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# Digital, Social Micro-Interventions to Promote Physical Activity Among Midlife Adults With Elevated Cardiovascular Risk: An Ambulatory Feasibility Study With Momentary Randomization

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## Abstract

**Background** Although regular physical activity (PA) mitigates the risk for cardiovascular disease (CVD) during midlife, existing PA interventions are minimally effective. Harnessing social influences in daily life shows promise: digital *micro-interventions* could effectively engage these influences on PA and require testing.

**Purpose** This feasibility study employed ecological momentary assessment with embedded micro-randomization to activate two types of social influences (i.e., comparison, support; NCT04711512).

**Methods** Midlife adults ($N$ = 30, $M_{Age}$ = 51, $M_{BMI}$ = 31.5 kg/m$^2$, 43% racial/ethnic minority) with ≥1 CVD risk conditions completed four mobile surveys per day for 7 days while wearing PA monitors. After 3 days of observation, participants were randomized at each survey to receive 1 of 3 comparison micro-interventions (days 4–5) or 1 of 3 support micro-interventions (days 6–7). Outcomes were indicators of feasibility (e.g., completion rate), acceptability (e.g., narrative feedback), and potential micro-intervention effects (on motivation and steps within-person).

**Results** Feasibility and acceptability targets were met (e.g., 93% completion); ratings of micro-intervention helpfulness varied by intervention type and predicted PA motivation and behavior within-person (*srs*=0.16, 0.27). Participants liked the approach and were open to ongoing micro-intervention exposure. Within-person, PA motivation and behavior increased from baseline in response to specific micro-interventions (*srs*=0.23, 0.13), though responses were variable.

**Conclusions** Experimental manipulation of social influences in daily life is feasible and acceptable to midlife adults and shows potential effects on PA motivation and behavior. Findings support larger-scale testing of this approach to inform a digital, socially focused PA intervention for midlife adults.

## Lay Summary

Insufficiently active adults at risk for heart disease can lower their risk with physical activity. These adults respond positively to short, digital messages that offer social information, though responses differ by person and context.

**Keywords** Mobile health · Midlife · Ecological momentary assessment · Physical activity · Social influence · Cardiovascular risk

## Introduction

Cardiovascular disease (CVD) is consistently the leading cause of death in the USA [1], and during midlife (ages 40–60 [2]), risk for CVD increases sharply. Both women and men experience biological aging processes that increase CVD risk [3] and women's risk is exacerbated by sex-specific hormonal changes during menopause [4]. These changes are simultaneous with psychosocial stressors such as balancing multiple responsibilities (e.g., caring for children and/or aging parents; work; community groups) and role transitions (e.g., leadership positions; launching adult children [5]), which intensify during this period [6]. As a result, many midlife adults experience

high stress, depression, and anxiety [7], all of which further heighten CVD risk and the development of risk conditions such as hypertension and type 2 diabetes [8].

In contrast, regular physical activity (PA) has powerful health benefits for midlife adults [9], including improvement in clinical indicators among those with CVD risk conditions [10, 11], and is a primary target for improving cardiovascular health for these individuals. Although many PA interventions exist for this population, many require considerable time and energy, including in-person meetings or delivery of predetermined content at set times [12]. For PA promotion to be effective in this overburdened population, however, it needs to be flexible and accessible in daily life [13]. Emerging evidence shows that digital PA tools that provide flexible, in-the-moment support are acceptable to midlife adults [14], revealing a critical opportunity to develop innovative, tailored methods for improving PA interventions for this at-risk group.

Digital *micro-interventions* offer a promising approach. These involve short, highly focused intervention prompts that are delivered in daily life, often through text messages or mobile applications (apps) [15]. Micro-interventions can activate a range of effective behavior change techniques (BCTs) in the behavior change intervention ontology (BCIO [16]; e.g., goal setting). The BCIO is a comprehensive framework for behavior change interventions and their evaluation; it identifies several *social* processes shown to impact PA that can be targeted through digital micro-interventions, including social comparison and social support. These are among the most influential and desirable social influences for midlife adults [14], and thus hold particular promise as novel intervention targets.

Social comparison involves any BCT that draws attention to other people's behavior, thoughts, or feelings, and prompts self-evaluations relative to others in these domains [17], including the amount of PA achieved. Comparisons can be made to others who are perceived as doing better than the self (upward comparison targets), worse than the self (downward comparison targets), or similar to the self (lateral comparison targets) [18]. Social support is a group of BCTs that involve securing or delivering the aid of another person [16]. This includes informational support (e.g., offering tips for increasing PA), emotional support (e.g., offering encouragement to engage in PA), and supportive accountability (i.e., an approach that blends support with a sense of accountability to help individuals reach their goals) [19].

Both theory and evidence indicate that each type of comparison and support *could* be useful for increasing PA motivation and behavior. Social cognitive theory suggests that positive (e.g., supportive) interactions can boost motivation for healthy behavior [20, 21]; social comparison theory and its extensions (as well as social cognitive theory) highlight that comparison targets can serve as role models or behavioral models to emulate or avoid, and that relevant peers help to establish and enforce behavioral norms [22]. As a result, many behavioral PA interventions purport to activate these social processes (e.g., through PA leaderboards or community message forums) [12, 23], though often do not leverage these processes effectively. Simply providing opportunities for comparisons to or interactions with others (as in existing interventions) is not always beneficial, as it may not be powerful enough to engage the intended process and people differ widely in their preferences for and responses to these processes [24, 25]. This is true both between-person (i.e., stable differences between individuals) and within-person (i.e., differences in preferences for a given individual day-to-day or moment-to-moment, depending on the specific context) [26, 27].

For example, some people find information about others' PA motivating (and increase their own PA), while others find this information discouraging (and disengage; between-person effect). Similarly, response to social information often depends on immediate context and relative standing with respect to PA (within-person effect) [28]. Encouragement from others may similarly drive, hinder, or have minimal effect on behavior change, depending on the person and situation. Also, different types of social stimuli under these categories of social influence may not be equal. For instance, the effect of seeing information about just one other person's PA may differ from that of seeing one's own PA ranked against multiple others on a leaderboard, and not all types of support may be equally effective—overall, between individuals, or within individuals at different times. Thus, a tailored approach to leveraging social influences in daily life holds tremendous promise for promoting PA. To date, however, few interventions have attempted to leverage social influences in this way, in part because there is little existing evidence to directly inform such tailoring (i.e., what types of social prompts are most effective when). Additional information about responses to micro-interventions, in the target population and in their natural environment, is a critical step toward optimizing this promising approach to PA promotion.

In line with this goal, the present study was an initial short-term, proof-of-concept test of digital, social micro-interventions in the natural environment among midlife adults with elevated risk for CVD (i.e., NIH Stage 1 [29]; ORBIT Phase 2 [30]). We used an ecological momentary assessment design with embedded momentary randomization to evaluate proximal outcomes such as perceived helpfulness of each micro-intervention and changes in device-measured PA in the hours following each intervention. We also interviewed participants about their experience to inform future tailoring and refinements. Our first aim was to evaluate *feasibility*, using recruitment and retention rates, compliance with the study protocol, successful randomization at the moment level, and detection of within-person variability in predictors and outcomes of interest. Our second aim was to evaluate *acceptability*, via perceived helpfulness of social micro-interventions (in the moment, assessed quantitatively), participants' overall experiences, and their willingness to continue receiving micro-interventions after participation ended (both assessed qualitatively). Our third aim was to evaluate *indicators of manipulation effects* in the natural environment: differences in PA motivation and behavior between baseline and intervention phases and in response to randomly assigned intervention prompts. Consistent with the early phase nature of this study, the purpose of the last aim was to inform a larger, longer-term trial, rather than to evaluate efficacy.

## Methods

### Recruitment and Participants

Adults age 40–60 (inclusive) were eligible if they endorsed ≥1 of the following: (a) a physician diagnosis of (pre)hypertension, prediabetes, type 2 diabetes, metabolic syndrome, or high cholesterol and (b) current tobacco smoking or quitting in the past 3 months. Eligibility also required access

to a personal mobile device (for receiving momentary surveys with embedded micro-interventions), no active illness or injury that could impede PA behavior, and insufficient PA engagement (i.e., self-reports of <75 min of structured exercise per week or <7,000 steps per day in the past 4 weeks). Our goal was to target an at-risk population for whom effective, low-intensity interventions are not yet available. Although adults who exceed these PA criteria could experience health improvements from increasing PA, they already exceed the amount of PA that is associated with clinical benefit [31, 32]. To ensure that we reached a population that is in particular need of effective PA resources, we established eligibility criteria to target those who do not already reach the amount of PA necessary for clinically relevant health benefits.

Participants were recruited via electronic announcements at supporting institutions, social media posts, and flyers posted in local community centers. The study was advertised as seeking those interested in becoming more physically active and as an opportunity to test (and help researchers learn about responses to) PA messages. Of the 52 people who expressed interest, 33 completed an initial survey and 30 enrolled in the study. The average participant was 51 years old with a BMI of 31.5 kg/m$^2$; 33% identified as men (10/30) and 43% identified with a racial/ethnic minority background (13/30). The largest subset reported a diagnosis of high cholesterol (62%, 19/30). Additional demographic information can be found in Table 1 and a CONSORT flowchart can be found in Fig. 1.

## Measures

Participants completed a survey at baseline to report their demographic and health information (see Table 1). As in prior proof-of-concept PA studies [33–35], feasibility was evaluated based on (a) participant recruitment, retention, compliance, and randomization at the moment level, and (b) ability to detect within-person variability. To evaluate success with recruitment, research staff tracked the number of initial contacts who proceeded with enrollment and contacts' reasons for not participating. Retention and compliance were evaluated based on the number of contacts who completed 7 days of participation and percent completion of momentary surveys, respectively. Effective randomization was assessed with respect to the rates of deployment for each micro-intervention type, relative to expected. As described below, detection of within-person variability in predictors and outcomes was determined with intraclass correlation coefficients (ICCs). Acceptability was assessed using participants' perceptions of the helpfulness of social micro-interventions were measured immediately following exposure to social comparison prompts and social support messages during momentary surveys. Participants rated micro-interventions on a scale from 0 (*not at all helpful*) to 3 (*very helpful*). Acceptability was also captured via narrative perceptions during exit interviews (see below), including their overall impressions, what they liked and disliked about micro-interventions, and their interest in continuing to participate in a similar study involving digital PA support for a longer period (e.g., 3 weeks). Similar methods have been used to assess acceptability in other PA intervention proof-of-concept studies. For example, one recent study among women aged 50 and older used post-intervention qualitative feedback to assess general intervention perceptions and, similar to asking about one's own interest in continuing to use the intervention, asked participants whether they would recommend the program to a friend [34].

Finally, indicators of experimental manipulation effects (micro-randomization) were self-reported PA motivation and device-assessed PA behavior in response to intervention prompts. Following exposure to micro-interventions, participants reported their motivation for PA in the next few

**Table 1** | Demographic Information for Participants ($N$ = 30)

| Demographics | *M* (SD) | | *n* (%) |
|---|---|---|---|
| Age | 50.83 (6.68) | Gender identification (Man) | 10 (33) |
| BMI | 31.50 (6.11) | Hispanic ethnicity | 1 (3) |
| Starting level of PA (steps/day) | 5,273 (1,073) | | |
| Education | *n* (%) | Household income | *n* (%) |
| High School/GED | 2 (7) | Under $25,000 | 2 (7) |
| Associate's degree/technical degree | 7 (23) | $25,001–$50,000 | 1 (3) |
| Bachelor's degree | 10 (33) | $50,000–$75,000 | 9 (30) |
| Graduate degree | 17 (57) | Over $75,000 | 22 (73) |
| Racial identification | *n* (%) | Marital status | *n* (%) |
| White | 17 (57) | Married | 24 (80) |
| Black/African American | 10 (33) | Widowed | 3 (10) |
| American Indian | 2 (7) | Divorced | 3 (10) |
| Asian American | 1 (3) | Separated | 1 (3) |
| CVD risk conditions | *n* (%) | | |
| Hypercholesterolemia or hyperlipidemia | 17 (57) | | |
| Hypertension or prehypertension | 15 (50) | | |
| Type 2 diabetes or prediabetes | 5 (17) | | |
| Metabolic syndrome | 3 (10) | | |
| Smoker (or quit in previous 3 months) | 3 (10) | | |

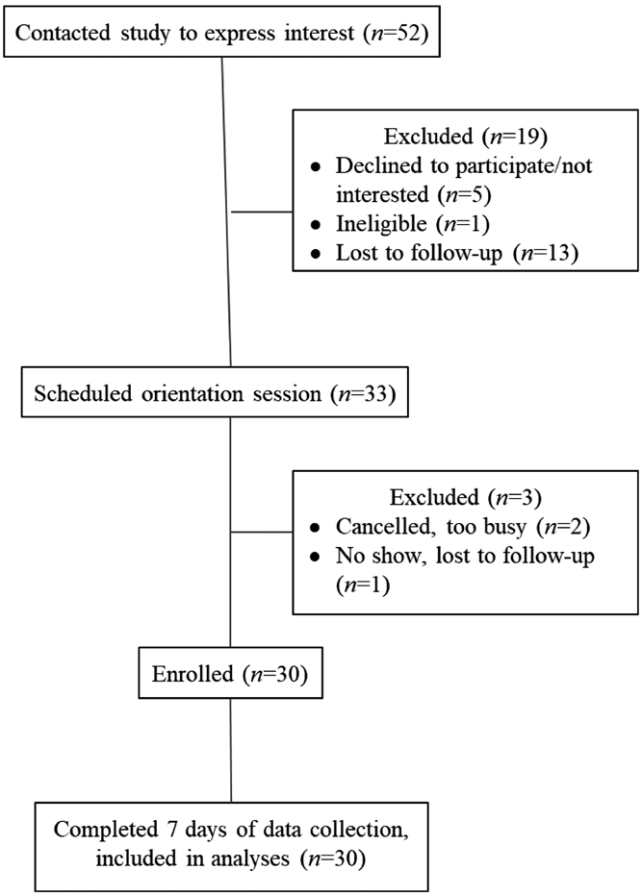


**Fig. 1.** CONSORT flowchart.

hours (first 3 surveys each day) or the following day (final survey of each day) on a scale from 0 (*not motivated at all*) to 3 (*very motivated*). Effects on PA behavior were based on a participant's steps per day and during the subsequent 3.5-hour observation period. Steps in these windows and per day were assessed using Accusplit AX2720MV pedometers (sent to them for use during the study; $n$ = 16, 53%) or the participant's own PA monitoring device (Fitbit, Apple Watch; $n$ = 14, 47%). The device used was consistent for each person across days of participation, in line with our within-person approach to evaluation, and sensitivity analyses showed no differences in response between those who used their own versus a study-issued device.

## Procedures

Micro-intervention content was pre-tested with the population of interest and refined with their input [36]. Data collection was fully remote and took place from April 2021 to January 2022, with a break in recruitment and enrollment June–September 2021. All procedures were remote and approved by the Institutional Review Boards at the supporting institutions, and the protocol was registered with clinicaltrials.gov (NCT04711512). Adults interested in participating completed a brief telephone screening with research staff and a 30-min orientation via Zoom. Those who did not have their own PA monitor ($n$ = 16) were sent a pedometer via mail. Baseline surveys were completed prior to orientations with electronic acknowledgment of consent. At orientations, participants provided documentation of consent via Adobe electronic signature and received an overview of the study from trained research staff. Staff also tested the distribution of momentary surveys with embedded micro-interventions to participants' mobile devices and scheduled their exit interviews. After each session, staff programmed distributions: 4 per day, separated by approximately 3.5 hours, aligned with participants' sleep/wake schedules. Semi-random survey timing was anchored to early riser (before 7:00 AM), standard riser (7:00–9:00 AM), and late riser (9:00 AM or later) schedules. Participants were randomly assigned to one of three schedules with unique survey timings each day, based on their wake time.

Participants then completed 7 consecutive days of survey completion. A 7-day period was selected to provide adequate opportunity to test the embedded micro-randomization (given that there were 4 surveys per day), and to gauge participants' experiences with and responses to the intervention content, while limiting participant burden in this early proof-of-concept trial. During Phase 1 (Days 1–3, observation only), they completed 4 surveys per day with no embedded micro-interventions. Phase 2 (Days 4–5) involved 4 surveys per day, each with randomization to 1 of 2 types of social comparison micro-interventions. The first survey each day showed a leaderboard of yesterday's steps per day that included 4 users, with the participant's ranking highlighted. Others on the leaderboard were described as other study participants, who were similar in age, starting level of physical activity, and physical health (i.e., with similar CVD risk factors). Leaderboards showed the participant's steps relative to 3 other users; ranking was randomized at each exposure using the survey software's randomization function. Subsequent surveys showed the specific step total of 1 other participant, described as "(their) steps so far today." Surveys displayed a step total designed to represent an upward, lateral, or downward comparison target (i.e., high, moderate, and low steps for that time of day, respectively, relative to U.S. PA guidelines) [37]. During Phase 3 (Days 6–7), comparison prompts were withdrawn and survey software randomization presented 1 of 3 types of social support messages [16, 19]: tips for being more active, encouragement to be more active, and supportive accountability to PA goals [38].

Examples of micro-interventions can be found in Supplementary Materials. After viewing each randomized micro-intervention, participants rated how helpful they found it for increasing their PA and how motivated they felt to be active in the next few hours (Surveys 1–3) or tomorrow (Survey 4). At the end of 7 days, participants returned for a brief, semi-structured exit interview with research staff to assess their experience of the protocol, willingness to continue receiving social micro-interventions, and feedback for future work. Trained research staff with backgrounds in qualitative interviewing and notetaking served as interviewers and followed a pre-specified interview guide. These interviewers took detailed notes on participants' responses, including direct quotations (cf [36, 39]). Of note, participants began and ended the study on different days of the week, based on their availability, and sensitivity analyses showed no change in results or conclusions when controlling for day of week.

## Data Analysis

To evaluate feasibility, rates of recruitment, retention, compliance, and successful momentary randomization were assessed descriptively. Variability in each construct was assessed using

multilevel mixed models, as described below. We examined two indicators of acceptability. First, we used numeric ratings of micro-intervention helpfulness, completed immediately after exposure to each intervention. We used 2-level multilevel models (moments nested in participants) in SAS PROC MIXED with restricted maximum likelihood to address missing data, which was minimal (<7%). We constructed empty mixed models to determine the immediate perceived helpfulness of micro-interventions overall and the extent of stability versus variability in helpfulness ratings (based on intraclass correlation coefficients [ICCs]). We also compared average helpfulness ratings between intervention phases (social comparison vs. support) and specific intervention types, and person-centered helpfulness ratings to test for within-person associations between helpfulness ratings and subsequent PA motivation and steps [40]. Second was participants' qualitative perceptions of the study, which were reviewed by the research team and categorized with consensus (i.e., positive, mixed, or negative). The first author also extracted data from these interviews that highlighted noteworthy concepts (e.g., retrospective or global perceptions of response social comparisons).

Other indicators of manipulation effects in the natural environment were PA motivation (at and across moments), steps per day, and steps per ~3.5-hour observation window. We also examined differences in average PA motivation and steps (a) between study phases (observation only vs. social comparison vs. social support) and (b) between moments with distinct types of social micro-interventions (within and across phases). Study phase and type of social micro-intervention were coded as categorical predictors; type of comparison intervention (leaderboard vs. 1 other participant), direction of comparison intervention (upward, lateral, downward), and type of social support intervention (tips, encouragement, accountability) were also coded as categorical predictors. As sensitivity analyses showed that controlling for time of day did not meaningfully affect conclusions, results are presented without this covariate.

Given the modest sample size for this feasibility study, *p*-values are reported but not interpreted; interpretation of results from multilevel models relies on effect sizes, presented as semipartial correlation coefficients (*sr*) and as differences in steps per day (which has real-world value). We considered *sr*s≥0.10 as potentially clinically meaningful, as they correspond to small but interpretable differences (i.e., Cohen's $d$ = 0.20) [41]. We also used our judgment in two ways. With respect to quantitative data, we selected individual participants' responses to visualize based on their illustration of noteworthy patterns (e.g., more positive responses to comparison than support prompts). With respect to qualitative data, we identified quotations from interviewer notes that aligned with, diverged from, or provided useful context for quantitative findings. Interpretation of findings did not use these visualizations or quotations in isolation; they are presented here to provide additional information to contextualize the main findings.

## Results

With respect to feasibility, it took 7 months to recruit 30 participants and enrollment completion was achieved at 58% of total contacts (30/52; see Fig. 1). Reasons for ineligibility or otherwise not enrolling included already achieving high levels of PA, poor timing due to travel or caregiving burden, and loss to follow-up. All 30 participants who arrived for an orientation elected to enroll and completed all study activities, for 100% retention through exit interviews. Compliance was high: of the 840 surveys distributed, 93% were completed (person $M$=93%, $SD$=.12, range 36%–100%). This resulted in deployment of 89% of the expected social comparison and 92% of social support micro-interventions. Less than half of the overall variability in ratings of perceived helpfulness of micro-interventions was attributable to between-person stability across moments (ICC=0.48). Similarly, less than 30% of the variability in momentary PA motivation (ICC = 0.27) and steps in each reporting window (ICC = 0.15) was attributable to between-person stability, suggesting that the present study procedures allowed for detecting expected within-person differences in each experience.

Concerning acceptability, across all moments and types, micro-interventions were perceived as somewhat helpful ($B$ = 1.50 out of 3, $SE$ = 0.15). Helpfulness ratings spanned the full range from 0 (*not at all;* 26% of ratings) to 3 (*very*; 27% of ratings) and showed <50% stability between-person (ICC = 0.48). Controlling for type, micro-interventions were perceived as most helpful at the beginning of the day, with ratings decreasing as the day progressed ($F$[3.85] = 6.72, $p$ = .0004, $sr$ = 0.31). Ratings also differed based on the type of micro-intervention. In the moment, support messages were perceived as more helpful than comparison prompts (contrast $F$[1,29] = 25.35, $p$ < .0001, $sr$ = 0.41), though helpfulness did not differ based on the specific type of support provided ($F$[2,53] = 0.32, $p$ = .73). Of the types of comparison micro-interventions, leaderboards were rated as more helpful than information about 1 other person's PA (contrast $F$[1,27] = 8.77, $p$ = .006, $sr$ = 0.31).

During exit interviews, all participants expressed positive impressions of the intervention and 29/30 indicated that they would like to continue to receive micro-intervention prompts. For example, participants offered:

- "I liked that it was very simple and it didn't feel invasive. A few short messages a day, something to think about as I do what I normally do." (Black woman, age 55)
- "I really liked encouragement messages, I found those motivating. I'd like to have them posted on my mirror at home so I can see them more often." (White woman, age 44)
- "I liked seeing information about other people. I saw it as a reference for how I was doing compared to others in the same age group." (Black man, age 50)
- "I liked being able to make comparisons. It made me feel a little competitive, which was motivating." (White man, age 40)

The remaining participant expressed enthusiasm about the approach, but indicated that they would only be willing to continue to receive prompts if they came fewer times per day:

- "It felt great seeing what others were doing and the messages about my attitude toward activity were very helpful. But it was way harder to [pay attention to the prompts] 4 times a day than I expected. I would keep going if there were 2–3 per day." (White woman, age 45)

Of note, multiple participants reported skepticism about the benefits of comparison information:

- "I try to avoid making comparisons…. Leaderboards and those kinds of things just motivate cheating and make people obsessive about their steps." (White woman, age 43)
- "I don't really compare myself. I don't think it would affect my physical activity." (Black woman, age 55)
- "I know my schedule and what I am capable of doing, so it does not help to compare…. [But] I liked being able to reflect on my own patterns. That made me sure I'm doing the best I can right now." (White woman, age 60)

There were no similar comments made for support, either generally or with respect to specific types. None of the participants reported noticing repeated micro-intervention content across exposures.

As noted, less than 30% of the variability in momentary PA motivation and steps in each observation window was attributable to between-person stability, leaving room for evaluating potential predictors of differences in each PA experience (i.e., indicators of manipulation effects). Although between-person stability in steps at the day level was ~50% (ICC=0.51), we detected ~50% variability within-person, allowing for both moment- and day-level comparisons between study phases. Both motivation to be active ($F$[2,58] = 1.46, $sr$ = 0.20) and steps per day ($F$[2,55] = 0.37, $sr$ = 0.14) differed between study phases, though steps in the subsequent reporting window did not ($F$[2,57] = 0.07, $sr$ = 0.09; $p$s 0.24–0.65). Unfortunately, both motivation to be active (contrast $F$[1,58] = 1.24, $p$ = .22, $sr$ = 0.20) and steps per day (contrast $F$[1,55] = 0.75, $p$ = .46, $sr$ = 0.16 or –364 steps) *decreased* from the initial observation period to the intervention phases. During the intervention phases (and controlling for the type of micro-intervention), however, at times when participants perceived the intervention prompt as more (vs. less) helpful than usual, they reported greater motivation to be active ($F$[1,393] = 5.00, $p$ = .03, $sr$ = 0.27) and took more steps in the following ~3.5 hours ($F$[1,340] = 0.57, $p$ = .45, $sr$ = 0.16 or 107 steps).

### Response to social comparison prompts.

Relative to 1 other comparison target, participants perceived themselves as more active when exposed to intended downward targets 80% of the time and less active when exposed to intended upward targets 62% of the time. Thus, in general, participants perceived their progress relative to the comparison target as intended the majority (though not all) of the time. As noted, social comparison micro-interventions were perceived as less helpful in the moment than social support messages ($F$[1,29] = 25.35, $p$ < .0001, $sr$ = 0.41). Between the two types of comparison interventions, however, leaderboards were perceived as more helpful than information about just one other person ($F$[1,27] = 8.77, $p$ = .006, $sr$ = 0.31). Further, motivation to be active ($F$[1,27] = 0.34, $p$ = .56, $sr$ = 0.11) and steps in the following ~3.5 hours ($F$[1,26] = 0.37, $sr$ = 0.14 or 199 steps) were also higher after exposure to leaderboards than to information about just 1 other person. Relative to the baseline period, motivation increased after participants viewed their rank as 3rd or 4th on the leaderboard (contrast $F$[1,204] = 1.63, $p$ = .11, $sr$ = 0.23) and decreased after they viewed their rank as 1st or 2nd (contrast $F$[1,204] = 1.90, $p$ = .17, $sr$ = 0.21; Fig. 2). Steps in the following ~3.5 hours showed a different pattern: relative to baseline, steps increased after participants viewed their rank as 1st or 4th on the leaderboard (contrast $F$[1,193] = 0.29, $p$ = .59, $sr$ = 0.13 or 214 steps) and decreased after they viewed their rank as 3rd (contrast $F$[1,193] = 0.08, $p$ = .78, $sr$ = 0.10 or 190 steps; Fig. 2). With respect to comparisons to 1 other person, steps decreased relative to baseline after viewing someone's steps that were moderate for that time of day (lateral comparison; contrast $F$[1,193] = 1.11, $p$ = .27, $sr$ = 0.19 or 354 steps).

### Responses to social support prompts.

Participants rated encouragement messages as the most helpful of the 3 support types and more helpful than tips or accountability messages (contrast $F$[1,53] = 0.59, $p$ = .44, $sr$ = 0.16). Motivation to be active and steps in the following ~3.5 hours also were lowest after exposure to accountability messages, and both were lower after this type of message than after tips or encouragement messages (motivation: contrast $F$[1,53] = 2.72, $p$ = .11, $sr$ = 0.23; steps: contrast $F$[1,49] = 0.22, $p$ = .64, $sr$ = 0.13 or 106 steps in the following window). Relative to the baseline period, motivation decreased in response to tips (contrast $F$[1,204] = 1.04, $p$ = .31, $sr$ = 0.18) and accountability messages (contrast $F$[1,204] = 4.93, $p$ = .03, $sr$ = 0.27), but did not differ in response to encouragement messages (contrast $F$[1,204] = 0.008, $p$ = .93, $sr$ = 0.05). Steps in the following ~3.5 hours decreased in response to all types of support, relative to baseline, with the largest decrease in response to accountability messages (contrast $F$[1,204] = 1.00, $p$ = .32, $sr$ = 0.18 or 272 steps; tips: contrast $F$[1,193] = 0.11, $p$ = .74, $sr$ = 0.10 or 92 steps; encouragement: contrast $F$[1,193] = 0.08, $p$ = .29, $sr$ = 0.10 or 83 steps).

Fig. 3 offers visual examples of within-person variability in motivation and steps in each reporting window for individual participants during each intervention phase. These figures illustrate variability in responses to micro-intervention type (comparison vs. support) both between- and within-person. For example, panel A shows positive responses to comparison interventions but less so to support, whereas panel B shows the reverse. Panels C and D show that the same participants had different responses to distinct types of comparison and support interventions.

## Discussion

CVD remains the leading cause of preventable death in the USA and risk escalates during midlife. PA is key to secondary prevention of CVD among midlife adults, and there is a critical need for theory-driven PA promotion methods that can (a) effectively harness social influences such as comparison and support and (b) provide easily accessible intervention with low intensity and low burden. The present study demonstrates feasibility and acceptability of digital, social micro-interventions to address this need. Although this study was not designed to evaluate efficacy, we evaluated proximal outcomes of interest (e.g., immediate post-intervention motivation, steps in the following hours), with mixed findings. Overall, this study highlights the promise of this approach for tailoring micro-interventions to people and contexts, and points to specific next steps for advancing the science of activating social behavior change techniques in real-world settings.

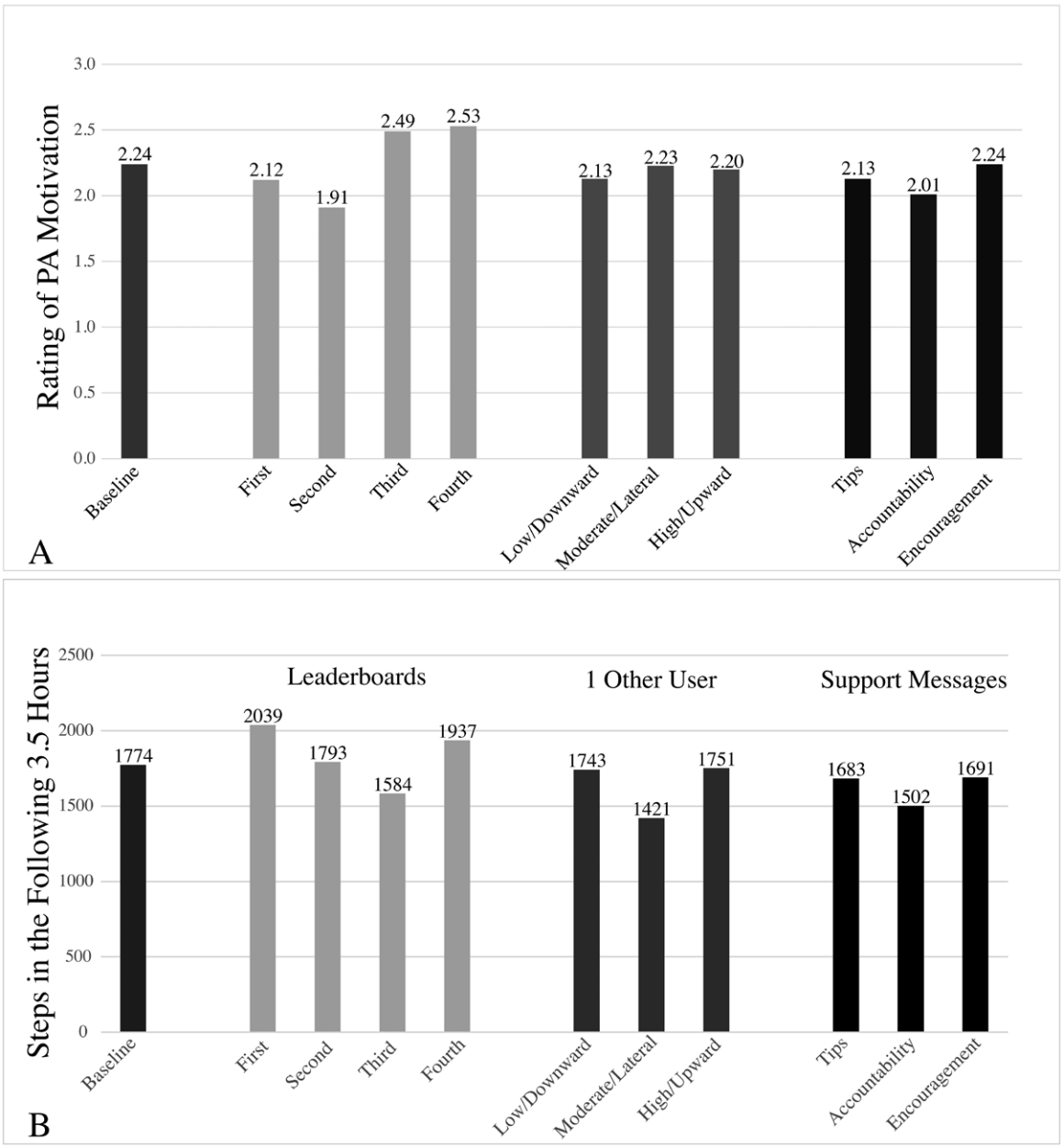


**Fig. 2.** Motivation to be physically active (Panel A) and steps in the following 3.5 hours during baseline observation (Days 1–3) and after distinct types of micro-intervention prompts (Days 4–7).

We were able to recruit the target number of participants in a reasonable time frame, and retention and compliance with the protocol were excellent. The observed feasibility metrics were also aligned with those of other PA intervention proof-of-concept studies. For example, the observed >50% enrollment rate exceeded the rate observed in a similar recent trial among insufficiently active adults with obesity (~25% of total contacts enrolled) [35], Our 7-month timeline to recruit 30 participants mirrors the goal timeline for a planned PA intervention among individuals at elevated risk for heart disease (target $n$ = 30 in 6 months) [33], and the observed 100% retention rate is commensurate to that achieved or planned in several trials among similar populations (rates of 80%–100%) [33–35]. Overall, deployment of micro-interventions occurred as planned across people and days and findings showed little indication of repeated exposure (i.e., to content categories or specific content). Importantly, participants highlighted the simplicity, accessibility, and ease of the approach and expressed positivity about many of the micro-interventions. Many commercial products exist that can provide similar resources (e.g., Fitbit). However, in this and prior studies [39, 42], midlife adults indicated a preference for quick, simple, easy-to-use tools over the complexity of options available with commercial products. This may stem from the need to manage PA and interventions in the midst of unique and often unpredictable demands and stressors of midlife [6].

Although participants expressed favorable attitudes toward the overall approach and were willing to continue receiving micro-interventions, in-the-moment ratings of helpfulness were variable. We wanted an indication of immediate subjective response, though it is possible that an immediate rating

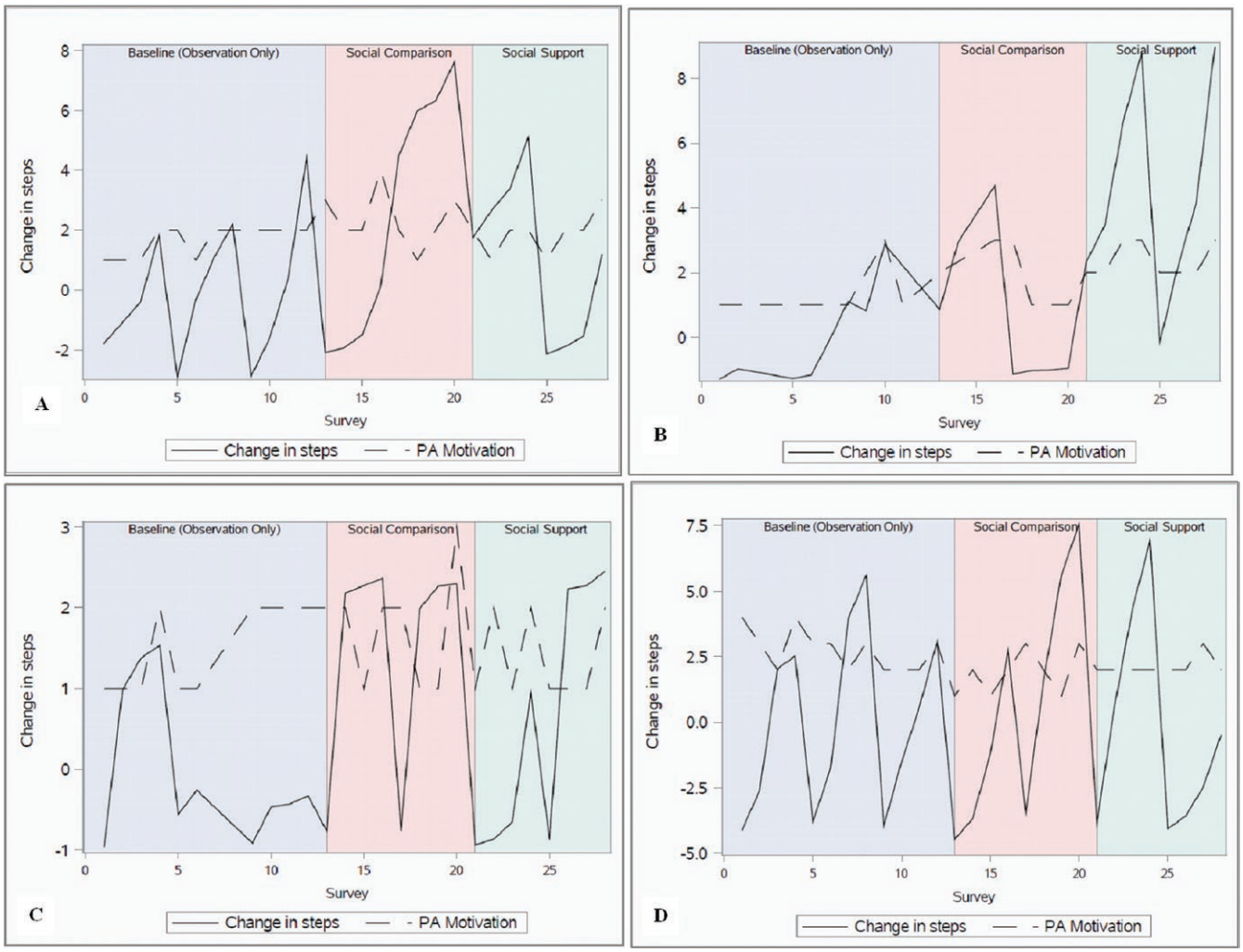


**Fig. 3.** Patterns of change from person means in motivation to be physically active and steps in the following 3.5 hours during baseline observation (Days 1–3) and after distinct types of micro-intervention prompts (Days 4–7), displayed for 4 individual participants.

of helpfulness is not particularly informative. Users may need time to process the intervention content, consider whether or how to put it into action, and whether it resulted in the desired (or any) behavior change. Thus, useful assessments of helpfulness may only emerge later, though this retrospective approach opens the door to known report biases (that differ from those of immediate responses) [43]. As discussed below, we also detected patterns in the types of micro-interventions that were perceived as most helpful on average, and there was <50% between-person stability in helpfulness ratings. Such differences across micro-intervention types and contexts could be more important from a tailoring perspective than a cumulative measure, especially given that both PA motivation and behavior were higher than usual at times when participants found the intervention more helpful than usual (within-person).

With respect to micro-intervention type, several participants expressed preferences for social support messages over comparison prompts and interest in content that is positive, encouraging, and validating over content focused on accountability. They also appeared to respond more favorably to the former with respect to short-term PA outcomes. This preference for encouragement instead of accountability contrasts with the initial desire for accountability that often brings people to behavior change interventions [44–46]. Although people recognize the benefits of accountability, providing this type of support in short messages may not be beneficial (relative to other approaches). Yet, the present study adds to evidence indicating that emotional support (encouragement) alone may not be enough to promote success [47]. Although participants' motivation and step counts were most favorable after exposure to encouragement messages (vs. accountability or tip messages), these more "favorable" outcomes were not the expected *increases* in PA motivation and steps. Rather, these outcomes were stability in motivation and less steep decreases in PA behavior.

Our approach to accountability introduced ways to hold oneself accountable (e.g., scheduling PA as an "appointment"), whereas encouragement promoted a positive attitude toward PA (e.g., remembering why it is important and that small changes add up). We kept stark distinctions between types of support messages to better understand how activating different types of support could prompt different responses. Refinements could present accountability using a positive tone and embedding encouragement (e.g., to try out the technique suggested or expressing confidence in one's ability to execute it). Ultimately, these messages may be more acceptable and/or more effective if combined with human

support (e.g., from a coach) or otherwise integrated a human perspective more explicitly (e.g., "I" statements) [19]. The former requires more of participants' time and can be more costly than the latter, but may be more powerful. As such, ongoing efforts to optimize mobile interventions by maximizing efficacy while minimizing burden on both ends will be critical to this line of work [48].

The importance of balancing what participants want, like, or find helpful with what works to change behavior is also relevant to social comparison. In this study, participants' only *increases* in motivation or steps from baseline were after social comparison micro-interventions—specifically, leaderboards. However, several (women) indicated that they "don't make comparisons" or "don't find comparisons helpful," and this is not unique among midlife adults (or more broadly) [49]. Comparisons have a bad reputation: they are often cited as "odious" and a "thief of joy," and midlife women in particular believe they reflect negative qualities such as judging other people [50]. The majority of participants to identify comparison components as desirable in the present study were men, and gender may be a useful tailoring variable for personalization. Though caution is needed when using a static, high-level construct such as gender, as there is variability in both preferences for and responses to the prompts within-gender. Thus, comparisons may be helpful for many individuals under the right circumstances.

Further, leaderboards may be preferable to information about 1 other person because they offer a range of comparisons, with respect to distance between one's own and others' behavior if not also with respect to direction (which is limited if the viewer is ranked first or last). This allows for making the comparison that is most helpful in the moment or for making multiple comparisons (e.g., to mitigate any negative effects of an initial comparison). Yet, evidence shows that people do not always choose to focus on health comparisons with positive outcomes, even when they have a range of options [51] such as on a PA leaderboard [26]. Their outcomes are also not universally positive even when they receive their preferred direction of comparison [24].

The number of participants and observations in this study does not support fine-grained tests of individuals' responses to different comparison opportunities. However, visual evidence aligns with and extends prior work showing the variable nature of comparison responses both between- and *within*-person (see Fig. 3). This variability could be used to tailor PA micro-interventions more effectively; at present, the optimal contextual determinants for tailoring are not yet clear. Theory and emerging evidence suggest that the extent to which one *identifies with* or *contrasts against* a comparison target may be useful for this purpose [22, 52, 53] Future work to test these hypotheses will be most informative if it combines the strengths of intensive ambulatory assessment and experimental methods.

In the present study, participants took more steps in the hours immediately following an intervention prompt when they perceived that intervention as more helpful than usual. These data provide initial support for the potential impact of micro-interventions on PA behavior. However, total steps per day *decreased* over only 7 days, raising questions about this approach as a stand-alone intervention. This may reflect short-term measurement reactivity, rather than iatrogenic effects. A recent systematic review and meta-analysis [54] revealed that measurement reactivity frequently occurs in response to digital, in-the-moment PA measurement and that this reactivity is most pronounced in the first hours to days of participation. In the present study, novel use of the PA monitor (for some participants) and the introduction of the study context (including researcher observation and expectation of comparison of their PA against that of others) may have led to artificially inflated PA patterns during the baseline period (Days 1–3) [55, 56].

It is also possible that digital, social micro-interventions are not especially potent for increasing PA when delivered on their own and instead are most useful as adjuncts to more comprehensive behavioral intervention. For example, in all phases of the study, participants received self-monitoring feedback via prompts to look at their PA monitor and enter their steps into each survey. This is known to serve as an effective intervention in itself [57]. However, they did not receive broader feedback on progress toward a goal or comment on their change over time, which could be useful. Social micro-interventions could be integrated with human coaching or with (micro-)interventions that activate additional BCTs (e.g., goal setting, feedback), or be used to support maintenance of PA after such intervention. These represent important options to be tested in future work. As noted, the present study was designed to provide proof-of-concept evidence of the potential for remotely delivered intervention components to affect PA outcomes, rather than to test efficacy—hence its short time frame. Evaluation of social micro-intervention effects on PA over a longer time period and with a larger sample will be critical for exploring this approach's efficacy and for determining how social micro-intervention can best be leveraged to promote PA behavior change (e.g., how many micro-interventions per day, over how many days of exposure), which may differ between people or for the same person over time [58].

This study benefited from the combined strengths of intensive ambulatory assessment and experimental methods, to reach participants in their daily lives while testing for effects of interest. As a result, it featured a rare combination of high ecological validity and high internal validity that can be achieved with widely available digital tools. As a proof-of-concept and feasibility study (NIH Stage 1 [29]; ORBIT Phase 2 [30]), this trial had a modest sample size and many participants had high levels of educational attainment and income. As 43% of participants identified with a racial/ethnic minority background, however, this low-intensity and fully remote approach to PA promotion may be particularly attractive to underrepresented groups, further underscoring its potential and need for additional testing. The study time frame was also short, making it unclear whether findings will generalize to a longer intervention period and follow-up. Increasing the number of experimental exposures and the length of the intervention and follow-up, as well as testing in samples with greater socioeconomic diversity, are critical to the next phase of intervention testing. These features will afford ample power for between- and within-person tests of person-context-intervention matching and to allow for longer-term efficacy testing in a more representative sample.

In this study, we also chose to minimize cost, participant burden, and human error by allowing participants who owned their own PA monitor to use it for assessments, rather than introducing a new device. As all inferential tests were within-person and focused on steps only, this mixed approach had minimal impact on conclusions. To increase the rigor of PA assessment in future studies, however, consistency in the PA

monitor used will be optimal. We also did not have the resources to record, transcribe, and formally code exit interviews or to conduct formal qualitative analysis. Although qualitative data are included here only to provide additional context, future work that maximizes the rigor of qualitative data collection and analysis will provide useful insight into feasibility, acceptability, and (potential) effects of micro-interventions.

In addition, we did not take into account limitations on opportunity for PA behavior in the hours following a micro-intervention prompt. Although suggestions for steps focused on small changes that could be made during work or caregiving hours (i.e., under circumstances with limited opportunity for large changes), it is possible that responses to micro-interventions were impeded by lack of opportunity or other external barriers (e.g., in an unsafe location for PA), or were delayed until later in the day. In future studies with larger samples and longer observation periods, opportunity could be taken into account as a covariate and delayed effects could be examined with greater power. We also elected not to randomize the order of intervention components (social comparison and social support). Although this approach has many advantages, our target sample size would not support meaningful comparisons between groups. This is an important next step for future work, to determine any order effects and/or to further personalize the intervention (by determining the order most beneficial to each user).

Finally, micro-interventions that prompt social comparison to 1 other user require further consideration. The step counts of these comparison targets should be close enough to the comparer's to be relevant, rather than representing a potentially unachievable or irrelevant goal [59]. This rationale guided our selection of comparison target step counts but did not achieve the intended direction of comparison in some cases. To induce the intended comparison, however, ongoing *adaptation* to the participant's own steps may be necessary [26, 38]. Although this is more technologically challenging and resource-intensive, given the low overall cost and promise of the present approach, the reduction in potential mismatch is likely worth the investment.

In sum, findings from the present study indicate that PA-based digital, social micro-interventions for midlife adults with elevated risk for CVD warrant expanded testing over a longer period. This fully remote, low-intensity, and low-burden approach is feasible and acceptable to the target group and we detected experimentally induced within-day changes in PA from baseline. Even small changes in PA can have powerful benefits for cardiovascular health in this population [60]. As such, further testing of this low-burden approach will help to reveal the precise mechanistic pathway(s) linking social processes to PA behavior (e.g., PA motivation, identification/contrast, affect) and thereby, improve our digital and/or hybrid interventions to promote PA and cardiovascular health in at-risk groups.

## Supplementary Material

Supplementary material is available at *Annals of Behavioral Medicine* online.

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## Compliance with Ethical Standards

**Authors' Statement of Conflict of Interest and Adherence to Ethical Standards** Authors (Danielle Arigo, Leah M. Schumacher, Kiri Baga, Jacqueline A. Mogle) declare that they have no conflict of interest.

**Authors' Contributions** Danielle Arigo (Conceptualized, Funding, Data analysis , Writing—original draft, Writing—review & editing), Leah M. Schumacher, Kiri Baga (Recruitment, Data collection, Data analysis , Writing—original draft, Writing—review & editing), Jacqueline A. Mogle (Data visualizations, Data analysis , Writing—original draft, Writing—review & editing)

**Transparency** This study was registered at clinicaltrials.gov. The analysis plan was not formally pre-registered. De-identified data, analytic code, and materials from this study will be made available by emailing the corresponding author. Clinical Trials Registration NCT04711512.

## References

1. Ahmad FB, Cisewski JA, Xu J, Anderson RN. Provisional mortality data – United States, 2022. *MMWR Morb Mortal Wkly Rep*. 2023; 72(18):488–492.
2. Brim OG, Ryff CD, Kessler RC. *How Healthy Are We?: A National Study of Well-Being at Midlife*. Chicago, IL: University of Chicago Press; 2019.
3. Rodgers JL, Jones J, Bolleddu SI, et al. Cardiovascular risks associated with gender and aging. *J Cardiovasc Dev Dis*. 2019; 6(2):19.
4. Matthews KA, Crawford SL, Chae CU, et al. Are changes in cardiovascular disease risk factors in midlife women due to chronological aging or to the menopausal transition? *J Am Coll Cardiol*. 2009; 54(25):2366–2373.
5. Lachman ME, Teshale S, Agrigoroaei S. Midlife as a pivotal period in the life course: Balancing growth and decline at the crossroads of youth and old age. *Int J Behav Dev*. 2015; 39(1):20–31.
6. Infurna FJ, Gerstorf D, Lachman ME. Midlife in the 2020s: opportunities and challenges. *Am Psychol*. 2020; 75(4):470–485.
7. Gomez-Bernal F, Madva EN, Puckett J, Amonoo HL, Millstein RA, Huffman JC. Relationships between life stressors, health behaviors, and chronic medical conditions in mid-life adults: a narrative review. *Psychosomatics*. 2019; 60(2):153–163.
8. Chaddha A, Robinson EA, Kline-Rogers E, Alexandris-Souphis T, Rubenfire M. Mental health and cardiovascular disease. *Am J Med*. 2016; 129(11):1145–1148.
9. Duggal NA, Niemiro G, Harridge SDR, Simpson RJ, Lord JM. Can physical activity ameliorate immunosenescence and thereby reduce age-related multi-morbidity? *Nat Rev Immunol*. 2019; 19(9):563–572.
10. Ahmed HM, Blaha MJ, Nasir K, Rivera JJ, Blumenthal RS. Effects of physical activity on cardiovascular disease. *Am J Cardiol*. 2012; 109(2):288–295.
11. Joseph JJ, Deedwania P, Acharya T, et al. Comprehensive management of cardiovascular risk factors for adults with type 2 diabetes: a scientific statement from the American Heart Association. *Circulation*. 2022; 145(9):e722–e759.
12. Arigo D, Romano KA, Pasko K, et al. A scoping review of behavior change techniques used to promote physical activity among women in midlife. *Front Psychol*. 2022; 13:855749.

13. Kendall C, Francis SL, Shelley M, et al. Middle age and older adults: their nutrition and physical activity needs and how best to address them. *J Nutr Gerontol Geriatr*. 2023; 42(2):59–71.
14. King AC, Hekler EB, Grieco LA, et al. Effects of three motivationally targeted mobile device applications on initial physical activity and Sedentary Behavior change in midlife and older adults: a randomized trial. *PLoS One*. 2016; 11(6):e0156370.
15. Baumel A, Fleming T, Schueller SM. Digital micro interventions for behavioral and mental health gains: Core components and conceptualization of digital micro intervention care. *J Med Internet Res*. 2020; 22(10):e20631.
16. Marques M, Wright A, Corker E, et al. The behaviour change technique ontology: transforming the behaviour change technique taxonomy v1 [version 1; peer review: 4 approved]. *Wellcome Open Res*. 2023; 8(308):1–25.
17. Festinger LA. theory of social comparison processes. *Hum Relat*. 1954; 7(2):117–140.
18. Wood JV, Taylor SE, Lichtman RR. Social comparison in adjustment to breast cancer. *J Pers Soc Psychol*. 1985; 49(5):1169–1183.
19. Mohr D, Cuijpers P, Lehman K. Supportive accountability: a model for providing human support to enhance adherence to eHealth interventions. *J Med Internet Res*. 2011; 13(1):e1602.
20. Bandura A. An agentic perspective on positive psychology. In: *Positive Psychology: Exploring the Best in People, Vol 1: Discovering Human Strengths*. Westport, CT: Praeger Publishers/Greenwood Publishing Group; 2008:167–196.
21. Bandura A. The role of self-efficacy in goal-based motivation. In: *New Developments in Goal Setting and Task Performance*. Milton Park, UK: Routledge/Taylor & Francis Group; 2013:147–157.
22. Buunk BP, Ybema JF. Social comparisons and occupational stress: the identification-contrast model. In: *Social Comparisons and Occupational Stress: The Identification-Contrast Model*. Mahwah, NJ: Lawrence Erlbaum Associates; 1997:359–388.
23. Howlett N, Trivedi D, Troop NA, Chater AM. Are physical activity interventions for healthy inactive adults effective in promoting behavior change and maintenance, and which behavior change techniques are effective? A systematic review and meta-analysis. *Transl Behav Med*. 2019; 9(1):147–157.
24. Mollee JS, Klein MCA. The Effectiveness of upward and downward xocial comparison of physical activity in an online intervention. Georgalas N, Jin Q, Garcia-Blas J, Carretero J, Ray I, eds. *2016 15th Int Conf Ubiquitous Comput Commun 2016 8th Int Symp Cyberspace Secur IUCC-CSS*. 2017:109–115.
25. Van der Zee K, Oldersma F, Buunk BP, Bos D. Social comparison preferences among cancer patients as related to neuroticism and social comparison orientation. *J Pers Soc Psychol*. 1998; 75(3):801–810.
26. Arigo D, Gray RC, Dallal DH, Villareale J, Zhu J. Selection of and response to physical activity–based social comparisons in a digital environment: series of daily assessment studies. *JMIR Hum Factors*. 2023; 10(1):e41239.
27. Corcoran K, Crusius J, Mussweiler T. Social comparison: motives, standards, and mechanisms. In Chadee D, ed. *Theories in Social Psychology*. Oxford, UK: Wiley-Blackwell; 2011:119–139
28. Arigo D, Mogle JA, Smyth JM. Relations between social comparisons and physical activity among women in midlife with elevated risk for cardiovascular disease: an ecological momentary assessment study. *J Behav Med*. 2021; 44(5):579–590.
29. Onken LS, Carroll KM, Shoham V, Cuthbert BN, Riddle M. Reenvisioning clinical science: Unifying the discipline to improve the public health. *Clin Psychol Sci*. 2014; 2(1):22–34.
30. Czajkowski SM, Powell LH, Adler N, et al. From ideas to efficacy: the ORBIT model for developing behavioral treatments for chronic diseases. *Health Psychol*. 2015; 34(10):971–982.
31. Paluch AE, Gabriel KP, Fulton JE, et al. Steps per day and all-cause mortality in middle-aged adults in the Coronary Artery Risk Development in Young Adults Study. *JAMA Netw Open*. 2021; 4(9):e2124516.
32. Ahmadi MN, Clare PJ, Katzmarzyk PT, Del Pozo Cruz B, Lee IM, Stamatakis E. Vigorous physical activity, incident heart disease, and cancer: How little is enough? *Eur Heart J*. 2022; 43(46):4801–4814.
33. Kariuki JK, Gibbs BB, Erickson KI, et al. The feasibility and acceptability of a web-based physical activity for the heart (PATH) intervention designed to reduce the risk of heart disease among inactive African Americans: protocol for a pilot randomized controlled trial. *Contemp Clin Trials*. 2021; 104:106380.
34. Wallbank G, Sherrington C, Hassett L, et al. Acceptability and feasibility of an online physical activity program for women over 50: a pilot trial. *Transl. Behav. Med.*. 2022; 12(2):225–236.
35. Schumacher LM, Kalala S, Thomas JG, Raynor HA, Rhodes RE, Bond DS. (2023). Consistent exercise timing as a strategy to increase physical activity: a feasibility study. *Transl J Am Coll Sports Med*. 2023; 8(2):e000227.
36. Arigo D, Lobo AF, Ainsworth MC, Baga K, Pasko K. Development and initial testing of a personalized, adaptive, and socially focused web tool to support physical activity among women in midlife: multidisciplinary and user-centered design approach. *JMIR Form Res*. 2022; 6(7):e36280.
37. U.S. Department of Health and Human Services. *Physical Activity Guidelines for Americans, 2nd Edition*. U.S. Department of Health and Human Services; 2018. https://health.gov/sites/default/files/2019-09/Physical_Activity_Guidelines_2nd_edition.pdf Accessibility verified April 1, 2024
38. Williamson C, Baker G, Tomasone JR, et al. The physical activity messaging framework (PAMF) and Checklist (PAMC): international consensus statement and user guide. *Int J Behav Nutr Phys Act*. 2021; 18(1):164.
39. Arigo D, Lassiter JM, Baga K, Jackson DA, Lobo AF, Guetterman TC. "You get what you need when you need it": a mixed methods examination of the feasibility and acceptability of a tailored digital tool to promote physical activity among women in midlife. *Digit Health*. 2023; 9:20552076231210654.
40. Hoffman L. *Longitudinal Analysis: Modeling Within-Person Fluctuation and Change*. Milton Park, UK: Routledge/Taylor & Francis Group; 2015.
41. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences*. 2nd ed. Milton Park, UK: Routledge; 2013.
42. Iancu I, Iancu B. I love it, but it is too complicated. Aging adults' perspective on mobile technology acceptance. *ESSACHESS – J Commun Stud*. 2020; 13(2(26):13–39.
43. Smyth JM, Juth V, Ma J, Sliwinski M. A slice of life: ecologically valid methods for research on social relationships and health across the life span. *Soc Personal Psychol Compass*. 2017; 11(10):e12356.
44. Metzgar CJ, Preston AG, Miller DL, Nickols-Richardson SM. Facilitators and barriers to weight loss and weight loss maintenance: a qualitative exploration. *J Hum Nutr Diet*. 2015; 28(6):593–603.
45. Faw MH. Young adults' strategies for managing social support during weight-loss attempts. *Qual Health Res*. 2014; 24(2):267–278.
46. Biedenweg K, Meischke H, Bohl A, et al. Understanding older adults' motivators and barriers to participating in organized programs supporting exercise behaviors. *J Prim Prev*. 2014; 35(1):1–11.
47. Siceloff ER, Wilson DK, Van Horn L. A longitudinal study of the effects of instrumental and emotional social support on physical activity in underserved adolescents in the ACT Trial. *Ann Behav Med*. 2014; 48(1):71–79.
48. Collins LM, Nahum-Shani I, Guastaferro K, Strayhorn JC, Vanness DJ, Murphy SA. Intervention optimization: a paradigm shift and its potential implications for clinical psychology. *Ann Rev Clin Psychol*. 2024; 20(1):21–47.
49. Helgeson VS, Taylor SE. Social comparisons and adjustment among cardiac patients 1. *J Appl Soc Psychol*. 1993; 23(15):1171–1195.
50. Arigo D, Mogle JA, Brown MM, Gupta A. A multi-study approach to refining ecological momentary assessment measures for use among midlife women with elevated risk for cardiovascular disease. *mHealth*. 2021; 7:53.

51. Arigo D, Cornell M, Smyth JM. Social comparisons in adults with type 2 diabetes: patients' reasons for target selection. *Psychol Health*. 2018; 33(7):906–924.
52. Baga K, Salvatore GM, Bercovitz I, Mogle JA, Arigo D. Daily social comparisons among women in midlife with elevated risk for cardiovascular disease: a within-person test of the Identification/Contrast Model. under revision. *Appl Psychol Health Well-Being*. 2024; 1–23.
53. Buunk BP, Ybema JF. Social comparisons and occupational stress: the identification-contrast model. In: *Social Comparisons and Occupational Stress: The Identification-Contrast Model*. Brighton and Hove, UK: Psychology Press; 2013: 359–388.
54. König LM, Allmeta A, Christlein N, Van Emmenis M, Sutton S. A systematic review and meta-analysis of studies of reactivity to digital in-the-moment measurement of health behaviour. *Health Psychol Rev*. 2022; 16(4):551–575.
55. Arigo D, König LM. Examining reactivity to the measurement of physical activity and sedentary behavior among women in midlife with elevated risk for cardiovascular disease. *Psychol Health*. 2024; 39(3):319–335.
56. Maher JP, Arigo D, Baga K, et al. Measurement reactivity in ecological momentary assessment studies of movement-related behaviors. *J Meas Phys Behav*. 2024; 7(1).
57. Compernolle S, DeSmet A, Poppe L, et al. Effectiveness of interventions using self-monitoring to reduce sedentary behavior in adults: a systematic review and meta-analysis. *Int J Behav Nutr Phys Act*. 2019; 16(1):63.
58. Nahum-Shani I, Smith SN, Spring BJ, et al. Just-in-time adaptive interventions (JITAIs) in mobile health: Key components and design principles for ongoing health behavior support. *Ann Behav Med*. 2018; 52(6):446–462.
59. Muller D, Fayant MP. On being exposed to superior others: consequences of self-threatening upward social comparisons. *Soc Person Psychol Compass*. 2010; 4(8):621–634.
60. Tudor-Locke C. Steps to better cardiovascular health: How many steps does it take to achieve good health and how confident are we in this number? *Curr Cardiovasc Risk Rep*. 2010; 4(4):271–276.