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Design and evaluation of theory-informed technology to augment a wellness motivation intervention

Siobhan McMahon, MPH, PhD, GNP-BC,[1] Mithra Vankipuram, PhD,[2] Eric B Hekler, PhD,[3] Julie Fleury, PhD, FAAN [4]

[1]School of Nursing, University of Minnesota, Minneapolis, MN, USA
[2]Hewlett-Packard Laboratories, 1501 Page Mill Road, Palo Alto, CA 94304-1126, USA
[3]School of Nutrition and Health Promotion, Arizona State University, 500 N. Third Street, Phoenix, AZ 85004, USA
[4]College of Nursing and Health Innovation, Arizona State University, 500 N. 3rd Street, Phoenix, AZ 85004, USA

Correspondence to: S McMahon
skmcmaho@umn.edu

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ABSTRACT
Integrating mobile technology into health promotion strategies has the potential to support healthy behaviors. A new theory-informed app was designed to augment an intervention promoting wellness motivation in older adults with fall risk and low levels of physical activity. The app content was evaluated for clarity, homogeneity, and validity of motivational messages; both the app and device were evaluated for acceptability and usability. The initial evaluation included nine adults (mean age, 75); four of whom also assessed the app's sensing abilities in the field. As part of an intervention feasibility study, 14 older adults (mean age, 84) also provided a follow-up evaluation of app usability. Evaluation participants assessed the app as valid, usable, acceptable, and able to sense most reported free-living activities, and provided feedback for improving the app. Design processes illustrate methodologic and interpretive efforts to operationalize motivational content in a theory-informed app promoting change in physical activity behavior.

KEYWORDS
Mobile health, Technology-supporting behavior change, Design, Persuasive technology, iOS accelerometer, Self-monitoring, Older adults, Physical activity, Health behavior intervention, Wellness motivation intervention, Behavior change technologies

Implications

Practice: Mobile health applications (apps) may be a promising adjunct to promoting physical activity among older adults, particularly when their design is informed by relevant behavioral theory and is user-centered.

Policy: To address complex processes of change required for the initiation and maintenance of these physical activity behaviors, policy makers supporting programs that target older adults need to invest in innovative solutions such as theory-informed, and user-centric technology that supports behavioral change.

Research: Researchers may use theory to inform the design and evaluation of technology that supports behavior change as a basis for further technology, intervention, and theory development.

Low levels of physical activity among older adults contribute to common, serious, and preventable causes of death and disability. Conversely, physical activity, including light intensity activity, confers a broad range of positive effects on health, function, and quality of life across older adult populations. Yet, fewer than 88.7 % of older adults report engaging in aerobic and strengthening activities on a regular basis; 16 % report engaging in strengthening activities [1]. Negative consequences associated with low levels of physical activity among older adults include decreased leg strength, decreased balance, and the potentially devastating effects of falls. At least 30 % of people over the age of 60 falls each year [2], often resulting in injury (e.g., traumatic brain injury or fractures); fear of falling; emergency room, hospital, and nursing home admissions; and death [3].

Empirical evidence supports the safety of interventions promoting leg strengthening, balance, and walking activities that reduce fall risk across older adult populations, including those with chronic illness and frailty [4]. Intervention content typically includes practicing specific exercises and walking according to individual preferences and comorbid conditions [4, 5]. Most of these interventions are based on kinesiology and dose response principles, yet often do not address strategies for promoting motivation to initiate and maintain these physical activity behaviors. Few have included physical activity behavior outcomes or technical strategies to support behavior change [5]. To build on current intervention research in the field of falls prevention, the design of a wellness motivation intervention, Ready~Steady, was tailored for use in older adults with low physical activity levels and fall risk. Its design was based on the wellness motivation theory (WMT), which addresses how people develop goals for health behavior change, how they imagine opportunities for action, and how they create strategies and plans for health-related behavioral change that is consistent with personally valuable goals [6]. Motivation for behavioral change in the WMT is posited to be dependent on social contextual resources and their dynamic inter-relationships with behavioral changes processes. Thus, the promotion and measurement of behavioral change are central to operationalizing the WMT; the behavior of interest in Ready~Steady being physical activity. The availability of modern mobile technology presented an opportunity to augment the Ready~Steady intervention through the use of app features enabling the provision of real-time and historical feedback to users [7], and the use of devices enabling objective physical activity measurement through built-in accelerometer.

For mobile technology to be usable by the targeted audiences and to support interventions promoting health-related behavioral change, such as Ready~Steady, considerations for user-centeredness and theoretical relevance should be integrated into design features. There is a common perception that older adults do not want to, or are unable to, use technology in their everyday life. However, evidence supporting the contrary is mounting. Among older adults over the ages of 65 and 75, respectively, 68 and 48 % report using cell phones (including smart phones); 16 and 3 % report using iPods or Mp3 players [8]. Researchers have found that older adults are not averse to using technology. Rather, they are capable and are interested in using several technology options, particularly programs and apps relevant to their personal goals and health, such as monitoring devices [8, 9].

Two apps promoting change in physical activity behavior among adult and older adult populations have been tested, incorporating relevant theory. The UbiFit Garden, an app encouraging people to live an active lifestyle, was informed by the presentation of self in everyday life and cognitive dissonance theories [10]. In a 3-month field study evaluating its effects, physical activity duration among treatment participants remained constant, whereas physical activity among control participants decreased [10]. Flowie, an app encouraging older adults to walk, was informed by the individual motivation theory and concepts in social psychology [11]. Two older adults evaluated the app as an acceptable and useful physical activity monitor. While UbiFit Garden and Flowie provide examples of how behavioral theory can inform technology design, there is limited discussion of how these apps operationalize intervention theory or link to mediating or outcome variables consistent with the theoretical perspective [12]. Specification of design processes for mobile technology which address operationalization of theory and content validity is essential to provide more critical and comprehensive theory testing, thereby improving theoretical and empirical understanding of health behavior change [13–15]. The use of expanded behavioral theories to inform mobile technology design should result in interventions that address the mechanisms of behavior change over time and incorporate dynamic feedback systems, resulting in more effective interventions.

As no existing app reflects user-centered considerations for older adults and elements of the wellness motivation theory, a new app was designed to augment content in the Ready~Steady intervention with the goal of enhancing motivation for physical activity among older adults. Key app functions were incrementally implemented, analyzed, evaluated, and redesigned. The purpose of this paper is to describe (a) the app's design; (b) the evaluation of the app's motivational messages for clarity, homogeneity, and validity; and (c) the evaluation of the acceptability and usability of both the app and device.

THEORETICAL PERSPECTIVE

According to the WMT, motivation is a complex, dynamic process of individual growth based on personal values and resources, which directs the emergence of new and positive health patterns [6, 16]. Dimensions in the WMT include social contextual resources, behavioral change processes, and action; each is linked to motivation for physical activity known to reduce fall risk in older adults. These dimensions and related constructs provide the theoretical perspective for design of the Ready~Steady app.

Social contextual resources, including environmental, biological, and social factors, influence motivation for physical activities, including those proven to reduce fall risk. Environments that are aesthetically pleasing and free from physical hazards and crime are associated with motivation for physical activity [2, 17]. Biological changes such as the presence of muscle weakness, gait changes, imbalance, pain, and chronic conditions can negatively influence individual motivation [18, 19]. Social factors such as friends, family, and healthcare providers encouraging older adults to *take it easy* can also negatively influence motivation for physical activity [20]. Conversely, social support for engaging in physical activities positively influences motivation [21]. The social contextual resource dimension in the WMT suggests that technology promoting motivation for changes in physical activity behavior among older adults should enable users to share feedback and data obtained from their app within their social networks (physical or virtual) as a platform for engaging in discussions about individual and community resources.

Behavioral change processes, including self-knowledge, motivation appraisal, and self-regulation, reflect the propensity to strive toward new goals and move beyond goals that have been achieved. Current research supports the role of self-knowledge in providing a context for meaning through which individuals interpret new information and establish goals and self-regulation strategies, while acknowledging hopes and fears about future health and gauging self-efficacy [22]. Hopes and fears about maintaining independence and autonomy, falling, being labeled a faller, and being vulnerable all influence motivation for engaging in physical activity [23, 24]. Through motivation appraisal, individuals assess their goals, make judgments about how to attain goals, generate plans and strategies to achieve goals, problem-solve potential barriers, and determine commitment to valued outcomes [6, 16]. Older adults may identify barriers to engaging in physical activity without exploring why they exist and how they might be overcome [25]. Through self-regulation, behavioral intentions are transformed into personalized action through cognitive, affective, and behavior strategies consistent with valued goals. Self-regulation guides individuals in goal-directed behaviors through selective processing of information, behavioral monitoring, judging individual performance, and engaging in self-evaluation [26, 27]. Older adults may not examine their own physical activity patterns or causes of pattern variance. They may not compare their behaviors with their valued goals, such as personal satisfaction and development. The behavioral processes dimension in the WMT suggests that technology promoting motivation for changes in physical activity behavior among older adults should provide positive messages and data-based feedback encouraging self-assessment of behavior in relationship to personal growth. Goals should be individualized according to personal values, capacity, and preferences. Progress toward daily goals accomplishment should be visible in images and trended displays to foster self-knowledge and self-regulation.

Action in the WMT is mediated through increased awareness and use of social contextual resources and increased behavioral change processes. It informs which behavioral and health outcomes are relevant to the problem and population being studied. In this case, the action dimension in the WMT suggests that technology promoting motivation for changes in physical activity behavior should be linked to the outcome of physical activity behavior.

METHODS

Design strategies

Iterative design processes, informed by the WMT, were guided by (a) theoretical principles for designing technology supporting behavioral change [10, 28], (b) technology design strategies relevant for older adults [28], and (c) knowledge in biomedical informatics. Key functions of the app prototype are illustrated in Fig. 1. Linkages between WMT dimensions, constructs, and problems contributing to decreased motivation for physical activity, as well as motivational tools in the app are highlighted in Table 1. The app was designed to enable older adults to easily and comprehensively evaluate their pattern of physical activity behavior and progress. Positive messages and illustrations promote self-assessment, setting realistic goals, problem-solving, receiving rewards, and self-regulating activities.

Consolvo et al. [10] outline theory-guided principles for designing technology that encourages people to live physically active lifestyles. These principles were incorporated into the design of the app supporting Ready~Steady, including interface characteristics that are: (a) abstract and reflective, (b) unobtrusive, (c) public, (d) esthetic, (e) positive, (f) controllable, (g) trending/historical, and (h) comprehensive.

Older adult populations are diverse, yet documented trends may influence the use of mobile computers and apps. Older adult populations report using mobile computers less than younger populations [8]. They also report experiencing sensory and dexterity changes more often [29, 30]. Thus, the design of this app was sensitive to new mobile

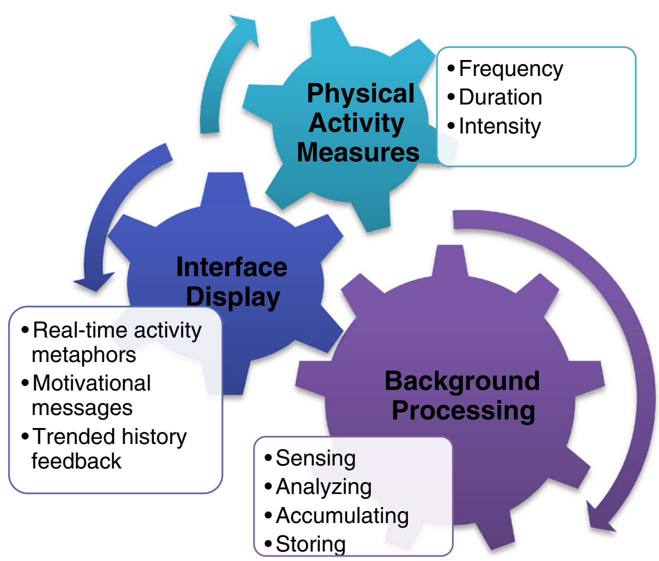

Fig 1 | Key functions of app prototype

Table 1 | Wellness motivation theory: links between theoretical constructs and motivational tools in the app augmenting the Ready~Steady intervention

Theoretical Dimensions	Theoretical Constructs	Problem(s) contributing to decreased motivation for balance and strengthening physical activity, and in turn fall risk	Motivational tools within the app that augment the Ready~Steady intervention
Social contextual resources	Environmental resources	Access	Interface displays serve as a platform for discussion of environmental resources
		Transportation	
		Physical environs	
	Social resources	Messages to take it easy	Interface serves as a platform for discussing the following in a socially supportive group
			Rewards
			Personal and community resources
			Problem solving
		Limited social support from friends, family and healthcare providers	
	Biological factors	Changes in strength, balance, and mobility	Interface provides
			Individual feedback (real-time and trended) about physical activity quantity and progress over time
			Encouragement to individualize goal setting and evaluation based on preferences and abilities
		Pain	
		Chronic illness	
Behavioral change processes	Self-knowledge	Gaps between desired and actual self	Motivational messages that are positive and emphasize the importance of personal goals
			Dream deep, for every dream precedes the goal
			Life is about creating yourself
			Anyone can start, right now!
			We are what we repeatedly do
		Lack of confidence	Participants individualize and control their short-term physical activity goals
		Fear of vulnerability	
		Belief that age prohibits benefits of physical activity and lends itself to inevitable falls	
	Motivational appraisal	Limited plans to meet valued goals	Positive motivational messages emphasize the importance of commitment to personal goals
			If not now, when?
			Do what you can, with what you have, where you are
			Where there's a will there's a way
			Bloom where you are
		Barriers identified without exploring why those are or how they might be overcome	Goal focused interface (goal statement, gauge/minute counter/blooming garden) informing progress toward goals
			Feedback illustrating physical activity quantity over time thereby enabling reflection on barriers and strategies to overcome them

Table 1 | (continued)

Theoretical Dimensions	Theoretical Constructs	Problem(s) contributing to decreased motivation for balance and strengthening physical activity, and in turn fall risk	Motivational tools within the app that augment the Ready~Steady intervention
	Self-regulation	Limited system for monitoring and evaluating behavior and goal accomplishment	Positive motivational messages encouraging engagement in and maintenance strategies to meet personal physical activity goals, even in the face of obstacles
			Energy and persistence conquer all things
			Slow and steady wins the race
			A man who wants something will find a way
			Every little bit helps
		Limited connection between physical activity behavior and valued goals such as personal satisfaction	Images that encourage self-monitoring and reflection about physical activity patterns as a basis for developing resources central to goal achievement
Action	Health behavior	Decreased physical activity	Feedback about physical activity that is trended over time, allowing individuals to share achievements and progress with family, friends, providers as desired

computer users with potential for changes in vision and dexterity, by including features such as (a) minimalist displays, (b) error prevention, (c) clear visual displays, and (d) help documentation and telephone support [30, 31].

The app uses the tri-axial accelerometer built-in to an iOS mobile platform to measure the quantity of physical activity (frequency, intensity, and duration). While the app may be used on any iOS mobile computer platform, in this case, the iPod touch® was chosen based on its availability and affordability. Although it is possible to program a range of sampling rates up to 100 Hz in this sensor accelerometer, 10 Hz was found to adequately sense physical activity intensity, duration, and frequency commonly practiced in this target population, while optimizing battery life [32]. The app was designed to allow the researcher to customize epoch sampling intervals; this pilot evaluation activity was effectively sampled in 5-s epochs every 15 s and then accumulated. The app was designed to be used by older adults whose usual physical activity involves sedentary (e.g., reading or watching TV while sitting quietly) and light intensity activity (e.g., walking leisurely or playing cards) [33, 34] in the context of mobility changes and multiple co-existing chronic conditions.

To remove noise in the accelerometer data, it was first smoothed using averages computed over a sliding window. Physical activity intensity was measured using *jerk*, the combined derivative of acceleration. The key assumption in utilizing *jerk* is that most gross human movement involves some *jerk*. This assumption is also used for *cut-point* classifications of physical activity in commonly used accelerometers such as the Actigraph [35] and therefore has strong empirical support. The Actigraph algorithms for *counts* are proprietary, however, and thus other methods for creating proxy *counts* are warranted [36]. Estimating *jerk* compensates for constant offsets, such as gravity, without the need for additional calibration [32]. *Jerk* measures are independent of device orientation, as three axes are added together [32].

Energy expenditure estimates (e.g., thresholds for light, moderate, and vigorous physical activity intensity) based on analyses of accelerometer measures have been demonstrated through calibration research [37, 38], yet this field is still developing. Many approaches appear to underestimate the energy cost of moderately intense lifestyle physical activities such as sweeping or vacuuming [37] and overestimate the energy cost of locomotor activities, such as walking and running [38]. To address limited differentiation, Crouter et al. [39] demonstrated that coefficients of variation are larger for lifestyle activities than they are for locomotion activities, and thus developed two regression equations accordingly. However, findings may not directly apply to older adults [38, 40]. Despite important progress made in estimating energy expenditure from accelerometers, more evidence is needed to understand how findings apply to free-living situations among older adults, including those known to be at risk of falls or frailty.

Considering the target population in this study may have several comorbidities, mobility changes, and fall risk, the range of energy outputs in the app was initially examined in a lab setting among four adults without known fall or health risks. *Jerk* was averaged over 90 s time frames on the treadmill at 0.5 miles per hour (mph) increments of speeds ranging from 0 to 5 mph. The average *jerk* sensed for each increment was found to be significantly greater using one-way ANOVA ($p<0.001$) [32]. Preliminary thresholds were identified for no activity and light, moderate, and vigorous activity intensities based on a simple rule-based classifier correlating energy outputs (*jerk*) with established metabolic equivalent of task (MET) values [41, 42] and treadmill speed as: (a) no activity (*jerk*=4–15; estimated MET, <1; 0–0.5 mph); (b) light intensity activity (*j*erk=16–100; estimated METs, 1–3; 0.5–3 mph); (c) moderate intensity activity (jerk= 101–160; estimated METs, 3.1–6; 3.1–3.9 mph); and (d) vigorous activity (*jerk*>160; estimated METS, >6; 4 mph). When the mobile computer rested on a counter top, *jerk* ranged from 0.10 to .39. The lab experiment demonstrated the ability to differentiate a broad range of locomotor physical activity intensities gauged by incremental treadmill speed. Initial thresholds were considered preliminary and not representative of the population. To enable further examination of physical activity intensity sensed by this app in older adults, data accumulated and stored includes average energy output (*jerk*) for each sampled epoch. The app allows researchers to configure thresholds of varied activity intensities (e.g., sedentary, light, moderate, and vigorous).

Evaluation

Iterative evaluation processes reported here capture the initial evaluation of the app and device. Motivational messages in the app were evaluated for clarity, homogeneity, and validity; and the app and device were evaluated for acceptability and usability. A follow-up evaluation of usability within a feasibility study of the Ready~Steady intervention is also presented. Approval from the Arizona State University institutional review board was obtained for both studies.

Initial evaluation

Convenience sampling was used in this initial evaluation to recruit adults over age 60 from rural and urban communities. The principal investigator, in collaboration with the local area agency on aging, recruited volunteers from existing community-based health promotion programs and a county fair. No incentives were provided for participation. The goal was to understand potential user interpretations of the app's interface display and usability as a basis for guiding its next iteration and integration into a feasibility study of a wellness motivation intervention.

The purpose of evaluation and general procedures were explained to potential volunteers. Semistructured interview protocols were developed to include 40 focused questions and 6 open-ended questions, lasting approximately 90 min. Field notes were also obtained. Interviews inquired about participant impressions of motivational content in the interface display with particular attention to message clarity, homogeneity of content, or the degree to which messages fit together conceptually, and whether the domain of each concept is reflected in messages [43–45]. Evaluation of each motivational message were on five-point scales ranging from 1 (strongly disagree) to 5 (strongly agree). Message clarity was evaluated both to determine if each message reflects a unique construct and for clarity of presentation. Homogeneity of content is a requirement for both reliability and content validity. In evaluating messages, the rating activity consisted of examining each message and answering the questions: "Do these messages generally belong together?" and "Does each message belong in the set?" The content validity of messages was determined based upon how messages represented the meaning of each construct. For ratings of content validity, raters were asked to respond to questions about the fit between construct definitions and messages presented.

Usability, acceptability, and use in free-living circumstances [46, 47] were measured to evaluate mobile app design strategies. This portion of the interview addressed learnability, effectiveness, and satisfaction as indicators of usability. Learnability, defined as ease with which a mobile computer app can be learned, evaluated design strategies used for error prevention and help documentation [46, 47]. Effectiveness, defined as perceived usefulness and value of personal feedback about physical activity, evaluated design strategies enhancing the app's controllability and feedback strategies. Satisfaction, defined as participant opinions about wearing the iPod touch® and looking at Ready~Steady's interface display, reflected design strategies used to create an unobtrusive, public, and esthetic app (e.g., comfortable) [10]. The seven questions evaluating usability (six using a five-point scale, one open-ended) focused on learnability, satisfaction, and effectiveness. Participants were asked to rate usability by indicating to what extent they agreed with each item using a scale ranging from 1 (strongly disagree) to 5 (strongly agree).

Four low fidelity interface, display images were also shared with participants to evaluate app acceptability. Images reflected design strategies used to create interface displays with minimalist, clear [30, 31] abstract, reflective, positive, and esthetic characteristics [10]. Two images were nonliteral and esthetically appealing. Two images represented different mechanical gauges. Participants were asked what each image illustrated, what information each provided, which of the images was easiest to understand, and which was most appealing.

Four participants in this initial evaluation volunteered to use the device (iPod touch®) and the app over seven consecutive days. They were given activity journals and asked to (a) identify the time and duration they engaged in meaningful activities for health or well-being each day and (b) write their observations and suggestions about using the app. Instructions for operating the app and writing in the journals were provided via demonstration, supervision of return demonstration, and a written document. To address additional questions and assist with troubleshooting, participants were called within 24 h of receiving initial instructions. They were also given a resource telephone number for additional follow-up.

Data were analyzed using descriptive statistics. Differences in usability ratings between participants with smart phone experience, and those without, were evaluated using Fisher's exact tests. Accelerometer data from the initial evaluation was analyzed for continuous sensing (at least 8 h per day) [48]. Comparisons of accelerometer energy output, estimated energy expenditure, and estimated MET of self-reported physical activities were examined using Spearman's rank correlation coefficient. Narrative data were transcribed, coded, and analyzed.

Follow-up evaluation

A follow-up evaluation of the app was conducted as part of a larger feasibility pilot of the Ready~Steady intervention, details of which are reported in another publication [49]. Purposive sampling was used in the feasibility study to recruit rural, community dwelling older adults with low levels of physical activity and fall risk. Participants were randomly assigned to an intervention group (Ready~Steady) or an attention control group. The goal of this follow-up evaluation was to understand the usability of the updated app in the context of the Ready~Steady intervention, as a basis for further development of the intervention and the app. Each participant was introduced to the app during a 30–45 min orientation and at least two follow-up phone calls or visits. This initial orientation, guided by a protocol based on results from the initial evaluation, focused on the purpose of the app, how to charge the device, and how to activate the app each morning. Orientation was delivered verbally and demonstrated, after which participants were encouraged to practice each of these basic functions. Guidance, reassurance, and positive feedback were provided during these return demonstrations. Written, illustrated instructions were provided to each participant along with a telephone number for troubleshooting help. Follow-up phone calls or visits were made within 24 and 48 h of initial orientation. Usability items and interviewing procedures mirrored those in the initial evaluation. Numeric data were analyzed using descriptive statistics. Narrative data were transcribed, coded, and analyzed.

RESULTS

Initial evaluation

Nine adults between ages 60 and 81 years of age (mean=74.6) volunteered for the pilot evaluation. Four volunteers were female; five were male. Four reported using computers on a regular basis and three owned smart phones. All nine participants responded to all items addressed during interviews.

Validity of theory-based motivational messages

Participants evaluated the clarity of motivational content in the 12 motivational statements as somewhat (3) to very clear (5), with means ranging from 4.2 to 4.8. Ten of the statements elicited overall positive responses to clarity, homogeneity, and correspondence to WMT constructs, with mean ratings ranging from 3.3 to 4.78. Relevance of two motivational statements ranged from not at all relevant (1) to very relevant (5) with an average of 3.1. All participants suggested at least one additional or modified motivational statement, such as "every little bit helps," "be yourself," "do your best at whatever level you are," "bloom where you are," and "getting old is not for sissies."

Usability

Responses to usability items ranged from somewhat agree (3) to strongly agree (5) with mean ratings ranging from 4.4 to 4.6; differences between smart phone owners and non-smart phone owners were not statistically significant. Narrative data addressing learnability, effectiveness, and satisfaction reflected both support for and potential barriers to app use. Most participants felt anyone could learn to use the app; two suggested that learning curves would vary in length. Suggestions for improving app instructions included providing 1:1 instruction with demonstration and return demonstration on charging the device and activating the app, as well as incorporating illustrations into written instructions. Two participants commented that the information they received from the app about physical activity behavior was more helpful than they expected. They found themselves checking the app frequently and adjusting their activity accordingly. In contrast, two other participants commented that they were not sure if the information on the interface

Table 2 | Bivariate Spearman correlations for preliminary application prototype thresholds, outputs, and estimated MET values

Variable	1	2	3
MET values	1.00		
Application prototype preliminary threshold	0.668[a]	1.00	
Energy output (median jerk)	0.807[b]	0.917[b]	1.00

[a] Correlation is significant at the 0.05 level (two tailed)

[b] Correlation is significant at the 0.01 level (two tailed)

display would be "valuable," and that they may not wear it in certain locations, such as church. One participant said "I would use it all the time if it was free." Participants noted that they shared information displayed on their app with friends and family.

In response to low-fidelity images, seven of the nine participants evaluated the image of a blooming garden as most acceptable, easiest to understand, and the most appealing. Narrative data characterized the image as illustrating positive affective characteristics and information about health. Participants noted that the illustration is "positive," "it makes me smile," and it provides information about "health" and "progress." Participants, both male and female, commented that having a gauge such as the sun in one illustration, and a minute counter, would help them to evaluate their daily activity and plan their actions accordingly. One participant suggested removing the individualized goal (daily minutes of activity) altogether.

Sensing physical activity in free-living circumstances

Four participants wore an iPod touch® for 8–12 h daily over the course of 4–7 days (mean=5), consistent with estimates of a "valid" days based on accelerometer data [34]. Reasons for wearing the iPod touch® less than 7 days included unanticipated travel plans and forgetting. Two participants also reported, and stored data confirmed, that the battery life of their iPod touch® was less than 8 h. Journal data recorded participant's engagement in sedentary activities such as reading quietly and low-intensity activities such as standing, cooking, walking leisurely, shopping, housekeeping, gardening, and attending a "bone builders" class. Three journals recorded moderate intensity activities (e.g., walking briskly and heavy gardening) and vigorous intensity activities (e.g., jogging and bicycling). All physical activity recorded in journals were sensed by the apps.

Table 2 presents Spearman rank correlations calculated between energy output (median *jerk*) and activity recorded in journals, estimated MET values for types of activities reported, and activity energy expenditure estimates sensed and analyzed by the app (using preliminary thresholds according to lab findings). Correlation values range from $p=0.668$; $P<0.05$ to $p=0.9167$; $P<0.01$. Sedentary activity was analyzed by the Ready~Steady app as no activity and the majority of self-reported light, moderate, and vigorous intensity activities were analyzed accordingly. Important inconsistencies included low-light intensity activities, strength and balance activities, and bicycling. For example, standing, considered to be a low-light intensity activity [50], elicited a median energy output of 7 and was therefore analyzed as no activity, consistent with other estimates of physical activity using accelerometetry [39]. Leg strengthening and balance activities (e.g., activities in "bone builders") elicited a median energy output of 10.6 and were analyzed as either light intensity activity or no activity. Jogging elicited a median energy output of 210 and was analyzed as vigorous activity. Bicycling 17 miles per hour elicited a median energy output of 49 and was analyzed as light activity.

Journal entries revealed that displaying accumulated activity minutes, even when beyond individual goals, helped participants monitor their physical activity patterns. One participant noted that "you can glance at it any time, it continues to count even after you meet your goal," "it does all the work." Two of the iPod touch® battery lives were less than 8 h, which increased to 12–14 h with the addition of a new battery sleeve. Participants preferred longer battery life so that apps could capture all their daily activity. Participants suggested that the range of minutes (0–60) on the graph displaying historical activity was not broad enough to record all their daily activity and thus requested the *y*-axis of the graph be expanded to at least 150 min so that high values for total daily activity are visibly credited. One participant observed that activity minutes accumulated when the device was on a car seat, but not when wearing it on a belt in the car, and thus suggested we include this information in directions to future users. Most participants preferred the elastic *small personal item* belt [51] to wearing the device in a pocket or on a belt clip.

Follow-up usability evaluation

Fourteen participants, randomly assigned to the intervention arm of the feasibility study evaluated the usability of the device and updated app augmenting the Ready~Steady intervention. The mean age of this group was 84 years and the average education level was 12 years. Similar to the initial evaluation of the app, participants in the follow-up evaluation of usability mastered app use within a few days and self-initiated troubleshooting help when needed, through neighbors, friends, and family members.

Most participants in this follow-up evaluation agreed or strongly agreed with items measuring the usability (e.g., is it learnable, satisfying, and effective) of technology integrated into the Ready~Steady intervention. On a five-point scale ranging from 1 (strongly disagree) to 5 (strongly agree), mean scores of these questions were 4.2, 4.46, 4.46, 4.46, 4.53, and 4.53, respectively. The narrative responses to an open-ended question about suggestions for improving the technology were categorized as *how to improve the app*, *learning to use the app and device*, and *wearing the device.* The majority of participants felt the app worked well. Narrative comments included, "It works fine for me," "I never thought about any improvement," and "It does more than I expected it to do." There was a "learning curve" for using the app and device, yet the majority of participants in Ready~Steady felt it was relatively easy to learn. Comments about learning to use the app included, "Anyone can use this," "Anyone can use this if I can," "I don't know anything about computers and I learned to use it." The majority of participants in the Ready~Steady intervention wore the iPod touch® daily in a belt for small personal items and used the app to view their activity levels and goal attainment.

Participants commented that "the belt did not bother me," "I wore it everywhere," and "I did not know I had it on." One woman did not use the app to monitor her activity, as she felt her own "internal gauge" kept track adequately. Several others checked their apps often as "incentive to keep going." For example, one man shared, "It surprised me, sometimes I felt I had probably met my goal, but found out I hadn't by looking at the monitor, then I would walk some more." Similarly, a woman shared, "If I didn't meet my goals by 6 pm, I would walk extra in the house." Another participant said it was a "reminder to keep moving," and fun to "compare and share numbers with others."

Field notes revealed information about learning to use the app and attitudes about using a monitor. Explicitly written instructions with illustrations demonstrating how to charge, activate, and wear the iPod touch® in the SPI belt were important aspects of initial orientation. Participants appreciated the instructive illustrations and the daily logs that provided cues for charging, wearing, and evaluating their progress. As mentioned previously, follow-up within 24–48 h was also important for reassurance and to review key instructions for use. Most participants sought instrumental assistance from others in their group, their friends, neighbors, or children when they needed help and then informed the PI about it the next day. Many participants showed their monitors to their physicians and family members and described positive responses. One participant said, "My doctor is impressed with my monitor and activities." Two participants were unable to operate the monitor well enough to use it reliably every day. They had difficulty tapping the app icon lightly enough to open the program. They also had difficulty connecting the charging cord and fastening the SPI belt. Both attributed difficulties to decreased dexterity in their hands due to arthritis. Another participant was unsure if she wanted to wear the monitor. She said, "I am not sure about this, I need to think about it and talk it over with my friends." She decided to wear it and later during discussions about how to keep track of physical activity, she said, "I just use the monitor." During group session conversations, several participants requested that battery life be extended beyond 14 h.

DISCUSSION

The design process presented illustrates methodologic and interpretive efforts to operationalize motivational content in a theory-informed app designed to enhance motivation for physical activity behavior that reduces the risk of falls among community-dwelling older adults. The process outlined furthers the design of theory-informed mobile technology interventions which target the mechanisms of behavioral change and provides a beginning step toward quantifying and integrating the views, experiences, and opinions of older adults into the design of technology that promotes physical activity. User-centered principles and iterative processes in technology design and evaluation ensures optimal usability [30, 46]. Findings from the initial evaluation guided the next iteration of the app developed for the Ready~Steady intervention, which are outlined in Table 3. Figure 2 illustrates various images of interface displays within the updated app.

Motivational statements in the app, evaluated as clear, homogenous, and consistent with WMT constructs will serve as a guide for future intervention integration, implementation, and evaluation [10, 52]. Two statements evaluated as less valid were removed from the app ("there is time for everything," "motivation is when your dreams put on work clothes"). One statement was changed from "every bit helps" to "every little bit helps," and one item, "bloom where you are," was added. Specificity in construct definition and motivational content chosen for the technology advance the ability to evaluate the intervention and evaluate the theoretical fidelity of the technology [13].

The app and device augmenting the Ready~Steady intervention were evaluated as a learnable, effective, and satisfying app among some older adults, particularly when 1:1 directions for use were provided and supplemented with clear, concise, and illustrated written instructions. Suggestions for improving help and support documentation were integrated into instruction manuals and protocols for the feasibility study (see Table 3). Although many older adults do not currently use mobile computer technology [53], participants in this evaluation were interested in technology and open to learning new ways of promoting physical activity. This is consistent with literature suggesting older adults effectively use health-related computer programs and Internet sites whose content is personally meaningful [9, 31]. Participants also noted that the app motivated them to be active, which is consistent with research suggesting that health promotion apps increase physical activity while decreasing sedentary time [11, 54]. Although, not formally evaluated, using the accelerometer built-in to a mobile computer hypothetically reduces user burden by combining multiple functions within one device.

The interface displaying a blooming garden, a sun that acts as a gauge and numerical feedback was preferred by initial evaluation participants. The blooming garden was appealing to participants, as it was positive, happy, and a metaphorical representation of activity levels. At the same time, participants were also interested in having specific numeric information as another way to evaluate their real-time and historical progress. These interface display characteristics were added to the app used in the follow-up evaluation; real-time minutes of physical activity in relation to an individualized goal are displayed below the illustration and daily minutes are trended on a graph whose *y*-axis ranges from 0 to 150 min (see Table 3). Despite feedback from a participant in the initial evaluation suggesting that the goal statement might not be useful, it was maintained and was evaluated as acceptable in the follow up feasibility study. Participant preferences in the initial and follow up evaluations were similar to

Table 3 | Characteristics of the mobile computer app augmenting the Ready~Steady intervention

Theory-guided strategies [1, 2]	
Abstract and reflective	Interface display of animated blooming garden acts a metaphor representing physical activity behavior and goal attainment according to individual goals, fostering self-knowledge.
	Minutes of actual and targeted daily physical activity are displayed below the picture.
Unobtrusive	Interface display is easily accessed when preferred by the user; it will not interrupt user activities and routines.
	Motivational messages, consistent with WMT constructs, are accessed by tapping the interface screen.
Public	The abstract garden display ensures the user is comfortable of others become aware of it during social situations.
	Mobile computers are frequently used mobile computer used in social situations.
	Individual feedback from app may be shared at user's discretion as a platform for discussing goals, progress, personal and environmental resources, and problem solving in socially supportive networks.
Esthetic	The garden display uses a feature that is traditionally esthetic.
	The iPod touch® is physically comfortable to wear when using small personal item belt.
Positive	Positive words and illustrations are used to encourage behavior; negative feedback is not used.
	Based on WMT, abstracted data are illustrated in a positive image encouraging users to reflect on personal behaviors in relationship to progress toward personal growth; positive messages encourage progress.
Controllable	Configurable app elements include interface display (e.g., blinded for research, feedback intra-intervention); threshold levels for estimating sedentary, light, moderate, and vigorous energy expenditure; epoch specifics.
	User physical activity goals are individualized according to personal capacity, preferences, and values.
Trending and historical	A trended display of daily activity minutes in week-long snapshots enhances user self-evaluation of activity patterns in light of social contextual factors and goals, thereby fostering self-regulation.
	Values on the y-axis of the weekly graphs were increased from 60 to 150 min.
	Mean energy output values were re-categorized in the app as non-wear time (0–0.7), sedentary activity (0.71–6), light intensity activity (6.1–80), moderate intensity activity (80–160), and vigorous intensity activity (>160).
Comprehensive	Physical activity data are sensed, analyzed, accumulated, and stored as intensity, duration, and frequency values. Data include energy output of each epoch sampled.
	In the WMT action is evidenced by a broad spectrum of physical activity behaviors. Individuals may intentionally integrate physical activities into everyday life; others may walk or engage in physical activities at scheduled times. In intervention mode, these data inform users of total activity time through interface images/minute counters/ graphs.
User-specific strategies [31, 32]	
Minimalist displays	Interface displays minimize clutter and complexity of text and illustrations.
	Three display screens accessible through corresponding icons constantly visible in app
	Home: is a simple garden illustration occupying most of the interface.
	Information: states, "watch the flowers BLOOM as you get more active" with corresponding illustration.
	Graph: a traditional graph displays activity minutes (0–150) on the *y*-axis and day of the week on *x*-axis.
	Arrows below the graph that enable users to scroll through weekly results.
Error prevention	Instructions are embedded into the app interface display.
	Wallpaper provides instructions for opening the program ("tap yellow icon").
	The information icon, described above, illustrates how to run the program.
	Other mobile computer functions and apps are placed in folders; Internet connections are turned off.
	Use of battery sleeve extends battery life up to 14 h.
Clear visual displays	Large-sized sans serif fonts are used.
	Each display uses high contrast illustrations and messages.
	Mobile computer is programmed to auto adjust brightness of the interface according to background lighting.
Help documentation and support	A protocol for providing 1:1 instruction and demonstration of charging the device and activating, using, and troubleshooting app was developed and tested that included written /illustrated instructions.
	Instructions also include information about a follow-up call (24–48 h) and troubleshooting contacts.

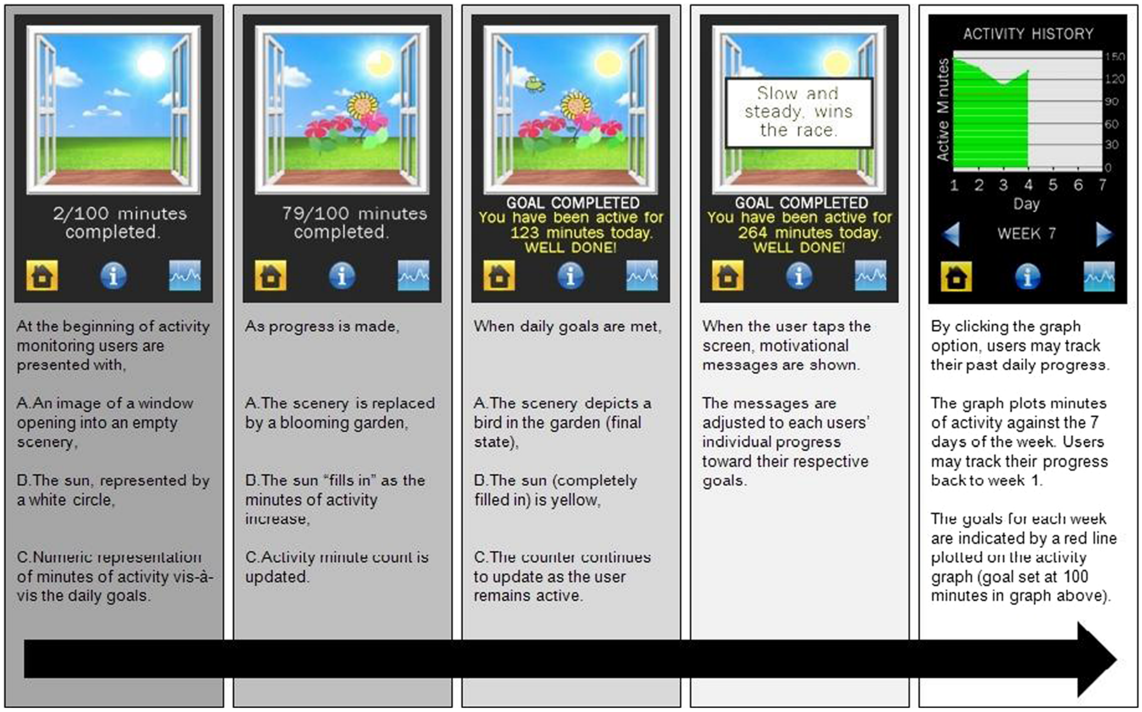

Fig 2 | Interface display images after initial participant evaluation of mobile computer app

those described by Albaina et al. [11] who reported that older adult participants in a walking study preferred feedback from an image of a growing flower, numeric information about steps in relation to goals, and a gauge trending progress. Minimalist displays whose designs combine esthetically pleasing and metaphorical images with literal feedback can be meaningful and acceptable to older adults.

Preliminary thresholds for no activity and light intensity activity were adjusted in the app according to energy output values observed by users in the initial evaluation who wore the iPod touch® for 4–7 days (see Table 3). Although the accelerometer function in the app measures varying intensities of physical activity for up to 14 h each day, this and previous studies have suggested that research is still needed to establish methods for estimating energy expenditure representing sedentary, light, moderate, and vigorous physical activity in older adults [40, 42, 55]. Individual differences in fitness, function, and age can influence the amount of energy expended for common activities [41]. For example, research examining accelerometer assessment in healthy adults over the age of 75 documents unique threshold estimations for moderate to vigorous activities [42] that are lower than those established for young adults [35]. Further, differentiating sedentary, low-light, and high-light intensity activities, including leg strengthening and balance activities, will be essential in this population [54, 56] as many older adults prefer light intensity activities and there is growing evidence that these and decreased sedentary behavior both improve health [50].

Limitations

The design of this app may be strengthened in future research (a) targeting diverse older adult populations, (b) evaluating theoretical fidelity of the technology, and (c) using methods for estimating energy expenditure in older adults. Although experts support at least five users in design evaluation to expose usability issues [57, 58], participants in the initial and follow-up evaluation may not be representative of diverse older adult populations and does not generate knowledge of technology usability, acceptability, and accuracy for different groups of older adults. Although narrative data suggested that evaluation participants found the app feedback helped them evaluate their physical activity patterns (e.g., self-regulation), this evaluation did not systematically inquire about theoretically postulated effects of the technology. Such an assessment would deepen the understanding of the influence of behavior change technology on the proposed theoretical constructs [13, 58]. Consistent with accelerometer validity research, this evaluation study identifies the need to further develop unique approaches to measuring physical activity intensity, duration, and frequency and specific categories in older adults [38, 40].

CONCLUSION

To advance research in the field of falls prevention, an intervention is being developed that combines wellness motivation strategies with fall-preventive physical activities. A mobile technology app was designed and developed to augment these wellness motivation strategies. This paper describes the design of the app and the evaluation of its content for clarity, homogeneity and validity of motivational messages, as well as its acceptability and usability. The WMT informed both the design of the app and the intervention it augments. The app design was guided by broad theoretical principles that support behavioral change technology and design strategies for older adults. Older adults (a) evaluated the motivational messages in the app as clear, homogenous, and consistent with WMT constructs; (b) identified acceptable displays for the app that combine an esthetically pleasing metaphorical illustrations with a minute counter and gauge; and (c) evaluated the app and device as usable and able to sense most reported free-living activities. Evaluation results suggest this theory-informed app is a promising adjunct to promoting motivation for physical activity behavior among older adults with low levels of physical activity and fall risk, while also enabling researchers to objectively measure a key variable of interest; physical activity frequency, intensity, and duration.

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