Move more

Mamede, André; Noordzij, Gera; Jongerling, Joran; Snijders, Merlijn; Schop-Etman, Astrid; Denktas, Semiha

DOI:
10.2196/preprints.19875

Publication date:
2020

Document Version
Early version, also known as pre-print

Move More: Combining gamification and physical nudges to promote walking breaks and reduce sedentary behaviour of office workers. A randomized controlled trial.

André Mamede Soares Braga, Gera Noordzij, Joran Jongerling, Merlijn Snijders, Astrid Schop-Etman, Semiha Denktas

Submitted to: Journal of Medical Internet Research
on: May 27, 2020

Table of Contents

Move More: Combining gamification and physical nudges to promote walking breaks and reduce sedentary behaviour of office workers. A randomized controlled trial.

André Mamede Soares Braga[1]; Gera Noordzij[1] BSc, MSc, PhD; Joran Jongerling[1] BSc, MSc, PhD; Merlijn Snijders[2] BSc, MSc; Astrid Schop-Etman[1] BSc, MSc, PhD; Semiha Denktas[1] BSc, MSc, PhD

[1]Erasmus University Rotterdam Campus Woudenstein, Burgemeester Oudlaan 50 3062 PA Rotterdam NL
[2]Municipality of Rotterdam Rotterdam NL

Corresponding Author:
André Mamede Soares Braga
Erasmus University Rotterdam
Campus Woudenstein, Burgemeester Oudlaan 50
3062 PA
Rotterdam
NL

Abstract

Background: Sedentary behaviour (SB) and lack of physical activity (PA) have been associated with poorer health outcomes and are increasingly prevalent in individuals working in sedentary occupations, such as office jobs. Gamification and nudges have attracted attention as promising strategies to promote health behaviour change. However, most studies of effectiveness so far lacked active controls, and few studies have tested interventions combining these two strategies.

Objective: This study investigated the effectiveness of an intervention combining a gamified digital intervention with physical nudges to increase PA and reduce SB in Dutch office workers.

Methods: Employees of the municipality of Rotterdam (N = 298) from two office locations were randomized at the location-level to either a 10-week intervention, combining a five-week gamification phase encompassing a gamified digital intervention with social support features and a five-week physical nudges phase, or to an active control (i.e. limited digital application with self-monitoring and goal-setting). The primary outcome was daily step count objectively measured via accelerometers. Secondary outcomes were self-reported PA and SB. Mixed-effects models were used to analyse the effects of the intervention on the primary and secondary outcome measures of participants up to one month after the intervention.

Results: A total of 234 participants completed the study and provided accelerometer data. During the gamification phase, participants in the intervention condition significantly increased their number of daily steps (from 10138 to 10901; 763.5 increase) compared to those in the active control (from 10403 to 10619; 215.6 increase) (p = 0.01). These improvements were not sustained during the physical nudges phase (p = 0.76) or follow-up (p = 0.88).

Conclusions: A digital intervention with gamification and social support features significantly increased the step count of office workers, compared to an active control encompassing self-monitoring and goal-setting. Physical nudges in the workplace were insufficient to promote maintanence of behaviour change achieved in the gamification phase. Future research should explore how to improve the long-term effectiveness of gamified digital interventions.

(JMIR Preprints 27/05/2020:19875)
DOI: https://doi.org/10.2196/preprints.19875

Preprint Settings

1) Would you like to publish your submitted manuscript as preprint?
✔ **Please make my preprint PDF available to anyone at any time (recommended).**
Please make my preprint PDF available only to logged-in users; I understand that my title and abstract will remain visible to all users.
Only make the preprint title and abstract visible.
No, I do not wish to publish my submitted manuscript as a preprint.

2) If accepted for publication in a JMIR journal, would you like the PDF to be visible to the public?

✓ **Yes, please make my accepted manuscript PDF available to anyone at any time (Recommended).**

Yes, but please make my accepted manuscript PDF available only to logged-in users; I understand that the title and abstract will remain v

Yes, but only make the title and abstract visible (see Important note, above). I understand that if I later pay to participate in <a href="http

Original Manuscript

Move More: Combining gamification and physical nudges to promote walking breaks and reduce sedentary behaviour of office workers. A randomized controlled trial.

Authors: André Mamede S. Braga[1]; Gera Noordzij[1,2]; Joran Jongerling[1]; Merlijn Snijders[3]; Astrid Schop-Etman[1]; Semiha Denktas[1]

Correspondence: mamedesoaresbraga@essb.eur.nl

1. Department of Psychology, Education and Child Developemnt, Erasmus School of Social and Behavioural Sciences, Erasmus University Rotterdam, The Netherlands
2. Erasmus University College, Erasmus School of Social and Behavioural Sciences, Erasmus University Rotterdam, The Netherlands
3. Department of Public Health, Well-being & Care of the Municipality of Rotterdam, The Netherlands

Key words: Internet; eHealth; mHealth; mobile; lifestyle; obesity; social network; serious games; multilevel analysis; physical exercise

Abstract

Background: Sedentary behaviour (SB) and lack of physical activity (PA) have been associated with poorer health outcomes and are increasingly prevalent in individuals working in sedentary occupations, such as office jobs. Gamification and nudges have attracted attention as promising strategies to promote health behaviour change. However, most studies of effectiveness so far lacked active controls, and few studies have tested interventions combining these two strategies. This study investigated the effectiveness of an intervention combining a gamified digital intervention with physical nudges to increase PA and reduce SB in Dutch office workers.

Methods: Employees of the municipality of Rotterdam (N = 298) from two office locations were randomized at the location-level to either a 10-week intervention, combining a five-week gamification phase encompassing a gamified digital intervention with social support features and a five-week physical nudges phase, or to an active control (i.e. limited digital application with self-monitoring and goal-setting). The primary outcome was daily step count objectively measured via accelerometers. Secondary outcomes were self-reported PA and SB. Mixed-effects models were used to analyse the effects of the intervention on the primary and secondary outcome measures of participants up to one month after the intervention.

Results: A total of 234 participants completed the study and provided accelerometer data. During the gamification phase, participants in the intervention condition significantly increased their number of daily steps (from 10138 to 10901; 763.5 increase) compared to those in the active control (from 10403 to 10619; 215.6 increase) (p = 0.01). These improvements were not sustained during the physical nudges phase (p = 0.76) or follow-up (p = 0.88).

Conclusions: A digital intervention with gamification and social support features significantly increased the step count of office workers, compared to an active control encompassing self-monitoring and goal-setting. Physical nudges in the workplace were insufficient to promote maintanence of behaviour change achieved in the gamification phase. Future research should explore how to improve the long-term effectiveness of gamified digital interventions.

Background

For decades, unequivocal evidence has demonstrated that moderate-to-vigorous-physical activity is associated with improved health outcomes [1]. However, more recently, evidence has been emerging linking sedentary behaviour (SB) to elevated risks of all-cause mortality [2] and reduced life expectancy [3], independently of compliance with the recommended guidelines of 150 minutes of moderate-to-vigorous physical activity (PA) per week. SB can be defined as any waking behaviour characterized by an energy expenditure ≤ 1.5 metabolic equivalent of task (METs) while in a sitting or reclining posture [4]. Prolonged SB and physical inactivity have been associated with higher risks of cardiovascular disease, diabetes type 2, and cancer [5,6], as well as higher levels of stress, anxiety, and depression [7,8]. Conversely, even modest amounts of light-PA are associated with improved health and psychological well-being [6,9,10], and higher frequency of sitting time interruptions reduces the risk markers for health problems related to SB [2]. Thus, even for individuals meeting guidelines for moderate-to-vigorous PA, it is recommended to reduce SB as much as possible by avoiding prolonged sitting through regular engagement in light-PA, such as walking breaks [11].

Despite these findings, sedentary lifestyle is an escalating epidemic. In recent decades, most common occupations became increasingly more sedentary due to technological advancements and, particularly for office workers, workplace sitting patterns are largely responsible for increases in SB [12,13]. A recent report showed that Dutch full-time workers were sitting on average for 10 hours per week day [14]. Given that workplace sitting is the largest contributor to SB [15], behaviour change interventions in this setting have the potential to bring considerable benefits at both the individual and societal level, for instance, through the prevention of health care costs associated with non-communicable diseases [16].

Influencing health behaviours: Behaviour Change Theory and Nudging

Non-compliance with health behaviours can be largely attributed either to a lack of motivation, or to insufficient capacity to self-regulate towards one's goals [17]. According to Bandura's Social Cognitive Theory

[18], several factors influence one's motivation for health behaviour change, such as whether people are confident in their capacity to change (i.e. self-efficacy) or whether people have social support to change. Social support may involve modeling by family and friends, feedback and support from peers, or social incentives enhancing accountability, competition and cooperation. Besides those motivational factors, people's ability to self-regulate to achieve behaviour change depends on the characteristics of their goals (e.g. difficulty), their ability to self-monitor, and their use of planning strategies and reminders [19]. Several behavioural change techniques (BCTs) can be used to influence these factors to promote behaviour change.

Certain BCTs attempt to motivate individuals to change by providing information on the risks of their current behaviour or on the future benefits of behaviour change. However, although these strategies can influence people's self-reported intention to change, they have, at best, a modest effect on behaviour change [20]. Recently, increased attention has been paid to using insights from behaviour change theory to help people to make better choices by modifying their environment (*nudging;* 20,21). Nudges are typically BCTs that exploit behavioural and cognitive tendencies to promote a desired behaviour, and various interventions have successfully utilized nudges to influence healthy choices in a workplace setting [23]. Motivational nudges can motivate participants to change by, for instance, providing feedback on the social norms around that behaviour or by conveying information on the benefits of behaviour change through an authority figure (e.g. doctor). Other nudges can help individuals self-regulate towards their goals. For instance, point-of-choice prompt nudges are cues that function by interrupting maladaptive habitual behaviours, such as prolonged sitting, and by highlighting opportunities in the environment to engage in alternative health-enhancing behaviours, such as walking breaks [24]. Although nudges are increasingly popular, partially due to their promising cost-effectiveness [25], the effect sizes of nudging interventions tend to be modest [23], and evidence for their effectiveness is still mixed [26,27]. One way of increasing the effectiveness of nudges is innovation in intervention delivery, for instance, by including nudges in interactive digital applications and combining it with physical nudges in the work environment, an approach that has been largely overlooked.

Gamification: Improving digital interventions to promote health behaviour change

Given the growing use of technology, digital applications are promising avenues for delivering behaviour change interventions. It is well established that digital behaviour change interventions provide an empirically supported, convenient, and potentially more cost-effective alternative for reaching large proportions of the public over long periods of time [28,29]. However, digital interventions still depend on active user engagement to promote behaviour change, which is challenging to maintain. Recently, gamification has emerged as a promising persuasive strategy to increase users' motivation, engagement, and social interaction in digital behaviour change interventions [30]. Gamification is an "umbrella term" refering to the use of game design elements in non-gaming context [31,32]. Gamified digital intervention can flexibly implement a wide range of BCTs, including nudges, such as educational strategies, social support, social compansion, self-monitoring, goal setting, rewards (e.g. badges) and personalized feedback, all of which have been associated with greater behaviour change [19,33,34]. Besides promoting self-regulation and increasing motivation for the initiation and maintanence of health behaviours (35,36), gamification can enhance social support and social comparison through competition, cooperation, and salient visualization of others' behaviour (e.g. leaderboards) [36,37]. Enhancing social support has also been shown to increase engagement, adherence and completion of digital intervention for PA [38] and seems particularly important for increasing PA in inactive, unmotivativated adults [39].

Despite the promising potential of gamification, recent reviews of gamified digital interventions have highlighted a lack of empirical studies comparing gamified digital interventions with active controls (i.e. non-gamified digital interventions) [36,40]. Moreover, although multiple BCTs and nudges can be flexibly incorporated in gamified digital interventions, the effectiveness of such interventions could still be further enhanced through complementary strategies that engage participants outside of the virtual environment. For instance, physical nudges in the workplace such as *motivational* and *point-of-choice prompts nudges* are easy to implement and could serve as a cost-effective manner to improve maintanence of the initial behaviour change promoted through gamified digital interventions. However, research is needed to explore whether these types of physical nudges could indeed complement and increase the effectiveness of gamification to promote behaviour change.

The present study: MoveMore

We conducted a cluster randomized controlled trial to evaluate the effects of “MoveMore”, a 10-week multicomponent intervention, on the PA and SB of office workers. The MoveMore intervention consisted of a five-week gamification phase that included a gamified digital application incorporating several BCTs and nudges, such as social support and social comparison, followed by a physical nudges phase for the last five weeks, in which physical *motivational* and *point-of-choice prompt nudges* were introduced to the workplace. Intervention effects were compared with an active control encompassing a limited version of the digital application. We hypothesized that during the gamification phase, participants in the intervention condition will increase their levels of objectively measured light-PA (i.e. daily step count), compared to the control. Similarly, we hypothesized that during the gamification phase, we would observe increases in self-reported light-PA, moderate-to-vigorous PA, and reductions in SB in participants in the intervention condition compared to control. We expected that improvements achieved during the gamification phase would be maintained during the physical nudges phase and at a one month follow-up.

Methods

Study Design

To evaluate the effects of the MoveMore intervention, a two-arm cluster randomized controlled trial (cluster-RCT) was conducted on two office locations of the Rotterdam Municipality, the second largest city in the Netherlands. Each office location was randomly allocated to either the control or intervention condition to minimize treatment contamination. The study protocol was approved by the Ethics Review Committee of the Department of Psychology, Education and Child Studies, Erasmus University Rotterdam (application number 18-039).

Study setting and population

Participants were office workers (N = 298) from two government workplaces in the city centre of Rotterdam (office locations A and B). Office location A consisted of a tall office building with 44 floors accommodating the city management and urban development departments, whereas office B consisted of a wide office building with five floors accommodating social development departments. In both locations, government employees belonged to several different occupational groups, including managers, administrative workers, and blue-collar workers.

Eligibility criteria

Individuals were eligible to participate if they: 1) were fluent in the Dutch language; (2) worked at a department that was not involved in another physical activity-related intervention; (3) had a smartphone capable of running the required digital application; and (4) provided written informed consent for participating in the research.

Recruitment

Eligible participants were invited to participate in the study by email, social media, and through their department team leaders. Once approximately 150 eligible office workers from each location had responded, the invitation was closed. In total, 125 office workers from location A were included in the intervention arm and 131 office workers from location B were included in the control arm. Participants were enrolled in October 2018 and followed through until February of 2019.

Procedure

Participants were invited to attend an information session held by a study representative from the Municipality, during which participants' baseline measurements and informed consent were collected.

Participants received written and verbal explanation of the intervention requirements before providing consent. In the session, participants received a wrist-worn, tri-axial accelerometer device (Fitbit Flex) to monitor step count [41], and were shown how to use it in combination with a digital application in their mobile phones. Participants authorized for their data to be captured for the study. Participants were told that the digital application was intended to support them in becoming more active, and that they should use it throughout the day to help them increase their PA. Participants received subsequent questionnaires (see Figure 1) via email during the interventions, at five weeks after baseline (T1), at 10 weeks after baseline (T2; post-intervention), and at 14 weeks after baseline (T3; follow-up). Figure 1 illustrates the flow of participants through the study.

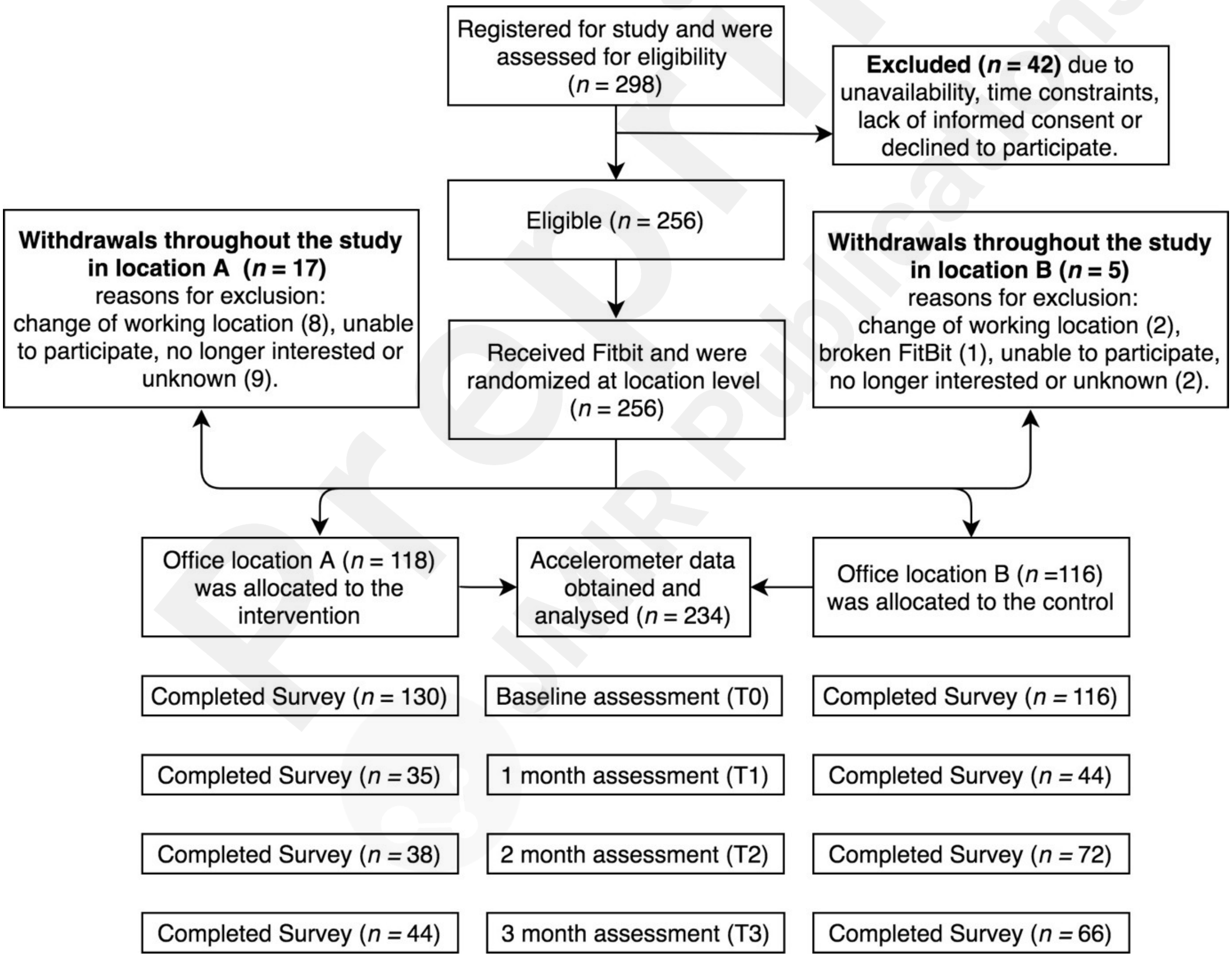


Figure.1 Consort diagram displaying the flow of participants through the study

Intervention and Control

Participants in the location receiving the MoveMore intervention were given the full version of the digital application, whereas those in the control location were given a limited version of the application (See

Supplementary file 1; 42). Both versions of the application were linked to the accelerometer, allowing participants to monitor their own PA in terms of step count and set daily goals. In the first five weeks of the MoveMore intervention condition (i.e. gamification phase), office workers were invited to participate in PA challenges through the digital application, which incorporated elements of gamification and social support and comparison features. After the gamification phase, physical nudges were introduced to the workplace of participants in the MoveMore intervention for another five weeks (i.e. physical nudges phase). An overview of the study and intervention design is illustrated in Figure 2.

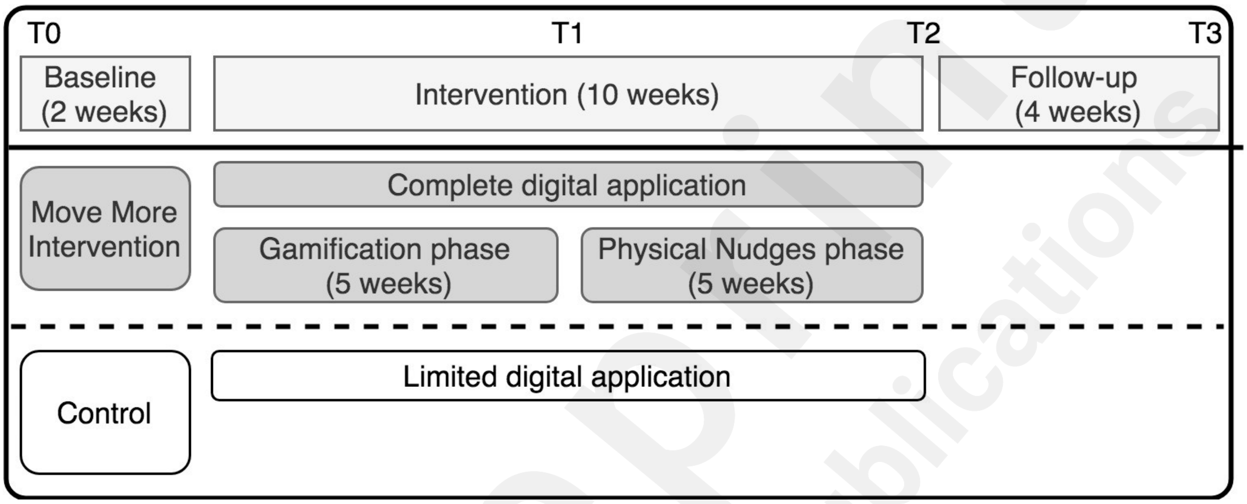


Figure. 2 Illustration of study and intervention design. T0-T3 represent the measuring moments

Gamification Phase

Relative to the control condition, participants in the MoveMore intervention had access to several additional components to motivate participants to engage in PA and help them self-regulate their behaviour. For example, the digital application used in the MoveMore intervention combined elements of gamification with several components enhancing social support and social comparison in an interactive platform [42]. During the first five weeks, office workers were invited to participate in two PA challenges with different themes, lasting two weeks each, with one week in between them. The challenges consisted of a "Virtual walking tour" (e.g. a roundtrip across Europe) representing a large goal, such as 190000 steps, that could be achieved by participants by attaining their daily goal of 8500 steps for two weeks. Pariticipant's progress was illustrated in the application by their virtual avatars crossing the virtual tour scenarios. To enhance motivation for PA, the two challenges became gradually more difficult. The default PA goal for the first challenge was the same as for default goal presented to those in the control condition (i.e. 8500 daily steps), while for the second challenge participants in the MoveMore intervention were encouraged to reach a more difficult default goal of 10000 daily steps. Participants could also set more challenging daily step goals.

During the challenge, participants in the MoveMore intervention were allocated to different teams (20 to 30 subjects), according to the department they worked on. In addition to progressing towards their daily step goals, participants daily steps contributed towards their team step goal (i.e. set as the number of participants in the team multiplied by their default daily step goal). A leaderboard served to enhance intra team cooperation and individual accountability, while promoting competition between the teams. Each team was allocated as a representative of a different charity organization, and by earning points and climbing the leaderboard ranks during each challenge teams could win gradually bigger prizes for their charity, which were sponsored by the Municipality. The first team earned 100 euros, the second team earned 90 euros, and so forth with the sixth and last team earning 50 euros. The application used in the gamification phase of the intervention also rewarded participants with virtual awards for certain individual (e.g. “Daily step goal achieved!”) and team-based PA achievements (e.g. “Your team completed a challenge!”). In addition to the weekly feedback on their personal step goals which is also provided by the limited digital application used in the control condition, participants in the MoveMore intervention received biweekly newsletters during the challenges with updates on the competition and their team’s progress.

Physical Nudges

After the gamification phase, physical nudges were introduced to the office workspace of participants in the intervention condition for five weeks to promote maintanence of behaviour change achieved. These nudges consisted of table signs aiming to: 1) further motivate participants to engage in PA and reduce SB, and 2) remind participants of the opportunities for PA in their work environment and routine. To achieve the former, motivational nudges incorporating several different behavioural insights were implemented. For example, one table sign poster portrayed an interaction between an employee and the office physician, in which the latter advises that “walking breaks are healthy and increase work productivity!” Another type of motivational nudge utilized social comparison to increase motivation for PA, with the following message: “Half of your colleagues try to move at least 10000 steps per day. What about you?” Complementarily, another type of nudge, namely point-of-choice prompts, reminded participants of their PA goals, highlighting opportunities for PA in a timely manner and prompting cognitive and behavioural rehearsal. For instance, a point-of-choice prompt nudge was placed in the coffee area of the workspace with the message “Grabbing a drink? Perfect moment to be healthy and go for a walking break!” The messages hereby reported have been translated from Dutch (see Additional file 2). The behavioural components utilized in the MoveMore intervention and in the active control are summarized in Table 1.

Table 1 BCTs used in the gamified digital application and the physical nudges (MoveMore Intervention), or in the limited digital application (Control)

Behavioural Components	MoveMore Intervention		Control
	Gamified Digital Application	Physical Nudges	Limited Digital Application
‘‘Push’’ component (i.e., notifications)	X		X
“Pull” component (i.e. information found via an in-app icon)	X		X
Objective PA assessment (i.e. accelerometer)	X		X
Information about health consequences	X	X	X
Information about emotional consequences	X	X	X
Self-monitoring	X		X
Goal setting (behaviour)	X		X
Discrepancy between current behaviour and goal	X		X
Personalized feedback on individual progress	X		X
Personalized feedback on team progress	X		
Graded tasks	X		
Reward (outcome)	X		
Social support	X		
Social reward	X		
Social comparison	X	X	
Prompts/cues		X	
Present information from a credible source in favour of the desired behavior		X	

Control condition

Similarly to the application used in the Move More intervention, the limited digital application used in the control condition allowed participants to self-monitor, and to set their own daily step goal. The limited application gave participants a default daily step goal of 8500 steps, which remained the same throughout the study duration. Participants in the control condition also received a weekly personalized feedback detailing their progress with their step count via email. This limited application served as an active control because it allowed for objective assessment of PA and its components (i.e. self-monitoring, goal-setting and personalized feedback) are effective in promoting PA [43].

Measures

Demographics and other variables. The demographic information collected during baseline included participant's age, gender, weight, length, BMI (i.e. calculated from self-reported length and weight), nationality, migrant background (i.e. parental nationality), highest education attained, occupation at the Municipality, weekly number of working days, and working hours.

Primary outcome measure. The primary outcome measure of walking behaviour was the number of daily steps objectively measured via FitBit Flex accelerometers (objective light-PA). Previous studies have determined that the Fitbit Flex accelerometer has acceptable reliability and validity for step count measurements [41].

Secondary outcome measure. Secondary outcome measures included self-report measures of worktime light-PA, moderate-to-vigorous PA and SB. SB at work was assessed with two-item self-report measures of workplace sitting time and breaks in sitting time. The self-report measures for assessing the duration of SB (Pearson r = 0.44, 95% CI = 0.24-0.60) and frequency of breaks from sitting (Spearman r = 0.26, 95% CI = 0.11-0.44) having been positively correlated with accelometer measurements in a sample of desk workers [44]. The item on frequency of breaks: "During a typical work day how many breaks from sitting (such as standing up, or stretching or taking a short walk) during one hour of sitting would you take at work?" and the item on duration of sedentary behaviour at work: ''Please estimate the total time during the last week that you spent sitting down as part of your job while at work or working from home.'' were translated to Dutch and assessed for face-validity. In our sample, the intraclass correlation coefficient (ICC) for different measurements of the duration of SB and frequency of SB breaks during work were 0.44 and 0.28 respectively, indicating poor test-retest reliability. To assess the intensity and levels of PA in various settings (i.e. at work, at home, active transport) the validated Dutch version of the SQUASH questionnaire was utilized [45,46]. The test-retest reliability of SQUASH items was poor for assessing hours per week spent in light-PA (ICC = 0.35), and moderate for items assessing moderate-to-vigorous PA at work (ICC = 0.60) and total days of moderate-to-vigorous PA (ICC = 0.55). Thus, suboptimal test-retest reliability of some of our self-report measures may have hindered the assessment of intervention effects on secondary outcomes.

Data management, monitoring and safety

Except for baseline, questionnaires were all administered electronically using the online survey platform Qualtrics [47]. FitBit Flex accelerometer data was obtained through the company responsible for the gamified digital intervention [42] via the FitBit application, and was downloaded at completion of the follow-up period. Data was exported into R statistical software version 3.5.2, and analysed with the R package *lmer* [48]. Hardcopy consent forms were stored in locked filing cabinets, and electronic data was stored on password protected drives accessible by study investigators.

Data Analysis

In this study, following a period of two weeks of baseline measurement, participants daily number of steps was measured for 14 consecutive weeks, resulting in a hierarchical data structure. Daily step counts observations (level 1) were nested within participants (level 2), who, in turn, were nested within deparment clusters (level 3). Recent statistical studies simulating variance in longitudinal data have shown that misspecifying the number of levels can lead to biased findings [49]. For that reason, we used a mixed-effects model approach to account for the nested hierarchical structure of the data by including random intercepts for the different levels when the variance at that level was significantly different from zero [50]. As recommended by Haan-Rietdijk et al. [49], we utilized autoregressive models (in combination with Akaike Information Criteria (AIC) scores) to assess the variance at different levels and determine which levels needed to be included in the model. Given that the variance at the department level was not significant (X^2 = 0, df= 1, p > 0.05), models were only adjusted for clustering of observations within participants (i.e. level 2) (X^2 = 4934.5, df = 1, p <

0.01).

Since we were interested in comparing different study phases (i.e. gamification, physical nudges and follow-up) to baseline, as well as in investigating potential interactions between intervention condition and different phases, study phase was not considered a level but rather included as a predictor in our models.

Considering multilevel models can handle data missing at random, partially complete records are included in the model to avoid biases associated with a completers only analysis [51]. Analysis were conducted in R using the lmer package [48]. In this primary analysis, baseline step count was estimated using the second week of data. The first week of data was ignored to diminish the potential upward bias from estimating higher activity during initial accelerometer use. Observations with less than 1,000 steps and more than 60,000 were considered missing because evidence indicates that these values are unlikely to represent capture of actual activity [52–54]. Such observations were considered either extreme outliers or the result of forgetting to wear the accelerometer.

To assess an interaction between intervention condition and time and study phases, a repeated measures mixed effect model was employed following intention-to-treat principles. Models were initially fit with a random intercept for participants, fixed effects of time, study phase (i.e. baseline, gamification, nudging and follow-up) and covariates. When the relationship between our outcome variable and time was quadratic or cubic, a quadratic and cubic parameter of time were respectively included in the model as fixed effecs. To avoid convergence issues in the primary analysis, time was rescalled to represent two week intervals. Covariates initially included in the model were age, gender, parental nationality, work occupation, number of weekly working hours, education and BMI (i.e. calculated from self-reported weight and length). Covariates that were not significant predictors of the outcome variable were excluded from the model. Next, the level 2 variable intervention condition (i.e. intervention versus control) was included as a fixed effect. Random slopes of study phase and time per participant were added to the model. When random slope of study phase per participant was significant, a two-way cross-level interaction between study phase and intervention condition was included in the final model to investigate the effects of the intervention during each phase. Additionally, in an exploratory analysis we investigated whether intervention effects were influenced by individual differences by examining interactions between intervention effects and relevant covariates. The model used in the primary analysis was refit using secondary outcome measures: [1] Mean number of hours spent in light-PA and moderate-to-vigorous PA during work, and the number of days engaging in sufficient amount of moderate-to-vigorous PA, as assessed by the SQUASH questionnaire; [2] Two self-reported items assessing SB: The average number of sitting breaks taken per hour during work, and the mean daily sitting time during work.

Results

Demographic statistics

Table 2 presents baseline descriptive statistics of the study sample per intervention condition. Relative to the control condition, the intervention condition had a significantly higher proportion of male participants and participants of lower educational backgrounds. Additionally, participants in the intervention condition weighted significantly more and had significantly higher body mass index (BMI) than participants in the control condition. Participants in the intervention group also logged a lower number of daily steps at baseline, although this difference did not reach statistical significance.

Table 2 Sociodemographic and behavioral characteristics of participants at baseline

Variable	Intervention (*n* = 118)	Control (*n* = 116)	*p* - value
Behavioural characteristics			
Number of daily steps (mean, sd)	10138 (SD = 4643.5)	10403 (4191.6)	0.219
Meeting PA guidelines (days per week, sd)	5.1 (2.0)	5.4 (1.0)	0.195
Hour sitting per week (mean, sd)[a]	30.1 (SD = 9.5)	29.2 (SD = 10.2)	0.454
Breaks per hour (mean, sd)[a]	1.8 (SD = 1.2)	1.9 (SD = 1.3)	0.489
Demographic characteristics			
Age (mean, sd)	47.5 (SD= 9.6)	45.9 (SD = 10.2)	0.251
Gender (female)	63 (55.3%)	83 (72.8%)	**0.017**
Weight (kg, sd)	82 (SD = 17.8)	75.7 (SD = 13.9)	**0.003**
BMI[b]	26.9 (SD = 5.0)	25.6 (SD= 4.5)	**0.038**
Nationality (Dutch)	101 (89.4 %)	104 (92.0%)	0.573
Parental nationality (Dutch)	88 (77.9%)	89 (78.1%)	0.626
Education (Higher education)	78 (69.6%)	99 (86.1%)	**0.005**

Work Position (Highly skilled)[c]	105 (97.2%)	110 (96.5%)	1.000
Number of weekly working days	4.4 (SD = 0.6)	4.3 (SD = 0.5)	0.161

Boldface indicates statistical significant ($p < 0.05$)
[a]The number of hours sitting per week and number of sitting breaks per hour refers specifically to SB during work time
[b]Body Mass Index, calculated from self-reported height and weight
[c]Non-manual labour occupations, such as managers and administrative positions, were coded as highly skilled

Primary analysis: Daily step count

After controlling for relevant covariates and subject-specific differences, our mixed-effects model investigated the effects of intervention condition, time, study phase and the interaction between study phase and intervention condition on the objectively measured step count of participants. During the gamification phase, step data that were missing or had values less than 1000 steps per day represented 13.5% (473 of 3492 participants-days) of observations for the control arm and 11.4% (445 of 3888 participants-days) for the intervention arm. During the follow-up period, these percentages increased to 39.6% (1154 of 2910) in the control arm and 59.6% (1932 of 3240) in the intervention arm, indicating susbtantial missing data in our sample during later study phases.

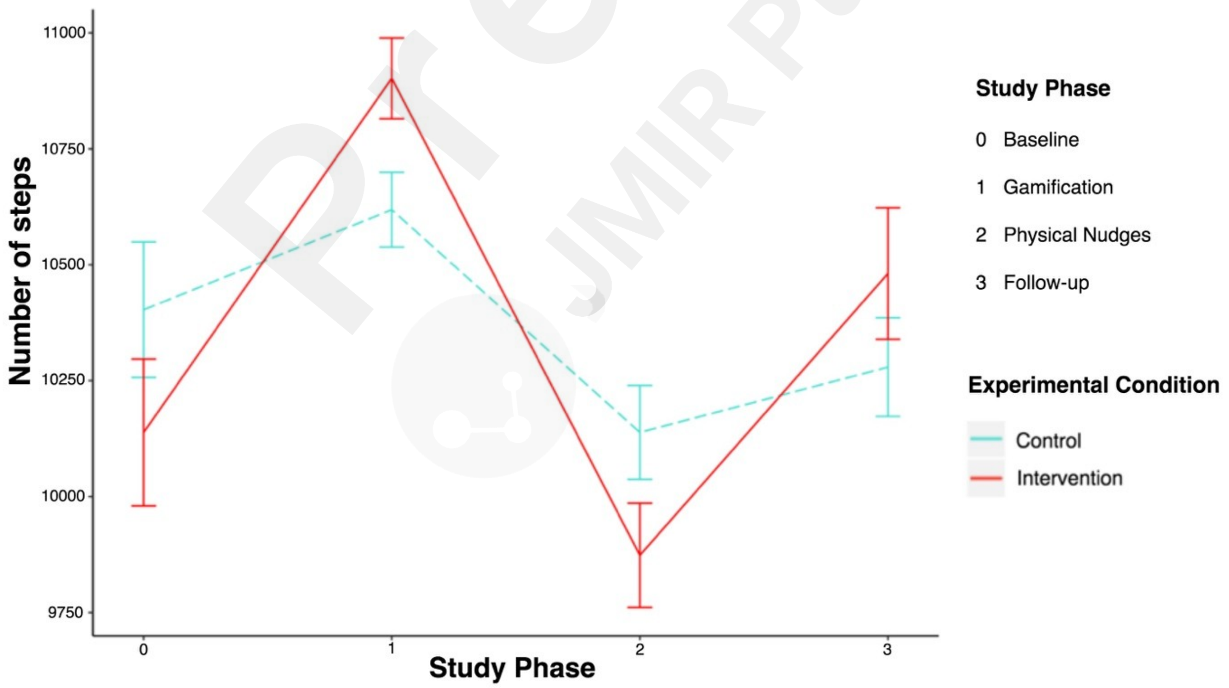


Figure. 3 Unadjusted differences in average daily step counts between intervention and control conditions over the study phases.

The first repeated measures mixed model analysis (Model 1; Table 3) included the effects of relevant covariates, study phase, time and intervention, as well as random slopes of time and study phase per participant. Model 1 revealed that daily number of steps was negatively associated with BMI (B = -178.03, SE = 38.94, t (168.61) = -4.57, p < 0.01) and positively associated with age (B = 35.85 , SE = 18.89, t (172.50) = 1.90, p = 0.059). These two predictors explained 12.6% of the variance at the participant level (R^2 = 0.126), with larger BMI and younger age being associated with lower daily step counts overall. The fixed effects of gender, work occupation, number of working hours, education, and nationality (both individual and parental) were removed from the model as they were not significantly related to step count.

Given the initial novelty of the gamification and physical nudges phase, which potentially wears off towards the end of each phase, it is plausible that daily step count occilated significant within each study phase. In support of that interpretation, our analysis revealed that linear, quadratic and cubic effects of time were significant, suggesting that changes in step count within a study phase occilated across time. Model 1 also revealed significant effects of the study phases on step count, but the main effect of intervention condition was not significant (Model 1; Table 3). These effects of study phases reflect that, after controlling for the effects of time and other covariates, participants from both groups increased their number of daily step during the novel gamification phase, and decreased their number of daily steps during the nudging and follow-up phase, compared to baseline.

Table 3. Results of models with and without cross-level interactions predicting number of steps taken per day

	Model 1			*Model 2*		
	Estimate	SE	*p*-value	Estimate	SE	*p*-value
Intercept	14003.0	1233.7		14063.9	1240.4	
BMI[a]	-178.0	38.9	< **0.001**	-177.1	39.02	< **0.001**
Age	35.9	18.9	0.059	36.0	18.92	0.059
Time[b]	-1261.9	308.0	< **0.001**	-1259.60	307.95	< **0.001**
$Time^2$	332.5	81.4	< **0.001**	332.4	81.36	< **0.001**
$Time^3$	-21.2	6.1	< **0.001**	-21.2	6.08	< **0.001**
Gamification	856.9	211.4	< **0.001**	541.9	241.7	**0.025**
Nudging	-690.9	326.6	**0.035**	-751.5	359.0	**0.037**
Follow-up	-1475.3	406.7	< **0.001**	-1520.2	441.2	< **0.001**
Intervention	-16.0	374.8	0.965	-222.3	416.4	0.594

Intervention*Gamification	634.0	244.8	**0.005**
Intervention*Nudging	98.2	325.5	0.763
Intervention*Follow-up	53.49	381.7	0.888

Boldface indicates statistical significant (p <0.05)
[a]Body Mass Index, calculated from self-reported height and weight
[b]Time is rescaled to represent two week intervals
$Time^2$ and $Time^3$ represent the quadratic and cubic functions of Time, respectively
Model 1 (AIC: 269682) and Model 2 (AIC: 269679) are the models respectively with and without the cross-level interactions between intervention and study phase. Model 2 significantly improved model fit (X^2 = 8.59, df = 3, p = *0.035*).

The changes in daily step count across study phases and time were different between participants, as evidenced by the significant random slopes of study phase and time per participant detected in Model 1. Adding cross-level interactions between study phase and intervention phase (Model 2; Table 3) significantly increased model fit, indicating that differences between participants in changes in daily step counts across study phases could be explained by intervention effects. Findings from Model 2 suggest that differences between participants in changes in daily steps are partially explained by significantly greater increases in daily steps during the gamification phase for participants in the intervention condition than in the control. This was evidenced by a significant interaction between intervention condition and gamification phase (B = 634.00, SE = 244.81, t (167.52) = 2.59, p < 0.01) in a one-sided test, which explained 20.3% of the variance between participants in changes during the gamification phase (R^2 = 0.203). There were no differences in changes in daily steps between participants in the intervention and control condition during the nudging phase (B = 98.23, SE = 325.52, t (163.28) = 0.30, p = 0.76) or follow up (B = 53.49, SE = 381.67, t (143.61) = 0.14, p = 0.89). Exploratory analysis showed that differences in changes in daily steps between participants could not be explained by individual differences, such as BMI or education. In essence, our findings indicate that the gamification phase of our intervention was effective in increasing daily step count of office workers, compared to an active control. However, improvements were not maintained during the physical nudges or follow-up phase.

Secondary Analysis: Self-reported PA and SB

The model 1 used in the primary analysis was refit using secondary outcome measures, including self-reported light-PA and moderate-to-vigorous PA, as well as duration of SB and frequence of breaks from SB. Higher BMI was associated with less time spent in SB (B = -0.21, SE = 0.07, t = -2.96, p < 0.01), but no association was found between intervention condition or study phase and time spent in SB. Participants in the intervention condition took less breaks from sitting than those in the control (*B* = -0.22, SE = 0.11, $t = -2.00$, $p < 0.05$), and participants in both conditions took less breaks during follow-up compared to baseline (*B* = -0.34, SE = 0.11, $t = -3.01$, $p < 0.01$). There was no effect of the intervention on hours spent in light-PA at the workplace (adjusted for nationality and age), but overall participants engaged in less light-PA at the end of the nudging phase (*B* = -4.39, SE = 1.45, $t = -3.03$, $p < 0.01$) and at follow-up (*B* = -3.47, SE = 1.40, $t = -2.48$, $p < 0.01$), compared to baseline. After controlling for BMI, there was no main effect of the intervention for self-reported engagement (hours and days) in sufficient moderate-to-vigorous PA (i.e., 150 minutes per week). However, a significant effect of study phase was detected, with participants on average engaging in more hours of moderate-to-vigorous PA (*B* = 0.55, SE = 0.19, $t = 2.82$, $p < 0.01$) and more days with sufficient moderate-to-vigorous PA (*B* = 0.33, SE = 0.16, $t = 2.14$, $p < 0.05$) during follow-up compared to baseline.

Discussion

This study tested a multicomponent intervention combining a gamified digital intervention with physical nudges in the workplace to promote walking behaviour (i.e. light-PA) and reduce SB in office workers. The MoveMore intervention consisted of an initial gamification phase encompassing a gamified digital application with social support features, followed by a physical nudges phase including motivational and point-of-choice prompt nudges. By offering the gamification and physical nudges components separately, we could gain insights about the independent effects of each component, as well as investigate whether physical nudges alone could promote maintanence of behaviour change following a gamified digital intervention.

In line with our main hypothesis, significant increases in daily step counts were observed for participants in the intervention condition after the gamification phase, compared to participants in the control. However, contrary to our expectations, improvements in daily step count for participants in the intervention condition were not maintained during the physical nudges phase or at follow-up. We also hypothesized that similar improvements in secondary outcomes would be observed during the gamification phase for participants in the intervention condition. Participants overall reported higher engagement in moderate-to-vigorous-PA during work at follow-up compared to baseline. Unexpectedly, participants in both conditions reported engaging in less light-PA during the physical nudges and follow-up phases than in baseline. Participants in the intervention condition reported taking less breaks from sitting than those in the control, and participants in both groups reported taking less breaks during later study phases relative to baseline. However, we could not investigate differences between intervention and control in changes of secondary outcome measures, and given the poor reliability of the self-report measures in our sample, these results should be interpreted with caution. Future studies could address these limitations by using more sophisticated accelerometers that measure SB, and providing virtual incentives in digital applications encouraging users to wear the accelerometers and complete all the assessments .

Nevertheless, our main findings suggest that adding *gamification* components with social support and social comparison features to a digital intervention seems to be an effective strategy for promoting PA in office workers, as evidenced by a significant interaction detected between the gamification phase and intervention condition. Exploratory analysis revealed that intervention effects were not influence by individual differences, for example, in BMI or education. The short term effects of the gamification phase on step count was modest (i.e. 763.5 increase in average number of daily steps for the participants in the intervention condition compared to a 215.6 increase for those in the control), but comparable to previous RCTs evaluating this type gamified digital interventions [37,55]. Similarly, those studies observed small, but clinically significant effects on PA and/or SB. However, systematic reviews of pedometer-based interventions found that these interventions typically increases physical activity by approximately 2000 steps/day [56]. Although the gamification phase of our intervention resulted in considerable increases in step count, considering the increases reported in other RCTs assessing similar gamification interventions [37,57], the effects of the MoveMore intervention may seem underwhelming.

Several factors may explain the smaller effect sizes reported in the present study, such as high daily step counts at baseline. Most similar intervention studies recruited inactive adults moving approximately 7000-7500 steps, which is far below the fairly disputed, yet often recommended guideline of 10000 steps per day [37,57,58]. Consequently, larger increases in step counts (i.e. ≅ 2000 steps) may have been observed in these samples precisely because low levels of PA at baseline allowed for and motivated participants to achieve greater improvements during the intervention period. Comparably, participants in the present study walked approximately 10270 steps per day at baseline. Although increasing one's daily number of steps beyond the recommended guidelines [59] is still beneficial, high rates of functioning at baseline may have hindered motivation and limited how much participants in our sample could improve (i.e. ceiling effect). Meta-analysis of PA interventions with healthy adults reporting that studies with active adults reported lower effect sizes than those with sedentary adults [60]. Therefore, the significant improvements in step count observed even in this highly active population speaks for the promising potential of gamified digital interventions to promote behaviour change. Given this ceiling effect, it is comprehensible that increases in step count of the highly active participants in our sample are lower and more difficult to maintain than that of interventions with inactive participants.

In addition to high rate of functioning at baseline, several other factors can partially explain our findings. For example, the use of an active control. Most studies exploring the effects of gamified digital interventions for PA and SB use either no-intervention controls [61] or self-monitoring controls [37,62]. To our knowledge, only a few studies investigating similar gamified digital interventions have utilized active controls with self-monitoring and goal-setting [57]. In the present study, implementing an active control allowed us to make stronger causal inferences about the effects of gamification and social support features on PA and SB. However, it is well established that the combination of self-monitoring and goal-setting alone leads to initiation of behaviour change [43,59]. A meta-analysis of worksite PA interventions found that studies implementing active controls unsurpringly report lower effect sizes than those with no-intervention controls [63], thus the use of active rather than no-intervention control is another possible explanation for the relatively smaller effect sizes detected in this study. Another factor that may have influenced our results was the short duration of the gamification phase (five weeks) may have limited its effectiveness. A systematic review suggests that PA interventions with longer duration (i.e. >24 weeks) are more likely to promote maintanence of behaviour change [64]. Thus, although behaviour change was initiated during the gamification phase, five weeks may have been too short to form the habit of walking breaks. Due to operational constraints, it was not possible to offer the gamification phase for longer durations in the present study, but future research should explore the effects offering gamified digital interventions for longer durations to help establish habit formation.

We anticipated that physical nudges in the workplace could promote maintanence of the behaviour change achieved during the gamification phase. When designing the social norms nudges and point-of-choice prompts, fellow office workers from the intervention condition served as role models, which could acts as motivators and goal reinforcement [18,65]. Studies have found that combining motivational and point-of-choice prompt nudges was more effective than a control or either strategy alone in increasing stair-climbing behaviour [66]. However, in this study, combining motivational nudges based on social norm and authority with point-of-choice-prompts for walking behaviour did not result in further increases in step count nor maintenance the behaviour change achieved through the gamified digital intervention.

A possible explanation for these results may lie in the differences between the two locations. The effectiveness of certain BCTs, particularly nudges, is largely influenced by the context of implementation [23]. The two offices randomly allocated to intervention and control differed considerably in location and design. The control location was a wide building located in the city center with large floor spaces and easy access to stairs and outside areas. Conversely, the intervention location was a tall building with less surface area per floor and difficult access to outside areas. Participants in the control location had more space to walk indoors, whereas participants in the intervention location worked on multiple floors, and may instead have had more opportunities to climb the stairs. Due to operational constraints no nudges for stair-use could be implemented in the office locations. Furthermore, weather conditions worsened (i.e lower temperature and more precipitation) throughout the course of the study, which may have discouraged participants to walk outside, maxizing the influence of the physical differences between the two locations. Additionally, due to the collaborative nature of the study, the nudges utilized the colors and logos of the Municipality of Rotterdam, which are also used in most of the other promotional materials found throughout the office locations. This may have hindered the attractiveness of the nudges, since they easily blended in with others unrelated promotional materials.

The ineffectiveness of the nudges may also stem from the possibility that the physical nudges in the workplace in the form of table signs were not sufficiently engaging and motivating, especially when compared to the gamified digital intervention encompassing several different types of BCTs. These findings, however, add support to the emerging evidence indicating that multicomponent interventions incorporating several nudges and BCTs, such as the gamified digital intervention used, are more effective at changing complex behaviour like PA than interventions relying on only one or a few BCTs, such as the physical nudges utilized [19]. Most importantly, our findings suggest that gamification can be a useful complementary tool that can be flexibly incorporated to digital interventions to improve their effectiveness.

Despite this study's constraints, our findings demonstrate that a gamified digital interventions incorporating social support features can effectively increase walking behaviour in office workers. Given that reviews of gamified interventions have called for stronger empirical evaluations isolating the impacts of gamifications [36], we consider the presence of an active control one of the strengths of this study. This study is one of the first to combine a gamified digital intervention with physical nudges to promote behaviour change. The possibility to gain insight into the effects of the gamification and the physical nudges was another advantage of this study's design, although order effects were a possible drawback. The use of objetive measurements (i.e. accelerometers) was another strength of our study, since self-reported measures of PA are often biased compared to objective measures, leading to false positive findings [67]. Additionally, the MoveMore intervention was implemented in the actual working environment of a large sample of Dutch office workers, rather than in a controlled setting, which adds to the ecological and internal validity of our findings.

Nevertheless, this study had several limitations inherent to field experiments, such as not being able to control for extraneous variables and operational constraints with regards to the the physical nudges and the time frame of the intervention phases. Although we controlled for baseline differences between groups, differences between locations were possible confounders. Due to financial constraints, we could not opt for accelerometers that objectively measured SB. We relied on self-report measures of SB, which had poor reliability in our sample and have been shown to underestimate SB in adults [68,69], possibly explaining why the hypothesized intervention effects on SB were not observed even though they were supported by accelerometer step count data. With regards to our statistical analysis, although we justifiably included quadratic and cubic effects of time in our model, we recognise that these higher order effects are less stable and may be specific to our sample. Additionally, considerable drop-out observed during physical nudges and follow-up phases hindered the assessment and interpretation of intervention effects during those phases.

Furthermore, while our findings support the effectiveness of gamification to promote PA in a sample of active office workers, further research is needed to confirm the generalizability of our findings and investigate its effects in more at-risk populations, such as inactive adults and adolescents from more disadvantaged backgrounds. Given the unexpected effects of physical nudges observed, future studies should carefully consider the design and context of nudges implemented. Nudges have gained attention because they are cost-effective to momentarily influence people’s behaviour. However, further research is needed to explore how physical nudges can be more effectively combined with other interventions to promote the maintanence of complex behaviours, such as PA, in the short- and long-term. For example, offering gamified digital interventions and physical nudges simultaneously, rather than sequentially, may increase intervention effectiveness. Research on gamification and nudging is still in its infancy. Future research with gamified digital interventions should continue innovating with the design of digital interventions by, for instance, testing different forms of social support and gamification components (e.g. leaderboards, competition, cooperations). Finally, future research of digital interventions should investigate complementary strategies to promote long-term maintanence of behavioural change, such as increasing engagement by tailoring the interventions to the participants’ needs, or using guided approaches incorporating personal coaches or peer-support.

Conclusion

Compared with an active control consisting of a digital application including self-monitoring and goal-setting, a gamified social support–based digital intervention was effective at promoting light-PA (i.e. objectively measured number of daily steps) in a sample of active office workers. Given the high prevalence of sedentary lifestyles and the associated health problems, both of which are highly costly to health-care systems, even small improvements in light-PA can have considerable effects at the population level. This study was one of the first to compare the effects of gamification to an active control, and to tests its effects on PA and SB of office workers. Our findings demonstrate that gamification can effectively complement the BCTs and nudges (e.g. social support and social comparison) used in digital interventions to promote clinically significant improvements in PA, even beyond recommended guidelines of 10000 steps. Policy-makers should explore the use of gamified digital interventions as a promising cost-effective strategy to promote behaviour change and improve the health of the population. Physical nudges in the workplace were insufficient to promote maintanence of behaviour change achieved during the gamification phase. Further research should explore how gamified digital interventions can be better leveraged to promote long-term behavior change, for instance, by investigating how to optimally tailor digital interventions to the users' needs.

Abbreviations

AIC: Akaike Information Criteria; BCT: Behavioural Change Technique; BMI: Body mass index; PA: Physical Acitivty; RCTs: Randomized Controlled Trials; SB: Sedentary Behaviour

Acknowledgements

The authors would like to thank Ruth Plaggenborg, and the team at SelfCare for designing and providing the MySelfCare and SelfCarePro applications used in the control and intervention condition respectively, as well as for their contributions to the design and implementation of the study. We would also like to thank Berdi Christiaansen, as well as other staff and participants from the Rotterdam Municipality for their involvement and contributions to the MoveMore study. Finally, we would like to thank Healthy'R (www.healthyr.nl), the expertise center on health behaviour of the Municipality of Rotterdam and Erasmus University Rotterdam. Healthy'R combines scientific knowledge in the field of behavior and health with practical knowledge and experiences to develop and investigate measures that lead to healthier choices of people in Rotterdam.

Funding

The costs of the acceleromenters, physical nudges and digital applications utilized in this study were funded by the Municipality of Rotterdam. The content is solely the responsibility of the authors and does not necessarily represent the official views and interests of the funders or the authors' affiliated academic institutions. The funders had no role in the design of the study, and were not involved in data analysis, decision to publish or preparation of the manuscript.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

AM designed the study, developed the intervention, managed data collection, conducted statistical analyses and interpretation, and wrote the manuscript. MS helped develop the intervention material, recruit participants and manage the data collection. JJ helped with the statistical analysis and interpretation, and provided feedback on the manuscript. AS, GN, and SD contributed to the study design, and provided guidance and consultation throughout the study, as well as feedback on the manuscript. All authors read and approved the final manuscript.

Ethics approval and consent to participate

This research was approved by the Ethics Review Committee of the Psychology Department of Erasmus University Rotterdam, in the Netherlands (application number 18-039). All participants provided written informed consent.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

References

1. Hupin D, Roche F, Gremeaux V, et al. Even a low-dose of moderate-to-vigorous physical activity reduces mortality by 22 % in adults aged ≥ 60 years : a systematic review and meta-analysis. *Br J Sport Med*. 2015;49:1262-1267. doi:10.1136/bjsports-2014-094306
2. Proper KI, Singh AS, Mechelen W Van, Chinapaw MJM. Sedentary Behaviors and Health Outcomes Among Adults. *Am J Prev Med*. 2011;40(2):174-182. doi:10.1016/j.amepre.2010.10.015
3. Katzmarzyk PT, Lee I. Sedentary behaviour and life expectancy in the USA : a cause-deleted life table analysis. *BMJ Open*. 2012;2(4):1-8. doi:10.1136/bmjopen-2012-000828
4. Tremblay MS, Aubert S, Barnes JD, et al. Sedentary Behavior Research Network (SBRN) – Terminology Consensus Project process and outcome. *Int J Behav Nutr Phys Act*. 2017;14(75):1-17. doi:10.1186/s12966-017-0525-8
5. Wilmot EG, Edwardson CL, Achana FA, et al. Sedentary time in adults and the association with diabetes , cardiovascular disease and death : systematic review and meta-analysis. 2012;55(11):2895-2905. doi:10.1007/s00125-012-2677-z
6. Lee I, Shiroma EJ, Lobelo F, et al. Effect of physical inactivity on major non-communicable diseases worldwide : an analysis of burden of disease and life expectancy. *Lancet*. 2012;380(9838):219-229. doi:10.1016/S0140-6736(12)61031-9
7. Biddle SJH, Asare M. Physical activity and mental health in children and adolescents : a review of reviews. *Br J Sport Med*. 2011;45(11):886-895. doi:https://doi.org/10.1136/bjsports-2011-090185
8. Salmon P. Effects of Physical Exercise on Anxiety, Depression and Sensitivity to Stress: A Unifying Theory. *Clin Psychol Rev*. 2001;21(1):33-61. https://doi.org/10.1016/s0272-7358(99)00032-x.
9. Penedo FJ, Dahn JR. Exercise and well-being: A review of mental and physical health benefits associated with physical activity. *Curr Opin Psychiatry*. 2005;18(2):189-193. doi:10.1097/00001504-200503000-00013
10. Bize R, Johnson JA, Plotnikoff RC. Physical activity level and health-related quality of life in the general adult population : A systematic review. *Prev Med An Int J Devoted to Pract Theory*.

2007;45(6):401-415. doi:10.1016/j.ypmed.2007.07.017

11. Weggemans RM, Backx FJG, Borghouts L, et al. The 2017 Dutch Physical Activity Guidelines. *Int J Behav Nutr Phys Act*. 2018;15(58):1-12. doi:https://doi.org/10.1186/s12966-018-0661-9

12. Miller R, Brown W. Steps and Sitting in a Working Population. *Int J Behav Med*. 2004;11(4):219-224. https://doi.org/10.1207/s15327558ijbm1104_5.

13. Clemes SA, Patel R, Mahon C, Griffiths PL. Sitting time and step counts in office workers. *Occup Med (Chic Ill)*. 2014;64(3):188-192. doi:10.1093/occmed/kqt164

14. (CBS) CB voor de S. *Leefstijlmonitor*.; 2015. https://www.volksgezondheidenzorg.info/sites/default/files/lsm_2015.pdf.

15. Parry S, Straker L. The contribution of office work to sedentary behaviour associated risk. *BMC Public Health*. 2013;13(296). doi:doi:10.1186/1471-2458-13-296

16. Chu AHY, Ng SHX, Tan CS, Win AM, Koh D. A systematic review and meta-analysis of workplace intervention strategies to reduce sedentary time in white-collar workers. *Obes Rev*. 2016;17(5):467-481. doi:10.1111/obr.12388

17. Schwarzer R. Modeling Health Behavior Change : How to Predict and Modify the Adoption and Maintenance of Health Behaviors. *Appl Psychol*. 2008;57(1):1-29. doi:10.1111/j.1464-0597.2007.00325.x

18. Bandura A. Health Promotion by Social Cognitive Means. *Heal Educ Behav*. 2004;31(April):143-164. doi:10.1177/1090198104263660

19. Webb TL, Joseph J, Yardley L, Michie S. Using the Internet to Promote Health Behavior Change: A Systematic Review and Meta-analysis of the Impact of Theoretical Basis, Use of Behavior Change Techniques, and Mode of Delivery on Efficacy. *J Med Internet Res*. 2010;12(1):1-30. doi:10.2196/jmir.1376

20. Webb TL. Does Changing Behavioral Intentions Engender Behavior Change ? A Meta-Analysis of the Experimental Evidence. *Psychol Bull*. 2006;132(2):249-268. doi:10.1037/0033-2909.132.2.249

21. Bucher T, Collins C, Rollo ME, et al. Nudging consumers towards healthier choices : a systematic review of positional influences on food choice. *Br J Nutr*. 2016;115(12):2252-2263.

doi:10.1017/S0007114516001653

22. Thaler RH, Sunstein CR. *Nudge: Improving Decisions About Health, Wealth, and Happiness.* New Haven: Yale University Press; 2008.

23. Kremers SPJ, Eves FF, Andersen RE. Environmental Changes to Promote Physical Activity and Healthy Dietary Behavior. *J ofEnvironmental Public Heal*. 2012;2012:10-13. doi:10.1155/2012/470858

24. Evans RE, Fawole HO, Sheriff SA, Dall PM, Grant PM, Ryan CG. Point-of-Choice Prompts to Reduce Sitting Time at Work. *Am J Prev Med*. 2012;43(3):293-297. doi:10.1016/j.amepre.2012.05.010

25. Benartzi S, Beshears J, Milkman KL, et al. Should Governments Invest More in Nudging ? *Psychol Sci*. 2017;28(8):1041-1055. doi:10.1177/0956797617702501

26. Broers J V, Breucker D, Broucke S Van Den, Luminet O. A systematic review and meta-analysis of the effectiveness of nudging to increase fruit and vegetable choice. *Eur J Public Health*. 2017;27(5):912-920. doi:10.1093/eurpub/ckx085

27. Arno A, Thomas S. The efficacy of nudge theory strategies in influencing adult dietary behaviour : a systematic review and meta-analysis. *BMC Public Health*. 2016;16(676):1-11. doi:10.1186/s12889-016-3272-x

28. Mohr DC, Ph D, Burns MN, et al. Behavioral Intervention Technologies : Evidence review and recommendations for future research in mental health. *Gen Hosp Psychiatry*. 2013;35(4):332-338. doi:10.1016/j.genhosppsych.2013.03.008

29. Free C, Phillips G, Galli L, et al. The Effectiveness of Mobile-Health Technology-Based Health Behaviour Change or Disease Management Interventions for Health Care Consumers: A Systematic Review. *PLoS Med*. 2013;10(1). doi:10.1371/journal.pmed.1001362

30. Hamari J, Koivisto J, Sarsa H. Does Gamification Work ? — A Literature Review of Empirical Studies on Gamification. In: 2014 47th Hawaii International Conference on System Sciences; 2014. https://doi.org/10.1109/HICSS.2014.377.

31. Cugelman B. Gamification : What It Is and Why It Matters to Digital Health Behavior Change Developers. *J Med Internet Res*. 2013;1(1):1-8. doi:10.2196/games.3139

32. Deterding S, Dixon D, Khaled R, Nacke L. From Game Design Elements to Gamefulness : Defining " Gamification ." In: *Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments*. ; 2011:9-15. doi:10.1145/2181037.2181040

33. Edwards EA, Lumsden J, Rivas C, et al. Gamification for health promotion : systematic review of behaviour change techniques in smartphone apps. *BMJ Open*. 2016;6(10):1-9. doi:10.1136/bmjopen-2016-012447

34. Crutzen R. Online Prevention Aimed at Lifestyle Behaviors : A Systematic Review of Reviews. *J Med Internet Res*. 2013;15(7). doi:10.2196/jmir.2665

35. King D, Greaves F, Exeter C, Darzi A. ' Gamification ' : Influencing health behaviours with games. *J R Soc Med*. 2013;106:76-78. doi:10.1177/0141076813480996

36. Johnson D, Deterding S, Kuhn K, Staneva A. Gamification for health and wellbeing : A systematic review of the literature. *INVENT*. 2016;6:89-106. doi:10.1016/j.invent.2016.10.002

37. Gremaud AL, Carr LJ, Simmering JE, et al. Gamifying Accelerometer Use Increases Physical Activity Levels of Sedentary Office Workers. *J Am Hear Assoc*. 2018;7(13):1-12. doi:10.1161/JAHA.117.007735

38. Shih PC, Han K, Northwest P, Rosson MB, Carroll JM. Use and Adoption Challenges of Wearable Activity Trackers John M . Carroll , The Pennsylvania State University. In: *IConference 2015 Proceedings.* ; 2015.

39. Rovniak LS, Kong L, Hovell MF, et al. Engineering Online and In-person Social Networks for Physical Activity: A Randomized Trial. *Ann Behav Med*. 2017;50(6):885-897. doi:doi:10.1007/s12160-016-9814-8

40. Sardi L, Idri A, Fernández-alemán JL. A systematic review of gamification in e-Health. *J Biomed Inform*. 2017;71:31-48. doi:10.1016/j.jbi.2017.05.011

41. Diaz KM, Krupka DJ, Chang MJ, et al. Fitbit ® : An accurate and reliable device for wireless physical activity tracking. *Int J Cardiol*. 2015;185:138-140. doi:10.1016/j.ijcard.2015.03.038

42. SelfCare. SelfCare Homepage. https://selfcare4me.com. Published 2019.

43. Michie S, Abraham C, Whittington C, Mcateer J. Effective Techniques in Healthy Eating and Physical

Activity Interventions : A Meta-Regression. *Heal Psychol*. 2009;28(6):690-701. doi:10.1037/a0016136

44. Clark BK, Thorp AA, Winkler EAH, et al. Validity of Self-Reported Measures of Workplace Sitting Time and Breaks in Sitting Time. *Med Sci Sport Exerc*. 2011;43(10):1907-1913. doi:10.1249/MSS.0b013e31821820a2

45. Wendel-vos GCW, Schuit AJ, Saris WHM, Kromhout D. Reproducibility and relative validity of the Short Questionnaire to Assess Health-enhancing physical activity. *J Clin Epidemiol*. 2003;56(12):1163-1169. doi:10.1016/S0895-4356(03)00220-8

46. Hollander EL De, Zwart L, Vries SI De, Wendel-vos W. The SQUASH was a more valid tool than the OBiN for categorizing adults according to the Dutch physical activity and the combined guideline. *J Clin Epidemiol*. 2012;65(1):73-81. doi:10.1016/j.jclinepi.2011.05.005

47. Qualtrics.

48. Bates D, Mächler M, Bolker BM, Walker SC. Fitting Linear Mixed-Effects Models Using lme4. 2015;67(1). doi:10.18637/jss.v067.i01

49. Haan-rietdijk S De, Kuppens P, Hamaker EL. What's in a Day ? A Guide to Decomposing the Variance in Intensive Longitudinal Data. *Front Psychol*. 2016;7(June):1-16. doi:10.3389/fpsyg.2016.00891

50. Barr DJ, Levy R, Scheepers C, Tily HJ. Random effects structure for confirmatory hypothesis testing: Keep it maximal. *J Mem Lang*. 2014;68(3):1-43. doi:10.1016/j.jml.2012.11.001.Random

51. Singer J, Willett J. *Applied Longitudinal Data Analysis: Modeling Change and Event Occurrence.*; 2003.

52. Folta SC, Kuder JF, Goldberg JP, et al. Changes in diet and physical activity resulting from the Shape Up Somerville community intervention. *BMC Pediatr*. 2013;13(157). https://doi.org/10.1186/1471-2431-13-157.

53. Van 't Riet J, Crutzen R, De Vries H. Investigating predictors of visiting, using, and revisiting an online health-communication program: a longitudinal study. *J Med Internet Res*. 2010;12(3):e37. http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L359958298.

54. Kang M, Zhu W, Tudor-locke C, Ainsworth B, Kang M, Ainsworth B. Experimental Determination of Effectiveness of an Individual Information-Centered Approach in Recovering Step-Count Missing

Data Experimental Determination of Effectiveness of an Individual Information-Centered Approach in Recovering Step-Count Missing Da. *Meas Phys Educ Exerc Sci*. 2009;9(4). doi:10.1207/s15327841mpee0904

55. Dantzig S Van, Geleijnse G. Toward a persuasive mobile application to reduce sedentary behavior. *Pers Ubiquitous Comput*. 2012;17:1237–1246. doi:10.1007/s00779-012-0588-0

56. Kang M, Marshall SJ, Barreira T V, Lee J. Effect of Pedometer-Based Physical Activity Interventions Effect of Pedometer-Based Physical Activity Interventions :a meta-analysis. *Res Q Exerc Sport*. 2009;80(3):37-41. doi:10.1080/02701367.2009.10599604

57. Patel MS, Benjamin EJ, Volpp KG, et al. Effect of a Game-Based Intervention Designed to Enhance Social Incentives to Increase Physical Activity Among Families The BE FIT Randomized Clinical Trial. *JAMA Intern Med*. 2019;177(11):156-1593. doi:10.1001/jamainternmed.2017.3458

58. Tudor-locke C, Jr DRB. How Many Steps / Day Are Enough ? Preliminary Pedometer Indices for Public Health. *Sport Medd*. 2004;34(1):1-8. doi:10.2165/00007256-200434010-00001

59. Tudor-locke C, Craig CL, Brown WJ, et al. How Many Steps / day are Enough ? For Adults. *Int J Behav Nutr Phys Act*. 2011;8(1):79. doi:10.1186/1479-5868-8-79

60. Conn VS, Hafdahl AR, Mehr DR. Interventions to Increase Physical Activity Among Healthy Adults : Meta-Analysis of Outcomes. *Am J Public Health*. 2011;101(4):751-758. doi:10.2105/AJPH.2010.194381

61. Trial RC, Allam A, Kostova Z, Nakamoto K, Schulz PJ. The Effect of Social Support Features and Gamification on a Web-Based Intervention for Rheumatoid Arthritis Patients : Corresponding Author : *J Med Internet Res*. 2015;17(1). doi:10.2196/jmir.3510

62. Chen Y, Pu P. HealthyTogether : Exploring Social Incentives for Mobile Fitness Applications. In: *In the Second International Symposium of Chinese, Toronto, ON, Canada*. ; 2014:25-34. http://dx.doi.org/10.1145/2592235.2592240.

63. Abraham C, Graham-rowe E. Are worksite interventions effective in increasing physical activity ? A systematic review and meta- analysis. *Health Psychol Rev*. 2009;3(1):108-144. doi:10.1080/17437190903151096

64. Fjeldsoe B, Neuhaus M, Winkler E, Eakin E. Systematic Review of Maintenance of Behavior Change Following Physical Activity and Dietary Interventions. 2011;30(1):99-109. doi:10.1037/a0021974

65. Morgenroth T, Ryan MK, Peters K. The Motivational Theory of Role Modeling: How Role Models Influence Role Aspirants' Goals. *Rev Gen Psychol*. 2015;19(4):465-483. doi:10.1037/gpr0000059

66. Lewis A, Eves F. Prompt before the choice is made: Effects of a stair-climbing intervention in university buildings. *Br Psychol Soc*. 2012;17:631-643. doi:10.1111/j.2044-8287.2011.02060.x

67. Prince SA, Adamo KB, Hamel ME, Hardt J, Gorber SC, Tremblay M. A comparison of direct versus self-report measures for assessing physical activity in adults : a systematic review. *Int J Behav Nutr Phys Act*. 2008;5(56). doi:10.1186/1479-5868-5-56

68. Clarke-cornwell AM, Farragher TM, Cook PA, et al. activity monitor Comparison of self-reported measure of sitting time (IPAQ) with objective measurement (activPAL). *Physiol Meas*. 2014;35(11). doi:10.1088/0967-3334/35/11/2319

69. Aguilar-farías N, Brown WJ, Olds TS, Peeters GMEEG. Validity of self-report methods for measuring sedentary behaviour in older adults. *J Sci Med Sport*. 2015;18(6):662-666. doi:10.1016/j.jsams.2014.08.004.

Additional files

Additional file 1:

File format : .doc

Content: Pictures displaying different pages of both the the limited version of the application and the full gamified version of the digital application, provided to participants in the control and intervention condition respectively.

Additional file 2:

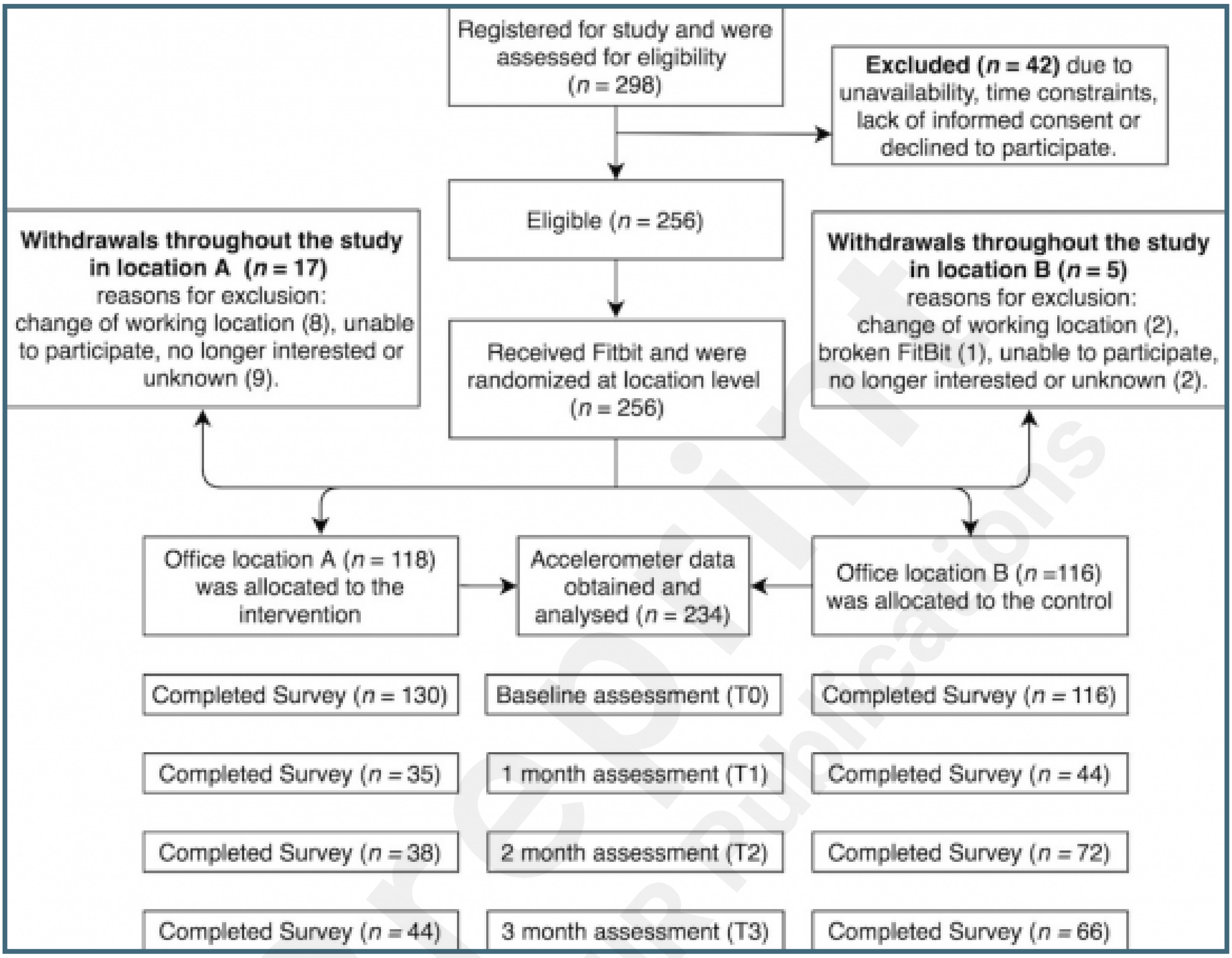
File format : .pdf

Content: Pictures displaying the original nudges (in Dutch) introduced to the workplace of participants in the MoveMore intervention condition during the physical nudges phase of the study.

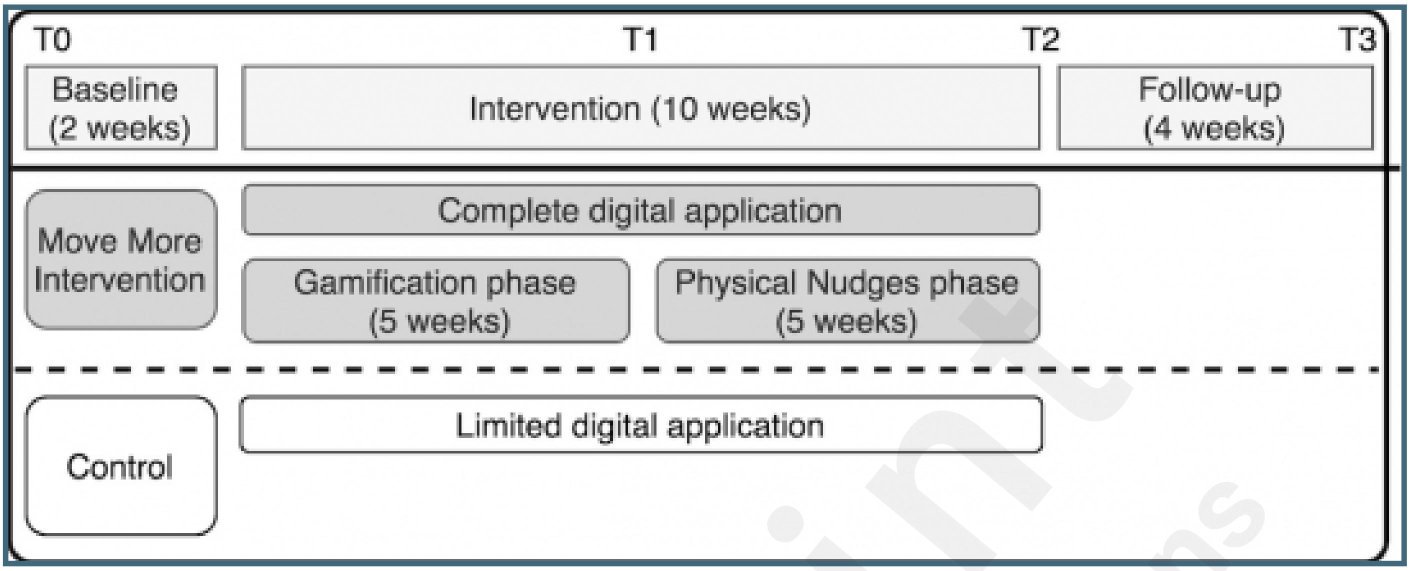
Supplementary Files

Figures

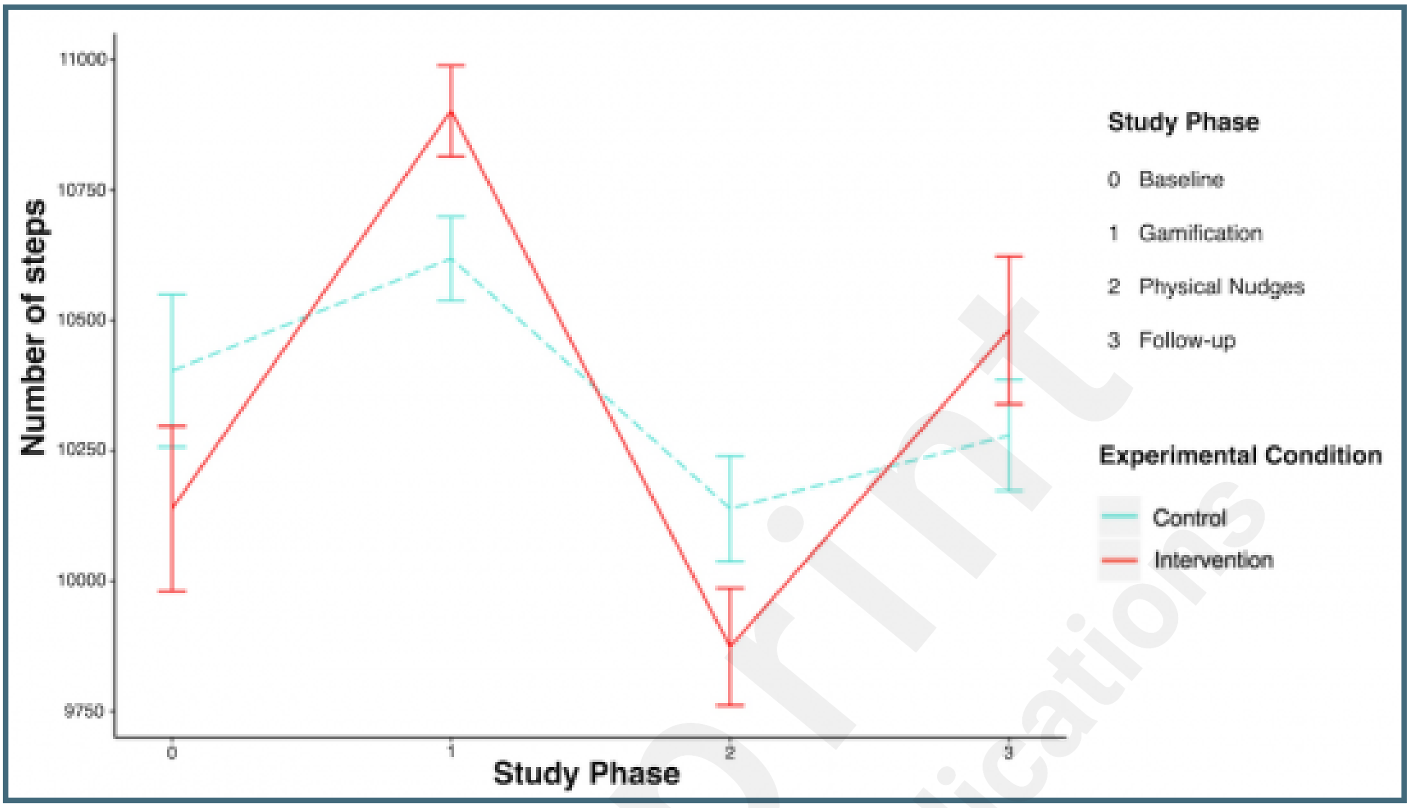
Consort Flow Diagram.



MoveMore Study Design.



Average number of steps of control and intervention participants across study phases.



Multimedia Appendixes

Screenshots of components in digital applications used by the intervention and control.
URL: https://asset.jmir.pub/assets/c935505ea9a77b7cee69c272822e359a.doc

Physical Nudges.
URL: https://asset.jmir.pub/assets/7f3160df3a0c6207f25014161ef1abb1.pdf

Checklist.
URL: https://asset.jmir.pub/assets/99566c1740ad08ed50fd11b767bc3927.pdf