kg (95% CI: −0.12 to −0.26 kg; $p < 0.0001$) (Online Appendix 3). Sitting duration decrease was associated with improvement in weight (a 1-h decrease in sitting duration was associated with a modest 0.08-kg decrease in weight (95% CI: −0.099 to −0.066 kg; $p < 0.0001$) (Online Appendix 3). Increased exercise days was associated with improvement in weight (Each +1 increase in days exercised was associated with a 0.15-kg decrease in weight (95% CI: −0.17 to −0.13 kg; $p < 0.0001$) (Online Appendix 3).

TABLE 2 Baseline Physical Activity Characteristics of Study Participants

	Noncompleting Stepathlon Participants (n = 32,657)	Completing Stepathlon Participants (n = 36,562)	Overall (n = 69,219)
Steps/day			
0–4,999	12,528 (38.4)	10,885 (29.8)	23,413 (33.8)
5,000–7,499	9,244 (28.3)	9,791 (26.8)	19,035 (27.5)
7,500–9,999	5,641 (17.3)	6,783 (18.5)	12,424 (18.0)
10,000–12,500	3,402 (10.4)	5,475 (15.0)	8,877 (12.8)
>12,500	1,842 (5.6)	3,628 (9.9)	5,470 (7.9)
Exercising, days/week			
0	1,801 (5.5)	2,613 (7.2)	4,414 (6.4)
1	7,984 (24.5)	6,305 (17.2)	14,289 (20.6)
2	5,453 (16.7)	5,375 (14.7)	10,828 (15.6)
3	5,506 (16.9)	5,812 (15.9)	11,318 (16.4)
4	3,632 (11.1)	4,141 (11.3)	7,773 (11.2)
5	4,003 (12.3)	5,321 (14.6)	9,324 (13.5)
6	2,283 (7.0)	3,583 (9.8)	5,866 (8.5)
7	1,995 (6.1)	3,412 (9.3)	5,407 (7.8)
Sitting, h/day			
0–4	6,239 (19.1)	7,654 (20.9)	13,893 (20.1)
5–8	16,979 (52.0)	19,553 (53.5)	36,532 (52.8)
9–12	8,261 (25.3)	8,540 (23.4)	16,801 (24.3)
13–16	1,102 (3.4)	775 (2.1)	1,877 (2.7)
17–20	65 (0.2)	38 (0.1)	103 (0.2)
20–24	11 (0.03)	2 (0.01)	13 (0.02)

Values are n (%). Baseline physical activity characteristics for Stepathlon participants are shown. Information is shown for step count/day, exercising days/week, and sitting duration in h/day. Comparison is shown between Stepathlon participants who completed pre- and post-event data collection (completing Stepathlon participants) and those for whom only pre-event data collection occurred (noncompleting participants).

DISCUSSION

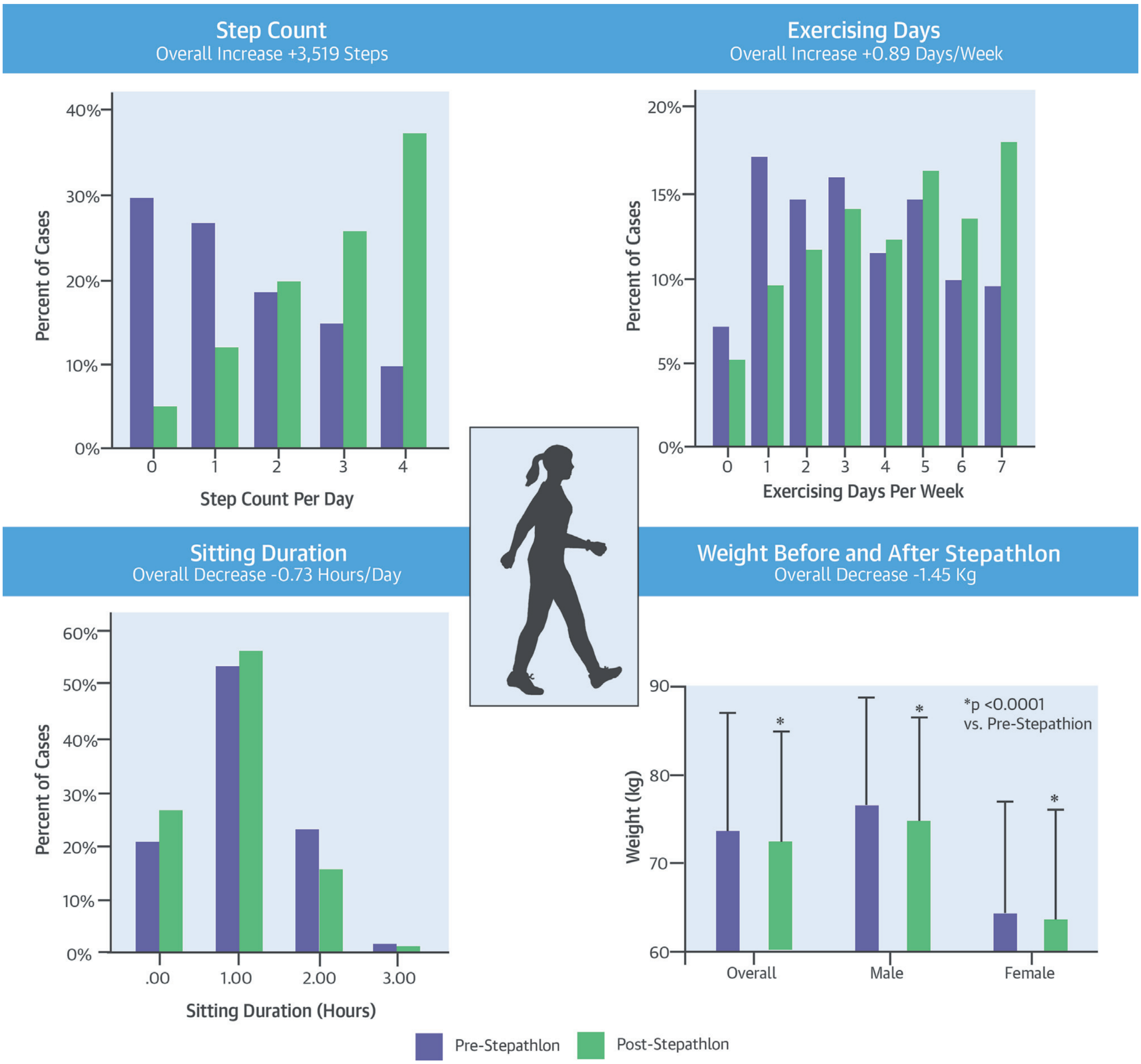
The current study demonstrates the feasibility of implantation and delivery of a low-cost, global, mass participation, workplace-based pedometer and wellness program, delivered electronically to an internationally distributed “real-world” participant base. The efficacy of the program is demonstrated by modest, year-by-year reproducible, statistically significant improvements in short-term measures of physical activity, sitting, and weight, seen in women and men in a variety of geographic and economic settings from both HIC and LMIC. The study demonstrates the capacity of endogenous innovation in LMIC to develop low-cost, internationally applicable mHealth programs. Finally, it demonstrates that the modest benefits in physical activity and weight change seen randomized settings may be translatable to an international setting.

To date, evaluations of workplace-based pedometer mHealth programs have predominantly been conducted in HIC, with few large-scale outcome data available from LMIC settings (6,11,17,18). The enormous global-scale crisis of physical inactivity, sedentary behavior, and excess weight suggests a need for mass-participation life-style interventions implementable in both HIC and LMIC. It is important, therefore, that mHealth life-style interventions are not only perceived as attractive and effective to participants around the world, but also delivered at sufficiently low cost to enable sustainable demand-driven growth in both the developed and developing world.

The advent of the internet age, and in particular the broad global penetration of mobile device technology (3), offers a new potential paradigm by enabling global large-scale distribution and implementation of low-cost, self-financing life-style programs. To date, the majority of studies evaluating mHealth life-style interventions have been conducted at a relatively small scale compared with the current study, typically in small numbers of sites, most often in single countries (4,6,7,9,11,19,20). Indeed, the total number of subjects in Stepathlon significantly exceeded total participant counts in previous meta-analyses of workplace (10,11,12) and mHealth interventions (7,9). To our knowledge, no studies have evaluated the feasibility and efficacy of any comparable low-cost, workplace-based distributed mHealth intervention implemented at this scale.

The Stepathlon was designed as a workplace exercise and wellness program with the objective of distributed delivery in workplaces distributed across

CENTRAL ILLUSTRATION Effect of an International Mobile Health Intervention on Physical Activity, Sitting, and Weight: Results of Stepathlon



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Histograms showing improvement in in distribution of step count, exercise days, and sitting duration before and after Stepathlon completion in participants who completed Stepathlon. Change in weight (kg) overall, in women and men. Weight is shown as ± standard deviation.

multiple countries. The workplace has long been recognized as an important location for health promotion and the implementation of activity and wellness programs. The current program utilized a number of elements derived from previous studies of mHealth and workplace life-style interventions, to simplify implementation and increase accessibility. These included a centralized web site (11) and the use of low-cost, noninteractive pedometer technology as a self-monitoring tool (12). Teams were used to facilitate social leveraging and camaraderie as a means to reinforce messages regarding physical

TABLE 3 Pre- and Post-Stepathlon Physical Activity and Weight Characteristics

	2012		2013		2014		All	
	Pre (n = 7,210)	Post (n = 7,210)	Pre (n = 8,861)	Post (n = 8,861)	Pre (n = 20,491)	Post (n = 20,491)	Pre (n = 36,562)	Post (n = 36,562)
Steps/day								
0–4,999	1,616 (22.4)	267 (3.7)	1,907 (21.5)	368 (4.2)	7,362 (35.9)	1,212 (5.9)	10,885 (29.7)	1,847 (5.1)
5,000–7,499	2,070 (28.7)	714 (9.9)	2,397 (27.1)	1,006 (11.4)	5,324 (26.0)	2,730 (13.3)	9,791 (26.8)	4,450 (12.2)
7,500–9,999	1,573 (21.8)	1,399 (19.4)	1,782 (20.1)	1,724 (19.5)	3,428 (16.7)	4,108 (20.1)	6,783 (18.6)	7,231 (19.8)
10,000–12,500	1,166 (16.2)	1,829 (25.4)	1,683 (19.0)	2,406 (27.2)	2,626 (12.8)	5,153 (25.2)	5,475 (15.0)	9,388 (25.7)
>12,500	785 (10.9)	3,001 (41.6)	1,092 (12.3)	3,357 (37.9)	1,751 (8.6)	7,288 (35.6)	3,628 (9.9)	13,646 (37.3)
Exercising, days/week								
0	935 (13.0)	482 (6.7)	1,678 (18.9)	1,407 (15.9)	0 (0.0)	0 (0.0)	2,613 (7.2)	1,889 (5.2)
1	695 (9.6)	380 (5.3)	590 (6.7)	520 5.9)	5,020 (24.5)	2,573 (12.6)	6,305 (17.2)	3,473 (9.5)
2	1,111 (15.4)	759 (10.5)	1,228 (13.9)	1,152 (13.0)	3,036 (14.8)	2,358 (11.5)	5,375 (14.7)	4,269 (11.7)
3	1,241 (17.2)	1,159 (16.1)	1,410 (15.9)	1,311 (14.8)	3,161 (15.4)	2,682 (13.1)	5,812 (15.9)	5,152 (14.1)
4	889 (12.3)	1,051 (14.6)	1,013 (11.4)	967 (10.9)	2,239 (10.9)	2,357 (11.5)	4,141 (11.3)	4,375 (12.0)
5	1,164 (16.1)	1,370 (19.0)	1,248 (14.1)	1,289 (14.6)	2,909 (14.2)	3,303 (16.1)	5,321 (14.6)	5,962 (16.3)
6	711 (9.9)	1,031 (14.3)	817 (9.2)	993 (11.2)	2,055 (10.0)	2,899 (14.2)	3,583 (9.8)	4,923 (13.5)
7	464 (6.4)	978 (13.6)	877 (9.9)	1,222 (13.8)	2,071 (10.1)	4,319 (21.1)	3,412 (9.3)	6,519 (17.8)
Sitting, h/day								
0–4	1,546 (21.4)	1,956 (27.1)	1,809 (20.4)	2,141 (24.2)	4,299 (21.0)	5,656 (27.6)	7,654 (20.9)	9,753 (26.7)
5–8	3,869 (53.7)	3,982 (55.2)	4,737 (53.5)	4,946 (55.8)	10,947 (53.4)	11,585 (56.5)	19,553 (53.5)	20,513 (56.1)
9–12	1,587 (22.0)	1,129 (15.7)	2,091 (23.6)	1,645 (18.6)	4,862 (23.7)	3,033 (14.8)	8,540 (23.4)	5,807 (15.9)
13–16	188 (2.6)	107 (1.5)	204 (2.3)	109 (1.2)	383 (1.9)	217 (1.1)	775 (2.1)	433 (1.2)
17–20	18 (0.3)	14 (0.2)	20 (0.2)	20 (0.2)	0 (0.0)	0 (0.0)	38 (0.1)	34 (0.1)
20–24	2 (0.03)	22 (0.3)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (0.01)	22 (0.1)
Weight, kg	73.4 ± 12.6	72.1 ± 12.1	73.7 ± 13.1	72.8 ± 12.5	73.4 ± 13.2	72.4 ± 12.7	73.5 ± 13.1	72.4 ± 12.5
Male	75.9 ± 11.5	74.5 ± 11.1	75.9 ± 12.1	75.0 ± 11.6	76.1 ± 12.0	75.0 ± 11.4	76.0 ± 11.9	74.9 ± 11.4
Female	62.8 ± 11.2	61.6 ± 10.7	65.4 ± 13.2	64.5 ± 12.5	64.8 ± 13.2	64.1 ± 12.8	64.6 ± 12.9	63.8 ± 12.4

Values are n (%) or mean ± SD. Paired pre- and post- Stepathlon physical activity for Stepathlon participants is shown in participants who completed both pre- and post-event data collection. Information is shown for step count/day, exercising days/week, sitting duration in h/day, and weight. Comparison is made between pre- and post-event in each year of the study.

activity (21,22). Importantly, the cost of the program delivery to consumers was low, facilitating distributed implementation and demand-driven program growth in both HIC and LMIC.

The Stepathlon program demonstrated overall improvements in physical activity, sitting duration, and weight of modest magnitude, which were consistent with those seen in previous meta-analyses of workplace (11,12) and mHealth interventions (7,9). Significantly, these effects were shown to be reproducible in the annualized cohorts studied in 2012, 2013, and 2014.

The mechanism of physical activity and weight changes seen in Stepathlon is unclear. However, it seems most likely to be multifactorial, with improvements occurring due to a combination of the effects of pedometers as a self-monitoring tool, social leveraging by the use of teams in a workplace environment, and the use of mHealth technology to provide a tool to engage participants with information and encourage behavioral change. The critical technological aspects of the interface to optimize engagement and improve outcomes remain an area for future investigation.

A specific consideration is the mechanism responsible for reductions in weight seen with Stepathlon. The relative contribution of increased physical activity and reduced dietary caloric intake in weight loss interventions remains incompletely understood (23–25). The Stepathlon intervention, although primarily a physical activity intervention, did include messaging about nutrition and diet in the user content. In Stepathlon, a modest relationship was seen at the population level between increased physical activity measures of steps/exercise days and sitting with reduced weight, but insufficient information was available to formally assess the relative impact of dietary change; however, the changes in weight seem most likely to have occurred due to a combination of physical activity and dietary modification.

RATES OF ATTRITION. Although attrition rates were significant in Stepathlon, they are in line with comparable life-style interventions (26–28). The level of attrition seen in Stepathlon should be interpreted in the context of large numbers of "real-world" participants who did, in fact, complete the program,

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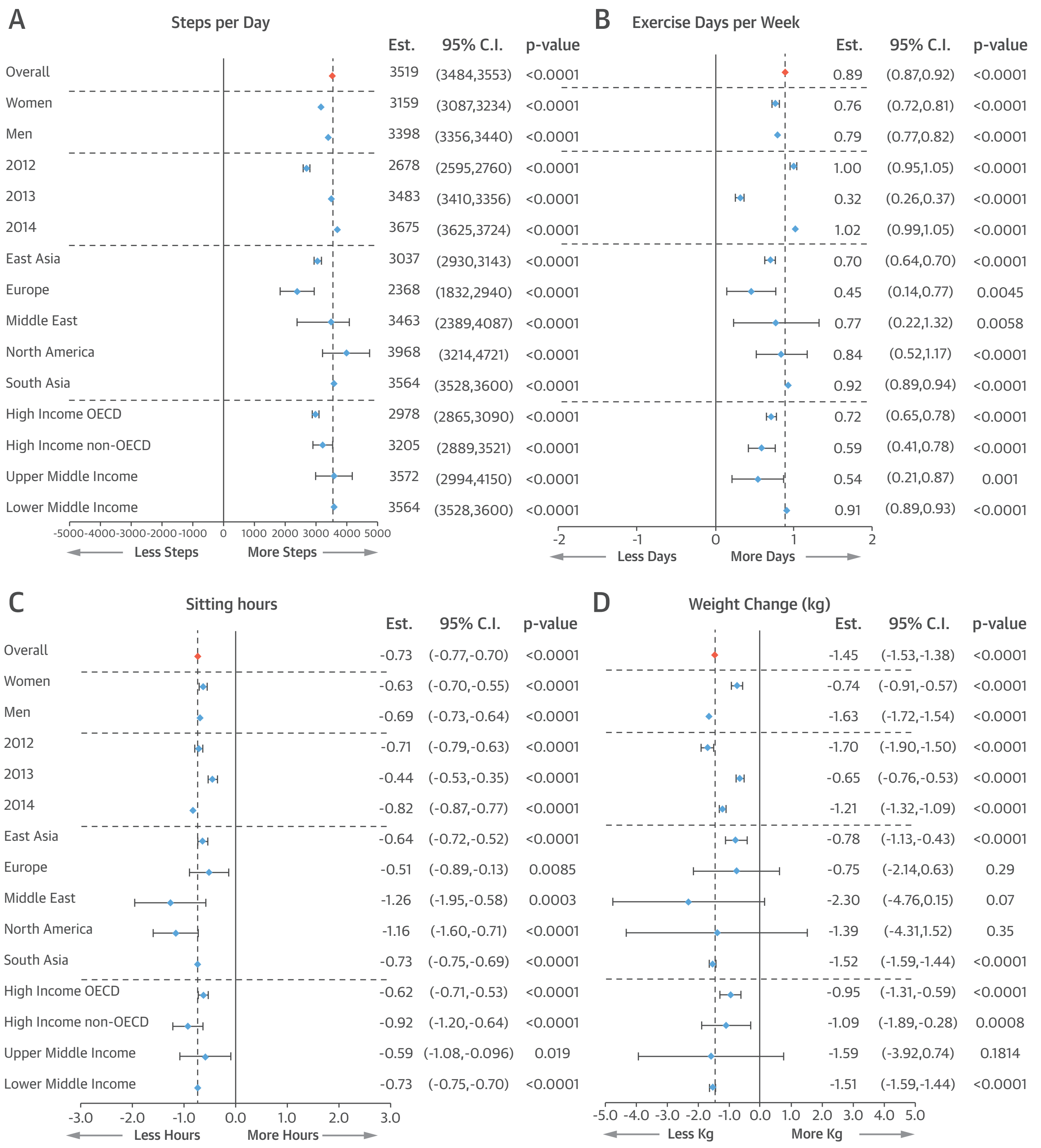
FIGURE 1 Forest Plots Showing Change in Step Counts per Day, Exercising Days, Sitting Duration, and Weight



Model estimates and 95% CI are shown, along with interaction p values. **(A)** For step count, the overall increase was +3,519 steps (95% confidence interval [CI]: 3,483 to 3,553 steps; $p < 0.0001$). **(B)** For exercise days, overall increase was +0.89 days/week (95% CI: 0.87 to 0.92 days/week; $p < 0.0001$). **(C)** For sitting duration, overall decrease was −0.73 h/day (95% CI: −0.77 to −0.70 h/day; $p < 0.0001$). **(D)** For weight, overall decrease was −1.45 kg (95% CI: −1.53 to −1.38 kg; $p < 0.0001$). OECD = Organisation for Economic Co-operation and Development.

demonstrating the capacity of the program to lead to improvements in large numbers of participants. The levels of attrition seen in the Stepathlon program are, to some extent, not entirely unexpected, and perhaps represent an important opportunity for future mHealth innovation to achieve improved participant engagement and program adherence via utilization of contemporary advances in "big data" and web analytics (29). Importantly, the data demonstrate the feasibility of mHealth technology to achieve scalable large-scale implementation across diverse geographic and sociocultural settings, with growth sustained by consumer demand.

IMPLICATIONS FOR mHEALTH. The current study has a number of important implications for the development and study of mHealth-facilitated life-style programs. The study provides confirmation in a large and highly heterogeneous participant population of previous data supporting the use of mHealth to facilitate improvements in physical activity and weight. The modest but replicable effects on physical activity and weight, if sustained, could be anticipated to lead to large-scale improvements in absolute cardiovascular disease risk (30). Future investigations will be required to determine the long-term effect of the program.

The study approach, conducted as an academic-private sector collaboration, is in line with the recommendation of the American Health Association's scientific statement on mHealth (6), which has called for more rigorous research to provide an improved evidence base in the mHealth sector. The current study contributes to the growing body of knowledge in the field of mHealth by providing an external scientific analysis of a large-scale multinational intervention. This type of study is needed to complement the growing body of mHealth data arising from interventions led or developed by health professionals in academic or clinical settings (6). An important feature of the current study is the demonstration of the capacity for mHealth to provide an opportunity for low-cost development and innovation to occur in private-sector LMIC settings.

IMPLICATIONS FOR PUBLIC HEALTH. The study may have important implications for public health. In recent years, there has been growing recognition of the importance of physical inactivity, sitting, and excess weight as key drivers of worldwide morbidity and mortality by their association with diabetes and cardiovascular disease (1,2). Reversal of this trend will require development of new forms of physical activity intervention designed to influence the behavior of large numbers of individuals toward movement and away from sedentary life-styles. In practice, reaching large numbers of participants with supervised forms of exercise therapy involves significant challenges, such as the time required per patient and high cost (31). This study demonstrates that utilization of mHealth on a large scale is a potential way to inexpensively communicate messages about behavior change that could be effective in both HIC and LMIC settings.

Of specific concern is the effect of Stepathlon on short- and long-term cardiovascular disease risk. In Stepathlon, without direct measurement of clinical markers of risk such as blood pressure or cholesterol, we were unable to directly estimate the effect of behavioral change in physical activity and diet on long-term CVD risk profile. Future investigations will be needed, perhaps using recently developed life-style-based risk assessment models (30), to provide an estimate of CVD events prevented by changing life-style parameters.

This study also may have specific implications for cardiovascular and diabetes prevention in South Asia in particular. Urbanization and changing life-styles with economic development are likely to be contributing to reductions in physical activity patterns in South Asian populations (32), a trend likely to be contributing to the increasing incidence of diabetes and cardiovascular disease (13,33). Large-scale technology-based physical activity interventions may be particularly important in overcoming this trend, because of the large and geographically dispersed populations in this region.

STUDY LIMITATIONS. The large-scale, low-cost, geographically distributed implementation of the Stepathlon program constrained some aspects of the study design, in comparison with investigations performed in more conventional clinical or academic settings. The distributed participant base meant that the study could only be feasibly conducted as a pre- and post-event comparison, without randomization or a comparator control group. An important limitation of the current study was that it was conducted with a relatively short-term follow-up. Long-term follow-up studies of comparable interventions, however, have demonstrated modest sustained improvements in life-style parameters and cardiovascular disease risk factors (34,35). Future studies involving follow-up of participants over multiple years or with additional longer-term follow-up are needed to assess whether the short-term behavior changes seen with Stepathlon are maintained over time. The cost associated with the program introduces the possibility of selection bias associated with recruitment and participation. The reliance on self-report introduces the possibility of recall and social desirability bias. The international, low-cost, mass-participation aspect of the study precluded the use of individual supervision by a health professional, which has been shown to improve adherence. Nonetheless, despite these potential limitations, the study demonstrated the feasibility and efficacy of an international mHealth intervention by leading to modest but reproducible gains in physical activity measures and weight, occurring in diverse economic and cultural settings and in a very large number of participants.

CONCLUSIONS

These data demonstrate that utilization of mHealth-based approaches may facilitate low-cost and large-scale global implementation of a workplace physical activity intervention, leading to modest but reproducible short-term population-level improvements in step counts, exercise duration, sitting, and weight.

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PERSPECTIVES

COMPETENCY IN PATIENT CARE: Light weight, low-cost, noninteractive pedometers can promote modest improvements in physical activity, sitting, and weight among private and public sector employees in diverse socioeconomic and health systems around the world.

TRANSLATIONAL OUTLOOK: Further studies are needed to evaluate the long-term effect of mHealth interventions on cardiovascular risk and outcomes.

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APPENDIX For supplemental methods, please see the online version of this article.