# SMARTPHONE-BASED TRACKING AND TEXTING INTERVENTIONS FOR PROMOTION OF PHYSICAL ACTIVITY IN CARDIOVASCULAR PREVENTION

by
Seth Shay Martin

A thesis submitted to Johns Hopkins University in conformity with
the requirements for the degree of Master of Health Science

Baltimore, Maryland
November, 2014

## ABSTRACT

**Introduction:** The recent advent of smartphone-linked wearable accelerometers offers a novel opportunity to promote physical activity using mobile health (mHealth) technology.

**Methods:** mActive was a 5-week, blinded, sequentially-randomized, parallel group, pilot trial that enrolled patients at an academic preventive cardiovascular center in Baltimore, Maryland from 1/17/14-5/20/14. Eligible patients were 18-69 year old smartphone users who reported low leisure-time activity by a standardized questionnaire. After establishing baseline activity during a 1-week blinded run-in, we randomized patients 2:1 to unblinded or blinded tracking in phase I (2 weeks), then randomized unblinded patients 1:1 to receive or not receive smart texts in phase II (2 weeks). Smart texts provided fully-automated, personalized, real-time coaching 3 times/day towards a daily goal of 10,000 steps. The primary outcome was daily step count.

**Results:** Forty-eight patients (22 women, 26 men) enrolled with a mean (SD) age of 58 (8) years, body mass index of 31 (6), and baseline daily step count of 9670 (4350). With 100% uptake of the intervention, the phase I change in activity was non-significantly higher in unblinded patients versus blinded controls by 1024 daily steps (95% CI -580-2628, $p=0.21$). In phase II, smart text receiving patients increased their daily steps over those not receiving texts by 2534 (1318-3750, $p<0.001$) and over blinded controls by 3376 (1951-4801, $p<0.001$).

**Conclusion:** In present-day adult smartphone users receiving preventive cardiovascular care in the United States, a technologically-integrated mHealth strategy combining digital tracking

with fully-automated, personalized, real-time text message coaching resulted in a large increase in physical activity.

**Advisor:** Josef Coresh

**2nd reader:** Mariana Lazo-Elizondo

## PREFACE, INCLUDING ACKNOWLEDGMENTS

**Trial team:** David I. Feldman, Roger S. Blumenthal, Steven R. Jones, Wendy S. Post, Chiadi E. Ndumele, Elizabeth V. Ratchford, Josef Coresh, Michael J. Blaha

**Funding:** This thesis work was funded in part by an unrestricted grant to MJB from the PJ Schafer Cardiovascular Research Fund, a 501(c)3 non-profit organization. Digital physical activity tracking devices were provided in-kind by Fitbug, a private for-profit company. This mActive trial was investigator-initiated and Fitbug did not provide cash payments for the research or writing of the manuscript. Fitbug did not participate in the analysis of the data or influence the conclusions. SSM is supported by a National Institutes of Health training grant (T32HL07024) for which JC serves as the Director. SSM receives additional support from the Pollin Cardiovascular Prevention Fellowship and the Marie-Josée and Henry R Kravis endowed fellowship. Furthermore, SSM received a modest monetary award in conjunction with the Howard C. Silverman prize for originality and creativity in medical research, which was awarded by the Johns Hopkins Division of Cardiology based on the preliminary design of the mActive trial. RSB is supported by the Kenneth Jay Pollin Professorship in Cardiology.

**Registration:** ClinicalTrials.gov Identifier NCT01917812

## TABLE OF CONTENTS

**LIST OF TABLES**

**LIST OF FIGURES**

**LIST OF PLATES**

## INTRODUCTION

For cardiovascular disease (CVD) prevention, physical activity is a central element of lifestyle guideline recommendations.[1] Each 2,000 step/day increase in physical activity was associated with a ~10% relative reduction in the incidence of CVD.[2] Benefits of physical activity may extend well beyond the cardiovascular system to prevention of cancer, diabetes, depression, lung and kidney disease, and other chronic diseases.[3] However, with current low-technology solutions available in the healthcare system, many adults do not meet minimum levels of physical activity advised by guidelines.[1, 4]

Pedometers are a possible tool for physical activity assessment and promotion that are relevant to a range of settings, including preventive healthcare clinics, physical rehabilitation programs, and employee wellness initiatives. In the workplace, the Cochrane Collaboration found limited and low-quality data for the effectiveness of pedometer interventions on physical activity and related health outcomes.[5] While a meta-analysis of short-term clinical trials provided general support for pedometer use, the benefit was dependent on using a step diary and having a daily goal (e.g., 10,000 steps/day).[6] It seems that pairing a pedometer with ways to increase self-awareness and elicit goal-oriented behavior may optimize their potential benefit.

The digital revolution has broadened the definition of pedometer to include smartphone-linked wearable sensors. Integrating smartphone-based digital activity tracking in real-time with text message feedback represents a widely applicable avenue for therapeutic mobile health (mHealth) intervention as most Americans now own a smartphone and ~1.4 billion people are using smartphones worldwide.[7] In this context, we conducted a pilot trial testing the effects of fully-automated smartphone-based tracking and texting interventions

on physical activity. We hypothesized that the interventions would increase physical activity by increasing self-awareness of activity and eliciting goal-directed behavior through personalized health coaching.

## METHODS

*Trial Design*

The mActive trial protocol was registered before patient enrollment at clinicaltrials.gov (NCT01917812) and was approved by the Johns Hopkins School of Medicine Institutional Review Board (full protocol included with submission). This pilot trial was a single-center, blinded, randomized, parallel group, mHealth trial lasting 5 weeks, including a 1-week blinded run-in to establish adherence and baseline activity, followed by sequential randomization to fully-automated smartphone-based tracking and texting interventions in phase I (2 weeks) and phase II (2 weeks). In phase I, we randomized patients in a 2:1 ratio to unblinded digital physical activity tracking or continued blinded tracking. In phase II, we randomized unblinded patients in a 1:1 ratio to receive or not receive texts. All patients continued to receive routine care and gave written informed consent. Patients were advised of the different groups being compared. There were no important changes to methods after trial commencement. After enrollment, further face-to-face visits were not routinely part of the interventions or assessments, but were offered for replacement of a lost device.

*Patients*

We enrolled patients at the Johns Hopkins Ciccarone Center for the Prevention of Heart Disease in Baltimore, Maryland, USA from January 17$^{th}$ to May 20$^{th}$, 2014. We included patients aged 18-69 years who were users of a Fitbug-compatible smartphone (i.e., iPhone 4S or newer, Galaxy S3 or newer). We excluded patients who were already using an activity tracker, had a preferred form of activity such as swimming that was not measurable by the tracker, and those who were prohibited from normal activity due to reliance on a

cane/walker, activity-limiting osteoarthritis, pregnancy, or other condition. As we anticipated interventions to predominantly modify leisure-time activity, we also excluded patients who reported ≥3 days of moderate or vigorous activity during leisure-time for ≥30 minutes/day by the long form of the International Physical Activity Questionnaire (IPAQ).[8] This standardized questionnaire is validated up to 69 years of age, which served as the rationale for the upper age limit in the trial. We did not have an eligibility restriction based on smartphone or Internet literacy, although all subjects confirmed having access to e-mail for pertinent trial communication.

Baseline characteristics of participants were obtained by a combination of patient self-report and medical chart review. Patients reported whether or not they owned a dog, their marital status, and employment including the type of work if they were employed. In addition, patient responses to the long form of the IPAQ were used to categorize them as having low, moderate, or high physical activity according to the IPAQ scoring protocol as follows:

- Low: not meeting criteria for moderate or high physical activity.
- Moderate:

  a) 3 or more days of vigorous-intensity activity of at least 20 minutes per day

  OR

  b) 5 or more days of moderate-intensity activity and/or walking of at least 30 minutes per day

  OR

c) 5 or more days of any combination of walking, moderate-intensity or vigorous intensity activities achieving a minimum Total physical activity of at least 600 MET-minutes/week.

- High:

  a) vigorous-intensity activity on at least 3 days achieving a minimum Total physical activity of at least 1500 MET-minutes/week

  OR

  b) 7 or more days of any combination of walking, moderate-intensity or vigorous-intensity activities achieving a minimum Total physical activity of at least 3000 MET-minutes/week.

Additional clinical characteristics were obtained from the patient's medical records. We extracted age, sex, race/ethnicity, and body mass index. We also determined whether a patient had known coronary heart disease and/or was an active cigarette smoker based on his or her problem list. In addition, we defined diabetes, hypertension, and dyslipidemia according to their presence or absence on the problem list or use of a medication for the condition (e.g., anyone prescribed a statin was classified as having dyslipidemia). Visit notes were reviewed to verify the information or obtain additional information. For example, the social history section was also scanned for information about cigarette use.

*Interventions*

Patients used their personally owned smartphones. Digital physical activity tracking was performed using the Fitbug Orb (Chicago, IL, USA) **(Plate 1)**, a display-free triaxial accelerometer with a diameter of 30 millimeters (1.2 inches, slightly larger than a quarter),

depth of 13 millimeters (0.5 inches), and weight of 0.3 ounces. It syncs via low-energy Bluetooth with one's smartphone. Fitbug Orbs were the commercially available form; a Johns Hopkins brand was not added. Patients were given the option to wear the device clipped to their clothes, in their pocket, or as a wrist band, per their preference and/or the recommended location for their main source of activity. The 3V lithium battery lasts about 6 months and thus did not require charging or replacement during the trial. Patients were instructed to wear the device continuously throughout the trial except when showering or submerging in water. They could keep the device after their participation in the trial was completed, but were not given cash payments for participation or adherence.

During enrollment, we installed the Fitbug app (Version 4.1.7) on the patient's smartphone, paired the Fitbug Orb to the smartphone, selected beacon mode for q15 minute data transmission, selected background and hub modes to enable data transmission even when logged out, and then logged out of the app. We set and concealed the username and password; because this information was necessary to log in and view activity data. As a result, all patients were blinded at the time of enrollment. We strongly advised leaving the app running in the smartphone's background and leaving Bluetooth enabled for the duration of the trial.

Regarding baseline physical activity, we pre-specified the latter four days of the 1-week run-in as representing baseline activity. Our rationale for excluding earlier days was that they may be more subject to the Hawthorne effect.[9] In addition to assessing baseline activity, the run-in was used to screen adherence with wearing the activity tracker. All those who enrolled met our criterion of adhering for ≥5 of 7 days, therefore no one was excluded during the run-in. The high level of adherence may have been partly related to automated

emails sent to all patients on the day of enrollment and day 3 reinforcing the importance of wearing the activity tracker.

In phase I, unblinded patients could view their daily step count, activity time, and aerobic activity time on their smartphone screen **(Plate 2)**. The Fitbug app also provided a history tab allowing review of data from prior days. The app indicated a step goal that was dynamic from day to day based on the amount of activity that a person attained and could go above 10,000 steps/day. Activity data were updated every 15 minutes if transmission occurred by beacon mode or were available at any time if a patient activated a manual data push or streaming mode.

In phase II, 'smart' text messages were automatically sent by a preprogrammed algorithm to patients' smartphones using Reify Health's system (Baltimore, MD, USA). 'Smart' indicates that texts were not general educational or motivational messages, but rather were personalized coaching texts based on a patient's real-time physical activity level, with content adapted to personal and clinical characteristics. Messages were written for a daily goal of 10,000 steps, consisting of positive reinforcement messages and also booster messages to motivate individuals when they were not on track to surpass their step goal. 'Smart' texts were sent 3 times/day (morning, mid-day, and evening) with the exact times personalized to the patient based on their usual wake time, lunch time, and time returning home from work. Content was based on the integration of self-efficacy, motivation, and habit theories[10, 11] with cardiovascular knowledge and clinical experience, and underwent internal testing and content iterations through pre-trial testing by the study team to optimize language.

On the day of enrollment, all patients completed a survey in order to personalize text messages **(Table 1),** which was later used in the 16 patients randomized to texts. Specific examples of texts sent during the trial are shown in **Table 2**. At enrollment, to identify future study text messages specifically as 'mActive' text messages, patients entered and labeled the mActive phone number in their smartphone. To promote privacy, we advised patients to set their phone to password protected mode.

*Outcomes*

Our pre-specified primary outcome measure was the mean change in accelerometer-measured daily (00:00:00 to 23:59:59) step count assessed from baseline (week 1) to phase I (weeks 2-3) and phase II (weeks 4-5). During the same time frames, using the same accelerometer, pre-specified secondary activity outcome measures were changes in total daily activity time and aerobic time. Aerobic time was defined as the time spent walking continuously for >10 minutes without breaking for more than a minute. An additional secondary outcome was satisfaction; qualitative feedback was obtained from patients upon trial completion through an online form and focus groups are currently being conducted. Once fully collected, satisfaction data will be synthesized and published.

*Physical Activity Data Accuracy*

The Fitbug Orb uses proprietary, internally-tested algorithms to translate raw accelerometer data into step counts, activity time, and aerobic time. To promote accuracy, we set each patient's individual stride length (calculated by multiplying height in inches by 0.413) and selected stride extender to account for the longer stride length with jogging or running relative to walking. We conducted accuracy testing at Hopkins prior to trial

enrollment, which showed the Fitbug Orb to be reasonably comparable to traditional pedometers, including the higher-end Accusplit AH120MAG (n=40, median difference 162; 25th-75th -392-827 steps) and the lower-end SM-2000 (n=7, median difference -609 steps; 25th-75th -972-618).

*Sample Size*

Previous randomized trials with a total of 24 to 58 patients have shown significant effects of activity tracker use.[6] For this trial, we estimated that the sample size needed to detect at least a 2000 step difference in means was 42 patients assuming a within-patient SD of 2200 steps, 2-sided alpha of 0.05, and Beta of 0.8.[12] Allowing for 15% attrition, our target enrollment was 48 patients.

*Randomization*

SSM and MJB decided on sex-stratified, block randomization and SSM generated random sequences in Stata 11.1 (College Station, TX). Allocation was concealed so it could not be foreseen in advance of, or during, enrollment. DIF enrolled patients who then entered the blinded run-in. SSM assigned patients to the phase I intervention by sending an email containing Fitbug login information on the first morning of week 2 to patients allocated to unblinding (confirmation of receipt requested). SSM assigned patients to the phase II intervention by selecting their account in the Reify system for smart texts beginning the first morning of week 4.

*Data Flow and Completeness*

With the tracker paired to patients' smartphones, activity data continuously uploaded throughout the trial and synced with the texting system via linkage of the Fitbug-Reify

application programming interfaces. In addition to automated emails (baseline, day 3, and weekly thereafter) reminding patients to wear their activity tracker, targeted emails were sent if data did not upload for three consecutive days. The reason for data not uploading tended to be an issue with Bluetooth connectivity between the Fitbug and smartphone. DIF emailed 20 (42%) patients and provided troubleshooting support to ensure data transmission (especially for the blinded group). In addition, a total of 5 (~10%) patients lost their accelerometer and required a replacement; one patient required 2 replacements. With these efforts, activity data completeness throughout the study, calculated by dividing the number of days with activity data by the total number of trial days, was 97.4%.

*Statistical Analysis*

Baseline characteristics were summarized using descriptive statistics – frequency (percentage) for categorical data and mean (standard deviation) for continuous data. All outcomes were compared between treatment arms by intention-to-treat. We did not conduct any interim analyses or have early stopping rules. We used Student's t test for mean comparison tests and calculated 95% confidence intervals. For comparisons of proportions, due to small cell sizes, we used Fisher's exact test. Given the very high level of data completeness, we did not impute data. We did not pre-specify any subgroup analyses. Statistical analyses were performed using Stata version 11.1 (College Station, TX) by the academic investigators independently from industry. SSM and MJB had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. For reporting, we followed the Consolidated Standards of Reporting Trials of Electronic and Mobile HEalth Applications and onLine TeleHealth (CONSORT-EHEALTH).[13]

## RESULTS

*Patient Flow*

The trial flow diagram is shown in **Figure 1**. Of 50 eligible individuals, 48 (96%) enrolled. There was 100% uptake of the intervention and all patients in the intervention arms completed the protocol. One blinded patient had data transmission issues in phase II and elected not to complete the protocol. The trial was stopped because target recruitment was achieved and follow-up was complete. There were no critical secular events during the trial period.

*Baseline Characteristics*

**Table 3** displays baseline characteristics. There were no statistically significant differences between groups. Overall, 22 women and 26 men participated with a mean age of 58 (8) years. Patients were primarily Caucasian (78%) and employed (88%), mostly in US Census Bureau defined management and professional occupations. The mean body mass index was 31 (6) with 54% of patients obese. A clinical history of coronary heart disease was present in 29% and diabetes in 23%.

*Association of Self-Reported and Measured Physical Activity at Baseline*

According to baseline self-report per the IPAQ, 10 patients (21%) were categorized at a low level of physical activity, 21 (44%) at a moderate level, and 17 (35%) at a high level (no significant differences between study arms). In these three groups, respectively, the measured baseline steps/day were 8745 (3428), 9184 (4373), and 10815 (4779). There was not a statistically significant association between self-reported and measured physical activity ($r=0.20$, $R^2=0.04$, $p=0.40$).

*Primary Outcome*

The baseline daily step count was 9670 (4350) in all patients, 10822 (4337) in the blind group and 9094 (4308) in the unblinded group (mean difference -1727, 95% CI -4389 to 934; p=0.20). In phase I **(Table 4)**, blinded control patients obtained a mean of 616 fewer steps/day (6% decrease) while unblinded patients increased their steps/day by a mean of 408 (4% increase). The between-group differential was non-significantly higher in unblinded patients versus blinded controls by 1024 steps/day (95% CI -580-2628, p=0.21).

In phase II **(Table 4)**, the blinded group further decreased its activity by 1042 steps/day (11% decrease) while the unblinded-no texts group decreased by 200 steps/day (0% change). In contrast, the unblinded-texts group obtained 2334 more steps/day (25% increase). The differential in activity levels was significant; text receiving patients increased their daily steps over those not receiving texts by 2534 (95% CI 1318-3750, p<0.001) and over blinded controls by 3376 (95% CI 1951-4801, p<0.001).

*Secondary Outcomes*

Secondary outcomes were broadly consistent with the primary outcome. The baseline total activity and aerobic times were 93 (45) minutes/day and 13 (18) minutes/day, respectively. In phase I, the unblinded and blinded groups were not significantly different in modifying their total activity times, while there was a borderline significant lower decrease in aerobic time in unblinded patients of -3 (12) minutes vs -11 (14) minutes (differential 8 minutes, 95% CI 0-16, p=0.05). In phase II, activity times continued to decrease in the blinded group and remained relatively stable in the unblinded-no texts group. In contrast, the unblinded-texts group increased its total activity time by 21 (20) minutes/day (23% increase) and aerobic time by 13 (11) minutes/day (160% increase), increases which were

highly statistically significant referenced to both the unblinded-no text group and blinded group.

*10,000 Steps/Day Goal Attainment*

At baseline, 23 (48%) patients had a daily step count ≥10,000 steps/day, 9 (56%) in the blinded group and 14 (44%) in the unblinded group **(Figure 2)**. In phase I, the ≥10,000 step/day goal was attained by one fewer patient in both the blinded group (n=8 of 16, 50%) and in the unblinded group (n=13 of 32, 41%). In phase II, the number of patients meeting the 10,000 steps/day goal was 7 (44%) in both blinded group and the unblinded-no texts group. In contrast, 13 (81%) of patients who were unblinded and receiving texts had a daily step count ≥10,000 steps/day, a difference that was statistically significant compared to the other groups (p=0.02).

*Qualitative Observations*

Our research team noted that data transmission between Fitbug and Reify was not seamless. We observed intermittent bugs resulting in texts that were generated based on incorrect physical activity data. This was noted by trial patients and by SSM who used the system during the trial to personally monitor it. Reify was not able to create a permanent fix, therefore the issue affected patients throughout the trial. In addition, there was a day when a bug in the Fitbug app caused all unblinded patients to see zero physical activity displayed.

## DISCUSSION

The most important finding from the mActive trial is that the group receiving activity information continuously via a smartphone-linked digital tracker together with fully-automated, real-time, personalized smart text message coaching achieved the best physical activity outcomes. This pilot trial lends support to the efficacy of this novel, technologically-integrated mHealth strategy in present-day adult smartphone users receiving preventive cardiovascular care in the United States. Potential advantages of the mActive trial strategy include reduction of attendance at in-person sessions, personalization of health coaching, more continuous patient contact, relatively low cost and reproducibility of the intervention, and scalability to larger target populations. The trial provides an initial step in addressing critical unanswered questions in an area of rapidly growing interest and represents a potentially widely applicable avenue for therapeutic intervention.

Our methods and design appear to provide a significant advance over current approaches in the area of activity tracker (pedometer) use, text messaging, and physical activity. Recent randomized controlled trials that did not show efficacy for pedometer use in insurance company employees in Finland[14] and adults with type 2 diabetes mellitus in southwest England[15] employed low-technology tracking and did not offer smart texts. We are aware of only one other group[16] providing text messages based on activity tracking. Unlike the system we implemented in the mActive trial, that system uses an activity tracker that uploads only through computer access points, not on-the-go through smartphones. We believe that allowing mobile activity data transmission anywhere will best support real-time, personalized smart messaging, and most harness the full power of these technologies in eliciting positive behavior change.

In addition to promoting physical activity, we suspect that the convenience offered by the truly mobile mActive design may have benefitted recruitment and retention. The trial met its recruitment target, enrolled 96% of eligible patients (as compared to the typical statistic of about 50%[17]), and all patients but one completed the protocol. Without specifically targeting recruitment of women, the mActive trial had nearly equal representation of men and women in comparison to the often disproportionately low representation of women in cardiovascular trials.[17] The mActive trial recruitment experience supports the data-driven hypothesis[17] that a trial design fostering convenience can enhance trial participation. Future trials are necessary to determine what aspects of the mActive trial can be scaled to larger and longer-term trials.

Another major strength of mActive was the very high level of physical activity outcome completeness obtained using a digital approach. During the intervention phases of the trial, we sent automated weekly email reminders to reinforce the importance of wearing the activity tracker. While digital uploading occurred mostly without the trial coordinator contacting patients, the availability of real-time information allowed prompt attention to missing data. Along with quick responses to lost devices and questions, mActive achieved nearly complete activity outcome data without in-person visits or follow-up. In prior activity tracking trials that did not use a digital strategy, physical activity had to be manually recorded in a log by participants, and such an approach yielded ~40% missing data.[2, 18, 19] As a result, the need arose for imputation of physical activity data.[19] However, the mActive trial indicates that digital tracking can prevent the need for imputation, at least in the short-term.

Regarding the use of text messaging in preventive healthcare, the Cochrane Collaboration has identified a knowledge gap in this area, which the mActive trial begins to

help address.[20] As the field progresses, it will be important to distinguish the features (i.e., content, timing) of texts that are most efficacious. It is important to emphasize that the texts in mActive were not simply general educational or motivational texts. Instead, they were smart texts intended to deliver personalized coaching based on personal and clinical characteristics and a person's real-time physical activity level. In addition, the positive reinforcement and booster texts were sent within the context of the healthcare system and aimed to leverage the doctor-patient relationship. Lifestyle improvement is a fundamental component of therapy in many clinical scenarios but the influence of behavioral counseling may be limited,[21] especially in the current health care delivery model wherein clinicians tend to see patients for brief visits every several months or annually. Aimed to fill the gap, the system ran fully-automated without day-to-day involvement of the physician and represents a resource-efficient strategy to facilitate more continuous monitoring and feedback between the healthcare system and patients. Overall, our patient-centered, digital, and real-time methodology may be a novel step forward that could help shape the prevention clinic of the future.

Physical activity is vital to cardiovascular health and a core element of wellness. Reported benefits include protection from congestive heart failure, ischemic heart disease, stroke, diabetes mellitus, obesity, hypertension, dyslipidemia, chronic obstructive pulmonary disease, chronic kidney disease, Alzheimer disease, anxiety or depression, and colon or lung cancer.[3] In line with benefits to the cardiovascular system and multiple disease processes, greater physical activity is associated with a dose-dependent reduction in both cardiovascular and all-cause mortality.[22, 23] Evidence supports a benefit from both exercise and non-exercise forms of physical activity. If sustained, the change in physical activity from tracking and

texting in this trial would be expected to be clinically significant. A similar increase of 2491 steps/day was associated with significant decreases in body mass index and systolic blood pressure[6] and over the long-term each 2,000 step/day increase in physical activity was associated with a ~10% relative reduction in the incidence of CVD.[2]

Although we cannot confirm this, we suspect that mActive group as a whole increased physical activity levels above their pre-trial baselines regardless of intervention. The overall activity levels by steps, even at baseline, were relatively high, and remained so even in the blinded group at the end of the trial (mean 9163 steps/day). Interestingly, however, the activity level in the blinded group progressively decreased during the trial and it remains uncertain what true baseline activity levels were. Even in blinded patients, there may be important effects arising from enthusiasm and focus on activity in a patient who received encouragement from his or her physician to participate in an activity trial and then chose to participate. Significant changes in behavior may also occur from being observed (Hawthorne effect) and from an activity tracker serving as a reminder to engage in activity regardless of numeric feedback or texts. Despite high overall steps, aerobic activity levels were disproportionately low, and appeared most responsive to intervention. The unblinded-texts group had a 160% increase in aerobic time in phase II and concluded the trial with more than a 4-fold higher aerobic time over the blinded group. Aerobic time may warrant particular attention in future trials.

*Limitations*

Like prior pedometer trials,[6] a key limitation was the short-term follow-up in this analysis. To address this, we will perform long-term follow-up of mActive participants. Additional follow-up will allow assessment of changes in body mass index, blood pressure,

and other risk factors. Further trials are necessary to assess the generalizability of the trial results. While mActive involved adult smartphone users from a single preventive cardiology clinic, we are cautiously optimistic that the findings could be applicable to much broader populations throughout the healthcare system. Wearable technologies and smartphones are expected to only go down in cost and become more widely used over time. Although we excluded those who reported high leisure-time activity by IPAQ, given the lack of correlation between self-reported and directly-measured activity levels, it would be reasonable to eliminate this exclusion in the future or replace it with a directly measured activity exclusion.

Additionally, there were two notable limitations to tracking-texting synchronization in mActive that can be improved upon in the future. First, texts were calibrated to the common clinical and scientific study goal of 10,000 steps/day, however the Fitbug app displayed a different goal that changed over time. We could not disable the app's goal and it may have created confusion among participants. Second, while the application programming interfaces of Fitbug and Reify were linked for the mActive trial, data transmission was not seamless. The blind group required more troubleshooting support than other groups to ensure physical activity data upload, which would bias to the null if there was any benefit from the added attention, or would bias away from the null if the frustration led to lower activity. We observed intermittent bugs in the texting system resulting in texts that were generated based on incorrect physical activity data. A better synchronized, seamless, and accurate smart text messaging system holds the potential to even further enhance physical activity levels and avoid frustration among users. Moreover, such a system could be more easily applied in the routine care environment.

*Conclusion*

In conclusion, in present-day adult smartphone users receiving preventive cardiovascular care in the United States, a technologically-integrated mHealth strategy combining digital tracking with fully-automated, personalized, real-time text message coaching resulted in a large short-term increase in physical activity. The mActive trial represents an encouraging early step in using technology to promote better health behaviors and extension of this line of work to larger, long-term trials is warranted.

## REFERENCES


1. Eckel RH, Jakicic JM, Ard JD, de Jesus JM, Houston Miller N, Hubbard VS, Lee IM, Lichtenstein AH, Loria CM, Millen BE, Nonas CA, Sacks FM, Smith SC, Jr., Svetkey LP, Wadden TA, Yanovski SZ. 2013 AHA/ACC guideline on lifestyle management to reduce cardiovascular risk: A report of the American College of Cardiology/American Heart Association task force on practice guidelines. *J Am Coll Cardiol*. 2014;63:2960-2984.
2. Yates T, Haffner SM, Schulte PJ, Thomas L, Huffman KM, Bales CW, Califf RM, Holman RR, McMurray JJ, Bethel MA, Tuomilehto J, Davies MJ, Kraus WE. Association between change in daily ambulatory activity and cardiovascular events in people with impaired glucose tolerance (NAVIGATOR trial): A cohort analysis. *Lancet*. 2014;383:1059-1066.
3. Willis BL, Gao A, Leonard D, Defina LF, Berry JD. Midlife fitness and the development of chronic conditions in later life. *Arch Intern Med*. 2012;172:1333-1340.
4. U.S. Department of Health and Human Services. 2008 physical activity guidelines for americans. http://www.health.gov/paguidelines/pdf/paguide.pdf.
5. Freak-Poli RL, Cumpston M, Peeters A, Clemes SA. Workplace pedometer interventions for increasing physical activity. *Cochrane Database Syst Rev*. 2013;4:CD009209.
6. Bravata DM, Smith-Spangler C, Sundaram V, Gienger AL, Lin N, Lewis R, Stave CD, Olkin I, Sirard JR. Using pedometers to increase physical activity and improve health: A systematic review. *JAMA*. 2007;298:2296-2304.
7. Leonard H. There will soon be one smartphone for every five people in the world. http://www.businessinsider.com/15-billion-smartphones-in-the-world-22013-2.
8. Craig CL, Marshall AL, Sjostrom M, Bauman AE, Booth ML, Ainsworth BE, Pratt M, Ekelund U, Yngve A, Sallis JF, Oja P. International physical activity questionnaire: 12-country reliability and validity. *Med Sci Sports Exerc*. 2003;35:1381-1395.
9. McCambridge J, Witton J, Elbourne DR. Systematic review of the hawthorne effect: New concepts are needed to study research participation effects. *J Clin Epidemiol*. 2014;67:267-277.
10. Aarts H, Paulussen T, Schaalma H. Physical exercise habit: On the conceptualization and formation of habitual health behaviours. *Health Educ Res*. 1997;12:363-374.
11. Schultz W. Behavioral theories and the neurophysiology of reward. *Annu Rev Psychol*. 2006;57:87-115.
12. Statistical considerations for a parallel trial where the outcome is a measurement. http://hedwig.mgh.harvard.edu/sample_size/js/js_parallel_quant.html.
13. Eysenbach G, CONSORT-EHEALTH Group. CONSORT-EHEALTH: Improving and standardizing evaluation reports of web-based and mobile health interventions. *J Med Internet Res*. 2011;13:e126.
14. Reijonsaari K, Vehtari A, Kahilakoski OP, van Mechelen W, Aro T, Taimela S. The effectiveness of physical activity monitoring and distance counseling in an occupational setting - results from a randomized controlled trial (CoAct). *BMC Public Health*. 2012;12:344.

15. Andrews RC, Cooper AR, Montgomery AA, Norcross AJ, Peters TJ, Sharp DJ, Jackson N, Fitzsimons K, Bright J, Coulman K, England CY, Gorton J, McLenaghan A, Paxton E, Polet A, Thompson C, Dayan CM. Diet or diet plus physical activity versus usual care in patients with newly diagnosed type 2 diabetes: The Early ACTID randomised controlled trial. *Lancet*. 2011;378:129-139.
16. Text to Move study. http://clinicaltrials.gov/show/nct01569243.
17. Martin SS, Ou FS, Newby LK, Sutton V, Adams P, Felker GM, Wang TY. Patient- and trial-specific barriers to participation in cardiovascular randomized clinical trials. *J Am Coll Cardiol*. 2013;61:762-769.
18. Strath SJ, Kaminsky LA, Ainsworth BE, Ekelund U, Freedson PS, Gary RA, Richardson CR, Smith DT, Swartz AM. Guide to the assessment of physical activity: Clinical and research applications: A scientific statement from the American Heart Association. *Circulation*. 2013;128:2259-2279.
19. Lee PH. Data imputation for accelerometer-measured physical activity: The combined approach. *Am J Clin Nutr*. 2013;97:965-971.
20. Vodopivec-Jamsek V, de Jongh T, Gurol-Urganci I, Atun R, Car J. Mobile phone messaging for preventive health care. *Cochrane Database Syst Rev*. 2012;12:CD007457.
21. Moyer VA; U.S. Preventive Services Task Force. Behavioral counseling interventions to promote a healthful diet and physical activity for cardiovascular disease prevention in adults: U.S. Preventive Services Task Force recommendation statement. *Ann Intern Med*. 2012;157:367-371.
22. Kodama S, Saito K, Tanaka S, Maki M, Yachi Y, Asumi M, Sugawara A, Totsuka K, Shimano H, Ohashi Y, Yamada N, Sone H. Cardiorespiratory fitness as a quantitative predictor of all-cause mortality and cardiovascular events in healthy men and women: A meta-analysis. *JAMA*. 2009;301:2024-2035.
23. Gupta S, Rohatgi A, Ayers CR, Willis BL, Haskell WL, Khera A, Drazner MH, de Lemos JA, Berry JD. Cardiorespiratory fitness and classification of risk of cardiovascular disease mortality. *Circulation*. 2011;123:1377-1383.

**Table 1: Factors in Personalization of Text Messages**

| | |
|---|---|
| ▪ **Name** | ▪ **Occupation** |
| ▪ **Age** | ▪ **Name of spouse** |
| ▪ **Sex** | ▪ **Name of children** |
| ▪ **Physician name** | ▪ **Name of dog** |
| ▪ **Preferred activity** | ▪ **Local park** |
| ▪ **Favorite athlete** | ▪ **Gym** |
| ▪ **Cardiac risk factors** | ▪ **Work schedule** |
| ▪ **Body mass index** | ▪ **Television watching habits** |

**Table 2: Example Text Messages**

| Time of Day | Type of Message | Context | Text |
|---|---|---|---|
| Morning | Booster | 1006 steps under goal prior day | Megan, you were pretty active yesterday! You got 8994 steps yesterday, which is close to your goal of 10,000! Dr. P is impressed by your progress. There are IMMEDIATE benefits to exercise: you will feel better and have more energy! |
| Mid-day | Positive reinforcement | >5,000 steps mid-day; favorite athlete Lebron James | Jon, you are on track to have a VERY ACTIVE day! Outstanding! We might as well call you Lebron James! |
| Evening | Booster | 3878 under goal of 10,000 | Jane, giving someone a call tonight? Consider walking while you talk. Your exercise prescription for tonight is 3878 steps. |

Names changed for privacy purposes.

**Table 3: Baseline Characteristics of mActive Trial Participants**

| | All Participants (n=48) No. (%) | Unblind (n=32) | | Blind (n=16) No. (%) | p-value |
|---|---|---|---|---|---|
| | | No Texts (n=16) No. (%) | Texts (n=16) No. (%) | | |
| **Age, years, mean (SD)** | 58 (8) | 58 (8) | 55 (8) | 60 (7) | 0.22 |
| **Sex** | | | | | 1.00 |
| **Men** | 26 (54%) | 9 (56%) | 8 (50%) | 9 (56%) | |
| **Women** | 22 (46%) | 7 (44%) | 8 (50%) | 7 (44%) | |
| **White race** | 38 (79%) | 12 (75%) | 12 (75%) | 14 (88%) | 0.60 |
| **Dog owner** | 21 (44%) | 9 (56%) | 5 (31%) | 7 (44%) | 0.36 |
| **Married** | 35 (73%) | 13 (81%) | 9 (56%) | 13 (81%) | 0.19 |
| **Employed** | 42 (88%) | 13 (81%) | 15 (94%) | 13 (81%) | 0.67 |
| **Management, professional*** | 30 (63%) | 9 (56%) | 9 (56%) | 12 (75%) | |
| **Service** | 5 (10%) | 2 (13%) | 3 (19%) | 0 (0%) | |
| **Sales, office** | 5 (10%) | 2 (13%) | 2 (13%) | 1 (6%) | |
| **Construction, management** | 2 (4%) | 0 (0%) | 1 (6%) | 1 (6%) | |
| **CHD** | 14 (29%) | 5 (31%) | 2 (13%) | 7 (44%) | 0.15 |
| **Diabetes** | 11 (23%) | 5 (31%) | 2 (13%) | 4 (25%) | 0.44 |
| **Smoker** | 1 (2%) | 1 (6%) | 0 (0%) | 0 (0%) | 1.00 |
| **Hypertension** | 24 (50%) | 8 (50%) | 5 (31%) | 11 (69%) | 0.12 |
| **Dyslipidemia** | 39 (81%) | 14 (88%) | 12 (75%) | 13 (81%) | 0.90 |
| **BMI, Kg/m$^2$, mean (SD)** | 31 (6) | 30 (5) | 30 (7) | 33 (7) | 0.28 |
| **≥30** | 26 (54%) | 7 (44%) | 9 (56%) | 10 (63%) | |
| **IPAQ** | | | | | 0.50 |
| **Low** | 10 (21%) | 2 (12%) | 3 (19%) | 5 (31%) | |
| **Moderate** | 21 (44%) | 7 (44%) | 9 (56%) | 5 (31%) | |
| **High** | 17 (35%) | 7 (44%) | 4 (25%) | 6 (38%) | |

CHD = coronary heart disease; BMI = body mass index; IPAQ = International Physical Activity Questionnaire, Long-Form (overall categorization); *per US Census Bureau definitions

**Table 4: Changes in Activity Outcomes during Phase I and II Interventions**

**Phase I**

| | Unblind (n=32) Mean Change (SD) | Blind (n=16) Mean Change (SD) | Unblind - Blind Mean Difference (95% CI), p-value |
|---|---|---|---|
| **Steps, count/day (primary outcome)** | 408 (2701) | -616 (2385) | 1024 (-580 to 2628), p=0.21 |
| **Activity time, minutes/day** | 2 (27) | -6 (26) | 8 (-9 to 25), p=0.33 |
| **Aerobic time, minutes/day** | -3 (12) | -11 (14) | 8 (0 to 16), p=0.05 |

**Phase II**

| | Texts (n=16) | No Texts (n=16) | Blind (n=16) | Texts - No Texts | Texts - Blind | No Texts - Blind |
|---|---|---|---|---|---|---|
| | Mean Change (SD) | | | Mean Difference (95% CI), p-value | | |
| **Steps, count/day (primary outcome)** | 2334 (1714) | -200 (1653) | -1042 (2202) | 2534 (1318 to 3750), p<0.001 | 3376 (1951 to 4801), p<0.001 | 842 (-564 to 2248), p=0.23 |
| **Activity time, minutes/day** | 21 (20) | 0 (17) | -8 (23) | 21 (8 to 34), p=0.003 | 29 (13 to 45), P<0.001 | 8 (-7 to 23), p=0.28 |
| **Aerobic time, minutes/day** | 13 (11) | -1 (8) | -3 (10) | 14 (7 to 21), P<0.001 | 16 (7 to 23), P<0.001 | 2 (-6 to 8), p=0.71 |

**Figure 1: mActive Trial Flow Diagram**

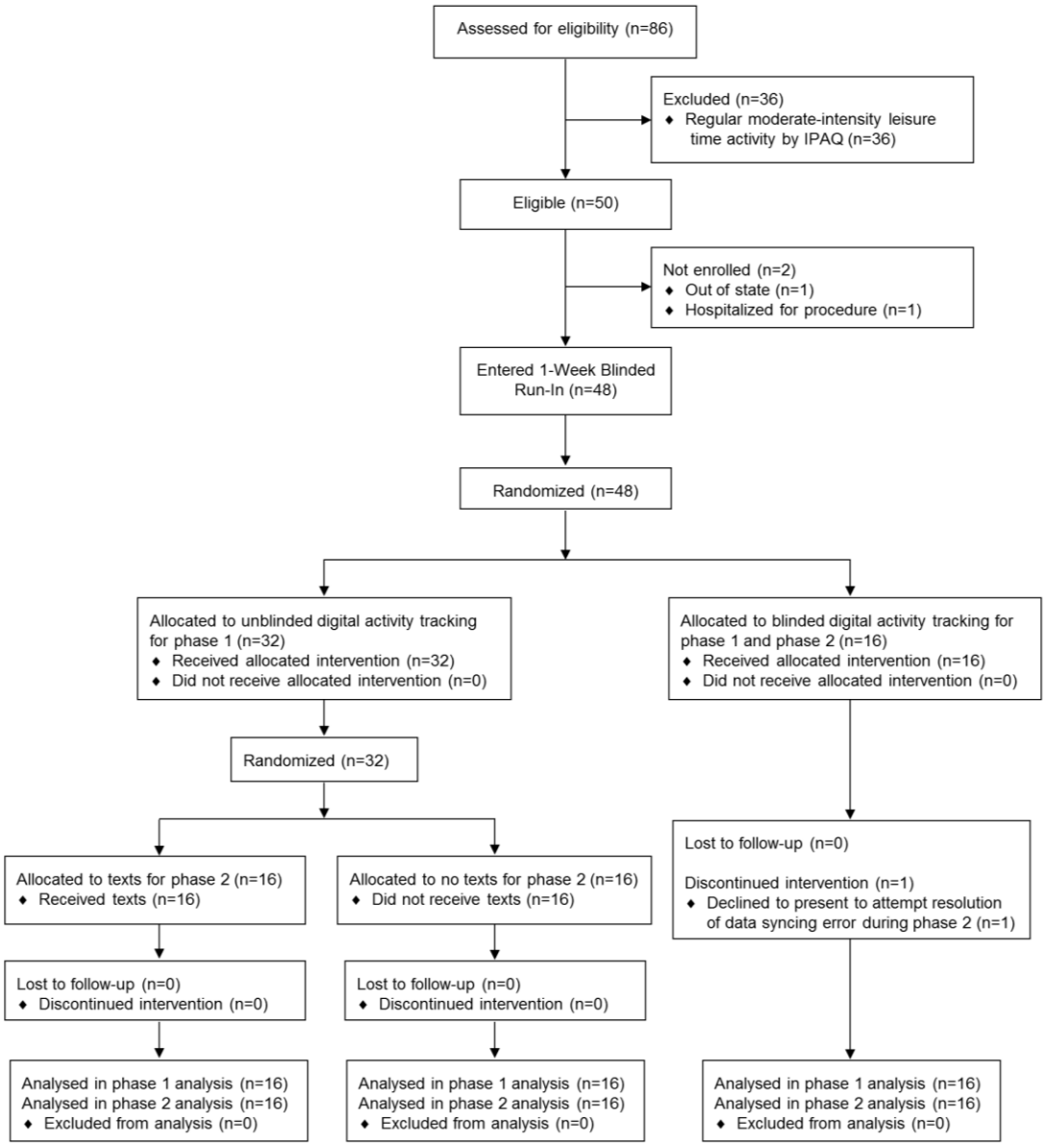

**Figure 2: Proportions Attaining the 10,000 Steps/Day Goal at Baseline, in Phase I, and Phase II, by Intervention Group**

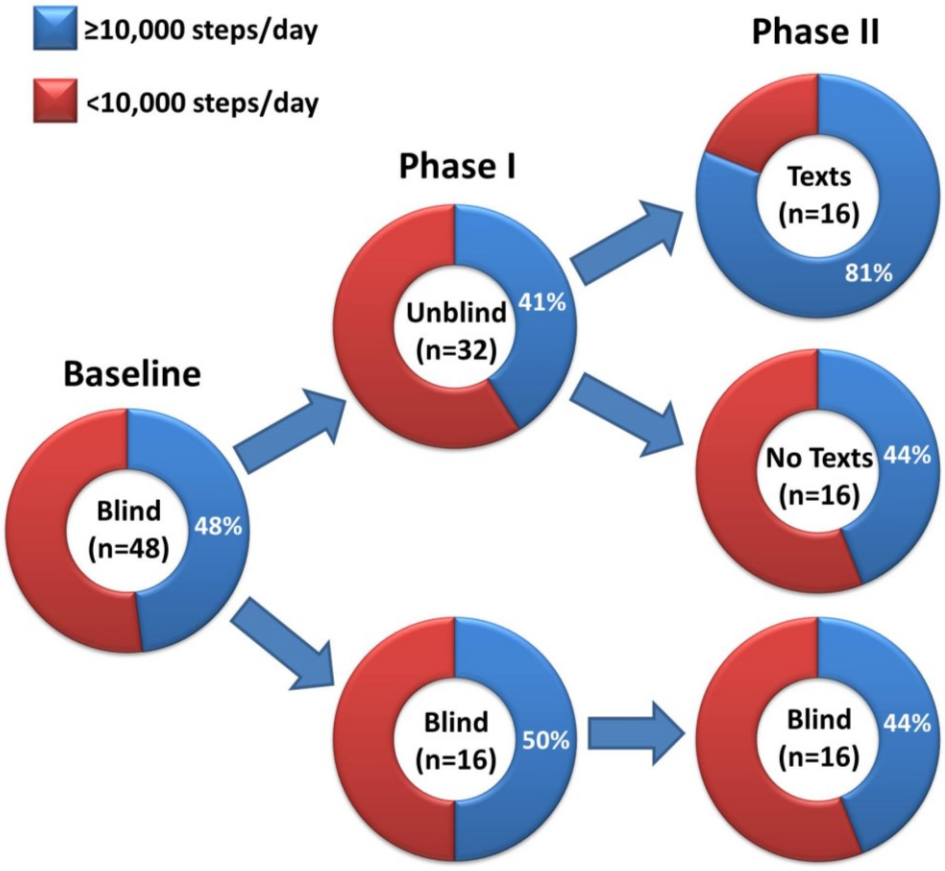

**Plate 1: Fitbug Orb and Accessories**

**Plate 2: Fitbug Smartphone App**

**BIOGRAPHICAL SKETCH**

| NAME<br>**Seth Shay Martin, MD** | POSITION TITLE<br>**Cardiology Fellow, M.H.S Candidate** |
|---|---|

EDUCATION/TRAINING

| INSTITUTION AND LOCATION | DEGREE *(if applicable)* | MM/YY | FIELD OF STUDY |
|---|---|---|---|
| Washington and Lee University, Lexington, VA | B.S. | 2000-2004 | Biology |
| University of Pennsylvania School of Medicine, Philadelphia, PA | M.D. | 2004-2008 | Medicine |
| Johns Hopkins Bloomberg School of Public Health, Baltimore, MD | M.H.S. candidate | 2013- | Cardiovascular Disease Epidemiology |

**A. Personal Statement**

Dr. Seth S. Martin presently serves as a senior cardiology fellow in the Division of Cardiology and Pollin cardiovascular prevention fellow in the Johns Hopkins Ciccarone Center for the Prevention of Heart Disease. He was awarded an NHLBI Training Grant in Cardiovascular Epidemiology and has completed core M.H.S. course work. He is an Editor for the journal *Clinical Cardiology*, and an Associate Editor for the Dyslipidemia Clinical Community on the American College of Cardiology (ACC) website Cardiosource.com. He was recognized by the ACC as an Up and Coming Future Star of Cardiology. Dr. Martin's research has been published in such journals as *JAMA, Circulation*, *Journal of the American College of Cardiology*, *European Heart Journal*, *Diabetes,* and *Atherosclerosis.*

Dr. Martin's passion for clinical investigation dates back over a decade. Beginning at the end of high school, he joined his father on clinical investigations examining the relationship of obesity to coronary restenosis and the pharmacodynamics of enoxaparin. In medical school, his interests evolved as he teamed up with Atif Qasim and Muredach Reilly to delve into the molecular mechanisms underlying obesity that promote cardiometabolic risk, honing in on leptin's interactions with inflammatory pathways. He was awarded the Gertrude M. & Ezra M. Eisen Prize, given annually to a medical student for outstanding performance in cardiology rotations and research.

As a house officer in Internal Medicine at Duke, he worked with Tracy Wang as a co-investigator on the clinical trial team for STABILITY, a multicenter project studying a novel anti-atherosclerotic agent. He helped with recruitment efforts and followed patients longitudinally as part of the site-based clinical trial team. Meeting some challenges with patient recruitment, he was motivated to assemble and analyze a database of patient and trial data for 15 cardiovascular RCTs that Duke had participated as a site in. He identified potentially modifiable

trial-specific barriers to consider in future trial designs. Twice during his residency, he was the recipient of the Robert M. Califf & Barton F. Haynes House Staff Research Award.

As a cardiology fellow at Hopkins, Dr. Martin found strong mentorship from the Ciccarone and Welch Centers. Dr. Martin's scholarly work at Hopkins has examined the accuracy of lipid measurements and associations of lipids with clinical outcomes. Most recently, Dr. Martin's interest has evolved towards informatics and mobile health (mHealth) intervention trials to combat against dyslipidemia, obesity, and cardiovascular disease. Dr. Martin designed a blinded, randomized mHealth trial of digital activity tracking and smartphone text messaging to promote physical activity. The cardiology faculty awarded this project the Howard S. Silverman Award, which is given annually to one cardiology fellow for originality and creativity in medical research. The findings of the trial are herein presented.

**B. Positions and Honors.**

**Clinical Training Positions**

**2008-2011:** Internal Medical Residency, Duke University Medical Center, Durham, NC
**2011- :** Fellowship in Cardiovascular Disease, Johns Hopkins Hospital, Baltimore, MD

**Editorial Positions**

| | | |
|---|---|---|
| 2012- | Editorial Board Member | Clinical Cardiology |
| 2012- | Editorial Board Member | CardioCareLive |
| 2013- | Associate Editor | ACC CardioSource Dyslipidemia Clinical Community |
| 2013- | Fellows Advisory Board | Cardiology Today |
| 2014- | Abstract Grader | American Heart Association Scientific Sessions |
| 2014- | Abstract Grader | American College of Cardiology Scientific Sessions |

**Honors**

*Washington & Lee University, Lexington, VA*

| | |
|---|---|
| 2001, 2002, 2003, 2004 | Intercollegiate Tennis Association Scholar-Athlete |
| 2003 | Vincent L. Bradford Merit Scholarship (for academic promise) |
| 2003 | James L. Gavin Memorial Merit Scholarship (for distinction in academics and leadership) |
| 2003 | Omicron Delta Kappa |
| 2003 | Alpha Epsilon Delta |

2004 Phi Beta Kappa

2004 Summa Cum Laude

2004 Unsung General (annual award to student with greatest campus contributions)

2004 Order of Omega

2004 National Dean's List

2004 Who's Who Among American Universities and Colleges

*Perelman School of Medicine at the University of Pennsylvania, Philadelphia, PA*

2008 Research Day 2008 - 1st Prize in Clinical Scholarly Pursuit

2008 ITMAT Research Paper Prize for Clinical Translational Research

2008 Gertrude M. & Ezra M. Eisen Prize (awarded annually to a graduating medical student for outstanding performance in cardiology rotations and research)

*Duke University Medical Center, Durham, NC*

2009 Robert M. Califf & Barton F. Haynes House Staff Research Award

2011 Robert M. Califf & Barton F. Haynes House Staff Research Award

*Johns Hopkins School of Medicine, Baltimore, MD*

2012 Johns Hopkins Division of Cardiology Research Retreat, Stanley L. Blumenthal, MD Cardiology Research Award, 2nd Place Prize for Oral Presentations

2012 Up and Coming Future Stars of Cardiology, American College of Cardiology Foundation CardioSource WorldNews

2013 Howard S. Silverman Research Award for Originality & Creativity in Medical Research

2013 Best of AHA Specialty Conferences Award for top scoring abstract, AHA Quality of Care and Outcomes Scientific Sessions

2013 Northwestern Cardiovascular Young Investigators' Forum Finalist (2nd prize in category of Fellows' Clinical Research)

2013 American College of Cardiology Mid-Atlantic Capital Young Investigators

Award Competition Finalist

**C. Selected peer-reviewed publications (selected from 110 peer reviewed publications)**

See Google Scholar Public Profile:
http://scholar.google.com/citations?user=mGx0e8EAAAAJ&hl=en

1. **Martin SS**, Qasim A, Reilly MP. Leptin resistance: a possible interface of inflammation and metabolism in obesity-related cardiovascular disease. *J Am Coll Cardiol.* 2008;52:1201-10.

2. **Martin SS**, Qasim AN, Mehta NN, Wolfe M, Terembula K, Schwartz S, Iqbal N, Schutta M, Bagheri R, Reilly MP. Apolipoprotein B but not LDL cholesterol is associated with coronary artery calcification in type 2 diabetic whites. *Diabetes.* 2009;58:1887-92.

3. **Martin SS**, Qasim AN, Wolfe M, St Clair C, Schwartz S, Iqbal N, Schutta M, Bagheri R, Mehta NN, Rader DJ, Reilly MP. Comparison of high-density lipoprotein cholesterol to apolipoprotein A-I and A-II to predict coronary calcium and the effect of insulin resistance. *Am J Cardiol.* 2011;107:393-8.

4. **Martin SS**, Qasim AN, Rader DJ, Reilly MP. C-reactive protein modifies the association of plasma leptin with coronary calcium in asymptomatic overweight individuals. *Obesity.* 2012;20:856-61.

5. **Martin SS**, Metkus TS, Horne A, Blaha MJ, Hasan R, Campbell CY, Yousuf O, Joshi P, Kaul S, Miller M, Michos ED, Jones SR, Gluckman TJ, Cannon CP, Sperling LS, Blumenthal RS. Waiting for the National Cholesterol Education Program Adult Treatment Panel IV guidelines, and in the meantime, some challenges and recommendations. *Am J Cardiol.* 2012;110:307-13.

6. **Martin SS,** Ou FS, Newby LK, Sutton V, Adams P, Felker GM, Wang TY. Patient- and trial-specific barriers to participation in cardiovascular randomized clinical trials. *J Am Coll Cardiol.* 2013;61:762-9.

7. **Martin SS**, Blaha MJ, Blankstein R, Agatston AS, Rivera JJ, Virani SS, Ouyang P, Jones SR, Blumenthal RS, Budoff MJ, Nasir K. Dyslipidemia, coronary artery calcium, and incident atherosclerotic cardiovascular disease: Implications for statin therapy from the Multi-Ethnic Study of Atherosclerosis. *Circulation.* 2014;129:77-86.

8. **Martin SS**, Abd TT, Jones SR, Michos ED, Blumenthal RS, Blaha MJ. 2013 American Cholesterol Treatment Guideline: what was done well and what could be done better. *J Am Coll Cardiol.* 2014;63:2674-8.

9. **Martin SS,** Blumenthal RS. Concepts and Controversies: The 2013 American College of Cardiology/American Heart Association Risk Assessment and Cholesterol Treatment Guidelines. *Ann Intern Med.* 2014;160:356-8.

10. **Martin SS**, Khokhar AA, May HT, Kulkarni KR, Blaha MJ, Joshi PH, Toth PP, Muhlestein JB, Anderson JL, Knight S, Li Y, Spertus JA, Jones SR; on behalf of the Lipoprotein

Investigators Collaborative (LIC). HDL cholesterol subclasses, myocardial infarction, and mortality in secondary prevention: The Lipoprotein Investigators Collaborative. *Eur Heart J*. 2014 Jun 30. pii: ehu264. [Epub ahead of print].

11. **Martin SS,** Jones SR, Toth PP. High-density lipoprotein subfractions: current views and clinical practice applications. *Trends Endocrinol Metab.* 2014;25:329-36.

12. Ankam J, Feldman DI, Blaha MJ, **Martin SS**. Improving lipid control following myocardial infarction. *Curr Opin Cardiol.* 2014;29:454-66.

**D. Research Support**

**T32 HL007024** (Coresh)
7/1/2013 – present
NIH/NHLBI
Role: Trainee

**Johns Hopkins Cardiovascular Disease Epidemiology Training Program.** Established in 1975, the program focuses on interdisciplinary training on the epidemiology of the leading cause of death in the United States. The program integrates knowledge on all aspects of cardiovascular disease: biology, behavior, treatment and prevention. Training emphasizes a collaborative approach and active participation in research on cohort studies and clinical trials.