Title

Interindividual Variability in Self-Monitoring of Blood Pressure Using Consumer-Purchased Wireless Devices

Journal
Nursing Research, 72(4)

ISSN
0029-6562

Authors
Zheng, Yaguang
Zhang, Yanfu
Huang, Heng
et al.

Publication Date
2023-07-01

DOI
10.1097/nnr.0000000000000654

Peer reviewed

HHS Public Access
Author manuscript
Nurs Res. Author manuscript; available in PMC 2024 January 01.

Published in final edited form as:
Nurs Res. 2023 ; 72(4): 310–318. doi:10.1097/NNR.0000000000000654.

Inter-individual variability in Self-Monitoring of Blood Pressure using Consumer-Purchased Wireless Devices

Yaguang Zheng, PhD[1], **Yanfu Zhang, MS**[2], **Heng Huang, PhD**[2], **Geoffrey H. Tison, MD, MPH**[3], **Lora E. Burke, PhD, MPH**[4], **Saul Blecker, MD**[5], **Victoria Vaughan Dickson, PhD**[1], **Jeffrey Olgin, MD**[3], **Gregory M. Marcus, MD, MAS**[3], **Mark J. Pletcher, MD, MPH**[3]

[1]New York University Rory Meyers College of Nursing

[2]University of Pittsburgh Swanson School of Engineering

[3]University of California, San Francisco School of Medicine

[4]University of Pittsburgh School of Nursing

[5]NYU Grossman School of Medicine, Department of Population Health, New York, NY 100101

Abstract

Background: Engagement with self-monitoring of blood pressure (BP) declines on average over time but may vary substantially by individual.

Objectives: We aimed to describe different 1-year patterns (groups) of self-monitoring of BP behaviors, identify predictors of those groups, and examine the association of self-monitoring of BP groups with BP levels over time.

Methods: We analyzed device-recorded BP measurements collected by the Health eHeart Study —an ongoing prospective eCohort study—from participants with a wireless consumer-purchased device that transmitted date-and time-stamped BP data to the study through a full 12 months of observation starting from the first day they used the device. Participants received no instruction on device use. We applied clustering analysis to identify 1-year self-monitoring of BP patterns.

Results: Participants had a mean age of 52 years, male, and White. Using clustering algorithms, we found that a model with three groups fit the data well: persistent daily use (9.1% of participants), persistent weekly use (21.2%), and sporadic use only (69.7%). Persistent daily use was more common among older participants who had higher Week 1 self-monitoring of BP frequency and was associated with lower BP levels than the persistent weekly or the sporadic use group throughout the year.

Conclusion: We identified three distinct self-monitoring of BP groups, with nearly 10% sustaining a daily use pattern associated with lower BP levels.

Corresponding author: Yaguang Zheng, PhD, yaguang.zheng@nyu.edu, NYU Meyers College of Nursing, 433 1st Avenue, New York, NY 10010.

Conflict of Interest statement: None

Clinical trial registration number and link to registration site: N/A

Keywords

blood pressure; blood pressure monitoring; mobile health; self

Approximately 46% of U.S. adults have hypertension, which is associated with increased cardiovascular disease risk and leads to target organ damage and complications (Fisher & Curfman, 2018). Hypertension accounts for more than 400,000 deaths each year in the U.S. and results in direct health care costs of approximately $131 billion each year (Mozaffarian et al., 2016). Controlling blood pressure (BP) reduces the risk of cardiovascular disease, stroke, and all-cause mortality; however, 75% of adults with hypertension do not have their BP under control (Centers for Disease Control and Prevention [CDC], 2023).

The American Heart Association recommends home BP monitoring for all people with high BP to help the health care provider determine whether treatments affect BP control (Shimbo et al., 2020). Self-monitoring of BP (SMBP) refers to use of a personal BP device by individuals outside of a clinical setting (U.S. Department of Health and Human Services & CDC, 2014). Using BP devices for SMBP has improved medication adherence and positive lifestyle changes, both leading to better BP control (Burke et al., 2015; Fletcher et al., 2016; Kaplan et al., 2017; Ye et al., 2018). Prior comparative effectiveness and systematic review have shown lower average BP among participants who performed SMBP compared with those who received usual care at 6 months (Reboussin et al., 2018; Sheppard et al., 2020; Tucker et al., 2017; Uhlig et al., 2012, 2013).

Although SMBP has been associated with better BP control, engagement—defined as regular use of the device to see improved outcomes—needs to be maintained (Spring et al., 2017). Most reported studies related to engagement with SMBP have been short-term, with the majority lasting ≤ 6 months (Burke et al., 2015; Fletcher et al., 2016; Kaplan et al., 2017; Ye et al., 2018), and very few studies extending beyond 12 months (Ostchega et al., 2017; Waalen et al., 2019). A single-arm study with a large sample ($n = 5115$) examined SMBP patterns and found an average decline of SMBP over time. Specifically, 100% of regular users declined to 74% at 2 weeks, 21% at 8 weeks, and only 1.9% at 22 weeks (Kaplan et al., 2017). The mean numbers of weekly measurements in the 4- and 14-week subgroups were 6 and 8, respectively (Kaplan et al., 2017). Similarly, a study that combined SMBP and pharmacist management of BP found a decline in SMBP at 18 months (Margolis et al., 2018). Numerous factors have been found to predict engagement with SMBP, e.g., age, sex, comorbidities of heart failure and diabetes, medications, and psychological factors (Ayala et al., 2017; Grant et al., 2015; Margolis et al., 2015; Muntner et al., 2019; Ostchega et al., 2017; Stergiou et al., 2018; Waalen et al., 2019; Wood et al., 2016). It is unclear, however, whether all participants follow a similar declining pattern of SMBP over time or whether there are qualitatively different patterns of SMBP over time.

The Health eHeart Study enrolls participants interested in cardiovascular health and collects data from home BP monitoring devices from consenting participants. We aimed to describe different 1-year patterns (groups) of SMBP behaviors, identify predictors of those patterns, and examine the association of SMBP groups with BP levels over time. Such analysis helps us to determine the SMBP profile so that clinicians can decide who needs certain types of SMBP and what is the best type of SMBP to use.

Methods

Study Design

We conducted a secondary analysis of data from the Health eHeart Study, an Internet-based, direct-to-participant, ongoing observational eCohort study coordinated by the University of California, San Francisco (UCSF) (Guo et al., 2017). The Health eHeart Study enrolls adult participants; those who own a WiFi- or Bluetooth-enabled consumer-purchased home BP monitoring device are invited to connect their device to the study and authorize the study to retrieve date- and time-stamped daily objective measurements of BP via a nightly automated server-to-server pull request. The Health eHeart Study offers no self-monitoring advice or BP device usage instructions, providing a unique ecological laboratory for observing SMBP daily and allowing us to analyze naturally occurring SMBP phenotypes in a participant's naturalistic setting. The study supports connections with BP monitors from three manufacturers: Withings, iHealth, and Qardio. After consent and authorization, all past BP measurements from the device data transmitted to the device manufacturer's servers (generally via a smartphone application on the user's phone) are transmitted from the manufacturer's server to the Health eHeart Study via the Eureka Research Platform. The data are then prospectively collected on a nightly basis. The parent study was approved by the institutional review board at UCSF; the secondary analysis of this data was approved by the institutional review board at the University of Pittsburgh. Informed consent was obtained from all individual participants included in the study.

Participants and Settings

As previously described, participation in the Health eHeart Study is open to adults ≥ 18 years old with Internet access. Participants have been actively recruited from XXX, other academic institutions, lay press, and social media, and through partnerships with advocacy groups and medical organizations—including the American Heart Association (Dixit et al., 2016). Participants completed the consent forms and surveys related to cardiovascular health online. Participants from the Health eHeart Study were eligible if they had at least 1-year SMBP data.

Measures

SMBP—Date- and time-stamped BP measurements were used to determine SMBP (any vs. none) for every day after the participants obtained the device. We calculated the number of days of SMBP per week for analysis, yielding 52 aggregated weekly counts over a 1-year period.

BP Outcomes—Systolic and diastolic BPs were assessed objectively via digital devices. Weekly BP levels in our study were calculated by averaging BP readings. We analyzed BP outcomes in two ways: Continuous BP measurements (mmHg) and proportion of BP measurements < 130/80 mmHg.

Predictors—Participant characteristics included self-reported age, sex, race/ethnicity, income, status of employment, and marital status. Participants were asked whether a doctor or nurse had told them they had medical conditions including coronary artery disease, congestive heart failure, diabetes, and hypertension. BMI was calculated based on baseline self-reported weight and height.

Statistical Analysis

Statistical analyses were conducted using SAS Version 9.4. Continuous variables were described using mean ± standard deviation (SD). Categorical variables (e.g., sex, race, and education) were described using frequency counts and percentages. We applied K-means clustering methods using Python Version 3.7.8 to identify different 1-year SMBP patterns. The appropriate number of clusters was determined through an iterative approach considering (Han et al., 2011) (a) the Akaike Information Criterion (AIC) and Bayesian Information Criteria (BIC); (b) the percent of participants assigned to each group; and (c) the clinical significance of differences between groups.

After settling on the number of clusters (groups), we examined group differences. Chi-square tests of independence and general linear modeling were performed to examine the differences in demographic, categorical, and continuous characteristics, respectively, between groups. We first analyzed differences separately for each demographic variable and medical condition by SMBP groups. After the crude unadjusted association for each predictor was determined, we used multivariate multinomial logistic regression to identify independent predictors of each SMBP group. The full multivariate model was first estimated with all predictor variables, including all demographic factors, medical conditions, and other factors (e.g., Week 1 SMBP frequency, Week 1 systolic and diastolic BP, and type of device). Next, parsimonious models were developed using a manual backward elimination approach removing predictor variables sequentially from the full multivariate model. Predictor variables were removed based on the *p*-value for the likelihood ratio chi-square test, with the *p*-value set at .05.

To examine the association of SMBP behaviors with BP levels over time, we applied linear mixed models with week as a within-subject continuous time variable (with t_1 set at first SMBP use for each participant), with polynomials of time (linear, quadratic, and cubic) being considered. We also added intercept as a random effect. The outcome of BP was the average of all BP measurements in a given week. Residuals were checked, and sensitivity analyses were conducted for potential outliers or influential cases identified through graphical methods. Conclusions remained unchanged when outliers were omitted; therefore, results using the full sample were reported. Then, we reexamined this association by adjusting for demographic variables (e.g., age, BMI, gender, race, education, income, status of employment, and marital status) as fixed effects in the mixed model.

Results

Among 214,097 participants who enrolled in Health eHeart prior to May 2019, a subsample (n = 2099) was identified with a full-year observation for SMBP using WiFi- or Bluetooth-enabled devices. Mean age was 52.0 years, SD = 12.3 (ranging from 20–86 years), and

BMI was M = 28.9kg/m^2, SD = 6.5. Most participants were male (89.1%), White (88.6%), received education higher than college (71.4%), employed (77.9%), had an income ≥ $50,000 (86.1%), married or living with a partner (75.2%). Many participants had comorbid medical conditions, including hypertension (52.8%), hyperlipidemia (46.4 %), diabetes (10.2%), coronary heart disease (8.4%), myocardial infarction (4.7%), congenital heart disease (2.7%), stroke (3.3%), and congestive heart failure (1.3%). All participants used their BP device at least once in the first week of observation; however, 74.4% had no measurements at Week 26 (6 months), and 79.2% had no measurements at Week 52 (12 months). Participants used three types of BP devices: Withing (66.2%), iHealth (23.8%), and Qardio (10.0%).

By comparison of AIC and BIC values, percentage of participants in each group and clinical judgment, we settled on a model with three groups (Figure 1); we named these three groups: persistent daily use (9.1% of participants), persistent weekly use (21.2%), and sporadic use only (69.7%). Supplemental Figures 1, 2, 3, 4, and 5 illustrated the 1-, 2-, 3-, 4- and 5-group models for comparison. Supplemental Table 1 included AIC and BIC values and percent of participants in each subgroup for each model.

Analysis of unadjusted associations for each predictor with group membership showed that the mean Week 1 SMBP frequency of persistent daily use ($M = 19.5$, $SD = 12.3$ years) was higher than that of the persistent weekly ($M = 20.5$, $SD = 12.2$) and the sporadic use group (M = 6.1, SD = 5.4; $p < .001$). Additionally, the mean age of persistent daily use ($M = 61.1$, $SD = 11.6$ years) was higher than that of the persistent weekly ($M = 53.4$, $SD = 11.6$) and the sporadic use group ($M = 50.4$, $SD = 11.5$). More daily users (38.9%) were unemployed than weekly (24.7%) and sporadic users (19.1%; $p < .001$). Compared with weekly (18.1%) and sporadic users (12.6%), a higher percent of persistent daily users' income (24.6%) was < $50,000 ($p = .001$). Similarly, more persistent daily users (37.8%) were not married compared with weekly (25.9%) and sporadic users (23.0%; $p = .005$). Persistent daily use group had lower Week 1 systolic BP levels (M = 128.1, SD = 12.8 mmHg) than the persistent weekly ($M = 131.2$, $SD = 14.4$ mmHg) and the sporadic use group ($M = 129.0$, $SD = 13.8$ mmHg; $p = .007$); similarly, persistent daily use group had lower Week 1 diastolic BP levels ($M = 77.2$, $SD = 10.0$ mmHg) than the persistent weekly ($M = 81.9$, $SD = 10.7$ mmHg) and the sporadic use group ($M = 80.4$, $SD = 9.6$ mmHg; $p < .001$). Compared with persistent daily use (57.6%) and persistent weekly use group (52.6%), the sporadic use group (71.5%) had a higher percentage of using Withing devices ($p < .001$). No significant differences were found among SMBP groups in BMI, gender, race, and education. Additionally, persistent daily users were more likely to have diabetes, coronary heart disease, and a history of myocardial infarction ($p < .05$ for all; Table 1). Multivariate multinomial logistic regression identified that age ($p = .001$) and the Week 1 frequency of use of BP devices ($p < .001$) were independent factors in full multivariate model (including all demographic variables and medical conditions). The factors of age ($p < .001$), marital status ($p = .01$), Week 1 SMBP frequency ($p < .001$), and Week 1 diastolic BP ($p = .0002$) were significant in the final parsimonious models (Table 1).

Figure 2a shows average systolic BP by SMBP groups over 12 months. Over 1 year, the persistent daily use group had lower systolic BP levels (mean±standard error: 126.3±0.8

mmHg) compared with the persistent weekly use (128.8±0.6) and the sporadic use (128.7±0.3) groups ($p < .001$). Figure 2b shows average diastolic BP by SMBP groups over 12 months. Over 1 year, the persistent daily use group had lower diastolic BP levels (mean±standard error: 76.3±0.6 mmHg) compared with the persistent weekly use (80.2±0.4) and the sporadic use group (80.2±0.4) groups ($p < .001$). The conclusions remained the same after adjusting for demographic factors (Tables 2 and 3).

There were significant differences in proportion of measurements with systolic BP > 130 mmHg among SMBP groups. Persistent daily use groups had lower (33.4%) proportion of records with high systolic values compared with the sporadic use group (40.6%) and persistent weekly use (43.0%) groups (Chi-square(x^2) = 189.3, $p < .001$). There were differences in proportion of measurements with diastolic BP > 80 mmHg among SMBP groups. The persistent daily use group had lower (33.2%) proportion of records with high diastolic values compared with the sporadic use group (44.3%) and persistent weekly use (48.0%) groups (chi-square(x^2) = 464.4, $p < .001$).

Figure 3a shows changes in systolic BP relative to systolic BP at Week 1 by SMBP groups over 12 months. Over 1 year, the sporadic use group had less reduction in systolic BP (mean±standard error: −0.71±0.20 mmHg) than the persistent daily use group (−1.85±0.51mmHg) and the persistent weekly use group (−2.44±0.34 mmHg; $p = .002$). Figure 3b shows changes in diastolic BP relative to diastolic BP at Week 1 by the SMBP groups over 12 months. Over 1 year, the sporadic use group had lower reduction in diastolic BP (mean±standard error: −0.52±0.14 mmHg) than the persistent daily use group (−0.92±0.36mmHg) and the persistent weekly use group (−1.75±0.24mmHg; $p = .001$).

Discussion

Our study found variabilities in continued engagement in SMBP in adults who use their personally owned Wi-Fi- or Bluetooth-enabled BP devices. Three distinct SMBP groups were identified, with nearly 10% sustaining a daily use pattern over 1 year. Individuals with older age, lower income, and unmarried were more likely to be in the daily use group pattern. The persistent daily use was also associated with lower BP levels that remained persistently lower than BP for less frequent SMBP users. Sporadic users had less reduction in BP than participants who used SMBP persistently on a daily or weekly schedule.

Our study identified three SMBP groups, nearly 10% sustaining a daily use pattern group over 1 year. Most reported studies related to engagement with SMBP have been short-term, with the majority lasting less than 6 months (Burke et al., 2015; Fletcher et al., 2016; Kaplan et al., 2017; Ye et al., 2018). For example, a single-arm study with a large sample (N = 5115) examined 22-week SMBP patterns and found a decline in BP monitoring across the whole sample (Kaplan et al., 2017). Similarly, a study that combined SMBP and pharmacist management found a decline in SMBP at 18 months (Margolis et al., 2018). Although the follow-up of that study was 18 months, the inter-individual variability was not examined. Additionally, individuals who do SMBP sporadically may only do so when they do not feel well; perhaps this might account for some discrepancies. We examined SMBP over a year and identified three distinct and common patterns of SMBP associated with different participant characteristics and outcomes.

We found daily users were likelier to be older, unemployed, have lower income, and have diabetes, coronary heart disease, or a history of myocardial infarction. One possible explanation for our findings that older adults were more likely to use SMBP persistently is that older adults may be more aware of the negative health consequences of cardiovascular disease, so they may be more motivated to monitor their BP status (Cassarino et al., 2021). The older population may also have more time to manage disease because they are retired (Westerlund et al., 2010). This finding is consistent with our previous analysis that older age was associated with daily self-weighing for weight management in a real-world population (Zheng et al., 2019). Earlier work also showed that older age strongly predicted meeting weight loss and physical activity goals (Brokaw et al., 2015; Diabetes Prevention Program Research Group, 2004). Our study also found that Week 1 SMBP frequency was an independent predictor of daily SMBP. There might be other potential predictors (e.g., use of physical activity tracking device, diabetes technology) which needs to be further explored.

Our study found that daily SMBP was associated with lower BP levels that remained persistently lower than the weekly or sporadic users over the 12-month observation period. The estimated systolic BP levels were about 2 mmHg lower in the persistent daily use group than the weekly use group, and the sporadic use group and the estimated diastolic BP levels were about 4 mmHg lower in the daily user group than the other two groups. Previous studies reported the impact of SMBP on BP levels but did not report the association between frequency of SMBP and BP levels and changes in BP levels. A prior systematic review found moderate evidence that supported a lower BP with SMBP (SBP/DBP −3.1/−2.0 mmHg at 6 months; Uhlig et al., 2012). An SBP reduction of 2–4 points—if caused by a different pattern of device use—could have an important impact on long-term cardiovascular outcomes; studies reported that a 5 mm Hg reduction of systolic BP reduced the risk of major cardiovascular events by about 10% (Canoy et al., 2022; Rahimi et al., 2021).

The main study limitation is that the sample was predominately White, male, well-educated, and self-selected participants in the Health eHeart Study. Additionally, we only examined the association between SMBP frequency and BP levels and changes but were unable to examine a more causal temporal relationship. There might be confounding variables; the possibility that BP levels may cause different SMBP patterns or varied baseline BP categories may exhibit different SMBP behaviors. Further work will examine the causal relationship between SMBP patterns and BP levels. Moreover, participants in our study used WiFi- or Bluetooth-enabled BP devices, while many people who monitor BP may not have access to this technology. The main strength of this study is that we used daily prospective data from a large free-living sample of participants who used their personal BP devices without receiving SMBP instructions, which allowed us to describe the natural patterns of SMBP in the first year of use.

Conclusion

Our study identified inter-individual variability in SMBP among adults who use their personally owned Wi-Fi- or Bluetooth-enabled BP devices without receiving instructions on device use from the research staff. Three distinct SMBP groups were identified, with nearly 10% sustaining a daily use group over 1 year. These findings can be considered in clinical practice or future studies when targeting improved engagement with SMBP, e.g., younger individuals without comorbid conditions may need additional intervention strategies to engage in regular, sustained SMBP. Future studies are needed to explore how to sustain general consumer interest in active use of a digital BP device for SMBP and how to use SMBP data most effectively to inform user engagement in better sustained self-management strategies that lead to BP control.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments/Sources of Funding

This study was funded by the National Institutes of Health [1U2CEB021881] and Salesforce Foundation. Y.Z was also supported by NIH T32 NR008857 Technology: Research in Chronic and Critical Illness when working on this manuscript.

References

Ayala C, Tong X, Neeley E, Lane R, Robb K, & Loustalot F (2017). Home blood pressure monitoring among adults—American Heart Association Cardiovascular Health Consumer Survey, 2012. Journal of Clinical Hypertension, 19, 584–591. 10.1111/jch.12983 [PubMed: 28371252]

Brokaw SM, Carpenedo D, Campbell P, Butcher MK, Furshong G, Helgerson SD, Harwell TS, & Montana Cardiovascular Disease and Diabetes Prevention Workgroup. (2015). Effectiveness of an adapted diabetes prevention program lifestyle intervention in older and younger adults. Journal of the American Geriatrics Society, 63, 1067–1074. 10.1111/jgs.13428 [PubMed: 26031428]

Burke LE, Ma J, Azar KMJ, Bennett GG, Peterson ED, Zheng Y, Riley W, Stephens J, Shah SH, Suffoletto B, Turan TN, Spring B, Steinberger J, & Quinn CC (2015). Current science on consumer use of mobile health for cardiovascular disease prevention: A scientific statement from the American Heart Association. Circulation, 132, 1157–1213. 10.1161/cir.0000000000000232 [PubMed: 26271892]

Canoy D, Nazarzadeh M, Copland E, Bidel Z, Rao S, Li Y, & Rahimi K (2022). How much lowering of blood pressure is required to prevent cardiovascular disease in patients with and without previous cardiovascular disease? Current Cardiology Reports, 24, 851–860. 10.1007/s11886-022-01706-4 [PubMed: 35524880]

Cassarino N, Bergstrom B, Johannes C, & Gualtieri L (2021). Monitoring older adult blood pressure trends at home as a proxy for brain health. Online Journal of Public Health Informatics, 13, e16, 10.5210/ojphi.v13i3.11842. [PubMed: 35079322]

Centers for Disease Control and Prevention. (2023). Facts About hypertension. Retrieved from https://www.cdc.gov/bloodpressure/facts.htm#print.

Diabetes Prevention Program Research Group. (2004). Achieving weight and activity goals among diabetes prevention program lifestyle participants. Obesity Research, 12, 1426–1434. 10.1038/oby.2004.179 [PubMed: 15483207]

Dixit S, Pletcher MJ, Vittinghoff E, Imburgia K, Maguire C, Whitman IR, Glantz SA, Olgin JE, & Marcus GM (2016). Secondhand smoke and atrial fibrillation: Data from the Health eHeart Study. Heart Rhythm, 13, 3–9. 10.1016/j.hrthm.2015.08.004 [PubMed: 26340844]

Fisher NDL, & Curfman G (2018). Hypertension—A public health challenge of global proportions. JAMA, 320, 1757–1759. 10.1001/jama.2018.16760 [PubMed: 30398584]

Fletcher BR, Hinton L, Hartmann-Boyce J, Roberts NW, Bobrovitz N, & McManus RJ (2016). Self-monitoring blood pressure in hypertension, patient and provider perspectives: A systematic review and thematic synthesis. Patient Education and Counseling, 99, 210–219. 10.1016/j.pec.2015.08.026 [PubMed: 26341941]

Grant S, Greenfield SM, Nouwen A, & McManus RJ (2015). Improving management and effectiveness of home blood pressure monitoring: A qualitative UK primary care study. British Journal of General Practice, 65, e776–e783. 10.3399/bjgp15X687433

Guo X, Vittinghoff E, Olgin JE, Marcus GM, & Pletcher MJ (2017). Volunteer participation in the Health eHeart Study: A comparison with the US population. Scientific Reports, 7, 1956. 10.1038/s41598-017-02232-y [PubMed: 28512303]

Han J, Kamber M, & Pei J (2011). Data mining: Concepts and techniques (3rd ed.). Elsevier Science.

Kaplan AL, Cohen ER, & Zimlichman E (2017). Improving patient engagement in self-measured blood pressure monitoring using a mobile health technology. Health Information Science Systems, 5, 4. 10.1007/s13755-017-0026-9 [PubMed: 29081974]

Margolis KL, Asche SE, Bergdall AR, Dehmer SP, Maciosek MV, Nyboer RA, O’Connor PJ, Pawloski PA, Sperl-Hillen JM, Trower NK, Tucker AD, & Green BB (2015). A successful multifaceted trial to improve hypertension control in primary care: Why did it work? Journal of General and Internal Medicine, 30, 1665–1672. 10.1007/s11606-015-3355-x

Margolis KL, Asche SE, Dehmer SP, Bergdall AR, Green BB, Sperl-Hillen JM, Nyboer RA, Pawloski PA, Maciosek MV, Trower NK, & O’Connor PJ (2018). Long-term outcomes of the effects of home blood pressure telemonitoring and pharmacist management on blood pressure among adults with uncontrolled hypertension: Follow-up of a cluster randomized clinical trial. JAMA Network Open, 1, e181617. 10.1001/jamanetworkopen.2018.1617 [PubMed: 30646139]

Mozaffarian D, Benjamin EJ, Go AS, Arnett DK, Blaha MJ, Cushman M, Das SR, de Ferranti S, Després J-P, Fullerton HJ, Howard VJ, Huffman MD, Isasi CR, Jiménez MC, Judd SE, Kissela BM, Lichtman JH, Lisabeth LD, Lui S, … Turner MB. (2016). Heart Disease and Stroke Statistics—2016 Update: A report from the American Heart Association. Circulation, 133, e38–360. 10.1161/CIR.0000000000000350 [PubMed: 26673558]

Muntner P, Shimbo D, Carey RM, Charleston JB, Gaillard T, Misra S, Myers MG, Ogedegbe G, Schwartz JE, Townsend RR, Urbina EM, Viera AJ, White WB, & Wright JT Jr. (2019). Measurement of blood pressure in humans: A scientific statement from the American Heart Association. Hypertension, 73, e35–e66. 10.1161/HYP.0000000000000087 [PubMed: 30827125]

Ostchega Y, Zhang G, Kit BK, & Nwankwo T (2017). Factors associated with home blood pressure monitoring among US adults: National Health and Nutrition Examination Survey, 2011–2014. American Journal of Hypertension, 30, 1126–1132. 10.1093/ajh/hpx101 [PubMed: 28633432]

Rahimi K, Bidel Z, Nazarzadeh M, Copland E, Canoy D, Ramakrishnan R, Pinho-Gomes AC, Woodward M, Adler A, Agodoa L and Algra A (2021). Pharmacological blood pressure lowering for primary and secondary prevention of cardiovascular disease across different levels of blood pressure: An individual participant-level data meta-analysis. Lancet, 397, 1625–1636. 10.1016/S0140-6736(21)00590-0 [PubMed: 33933205]

Reboussin DM, Allen NB, Griswold ME, Guallar E, Hong Y, Lackland DT, Miller EPR 3rd, Polonsky T, Thompson-Paul AM, & Vupputuri S (2018). Systematic Review for the 2017 ACC/AHA/AAPA/ABC/ACPM/AGS/APhA/ASH/ASPC/NMA/PCNA guideline for the prevention, detection, evaluation, and management of high blood pressure in adults: A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. Circulation, 138, e595–e616. 10.1161/CIR.0000000000000601 [PubMed: 30354656]

Sheppard JP, Tucker KL, Davison WJ, Stevens R, Aekplakorn W, Bosworth HB, Bove A, Earle K, Godwin M, Green BB, Hebert P, Heneghan C, Hill N, Hobbs FDR, Kantola I, Kerry SM, Leiva A, Magid DJ, Mant J, … McManus RJ. (2020). Self-monitoring of blood pressure in patients with hypertension-related multi-morbidity: Systematic review and individual patient data meta-analysis. American Journal of Hypertension, 33, 243–251. 10.1093/ajh/hpz182 [PubMed: 31730171]

Shimbo D, Artinian NT, Basile JN, Krakoff LR, Margolis KL, Rakotz MK, Wozniak G, & American Heart Association and the American Medical Association. (2020). Self-measured blood pressure monitoring at home: A joint policy statement from the American Heart Association and American Medical Association. Circulation, 142, e42–e63. 10.1161/cir.0000000000000803 [PubMed: 32567342]

Spring B, Pfammatter A, & Alshurafa N (2017). First steps into the brave new transdiscipline of mobile health. JAMA Cardiology, 2, 76–78. 10.1001/jamacardio.2016.4440 [PubMed: 27973672]

Stergiou GS, Parati G, McManus RJ, Head GA, Myers MG, & Whelton PK (2018). Guidelines for blood pressure measurement: Development over 30 years. Journal of Clinical Hypertension, 20, 1089–1091. 10.1111/jch.13295 [PubMed: 30003695]

Tucker KL, Sheppard JP, Stevens R, Bosworth HB, Bove A, Bray EP, Earle K, George J, Godwin M, Green BB, Hebert P, Hobbs FDR, Kantola I, Kerry SM, Leiva A, Magid DJ, Mant J, Margolis KL, McKinstry B, … McManus RJ. (2017). Self-monitoring of blood pressure in hypertension: A systematic review and individual patient data meta-analysis. PLoS Medicine, 14, e1002389. 10.1371/journal.pmed.1002389 [PubMed: 28926573]

Uhlig K, Balk EM, Patel K, Ip S, Kitsios GD, Obadan NO, Haynes SM, Stefan M, Rao M, Chang LKW, Gaylor J, & Iovin RC (2012). Self-measured blood pressure monitoring: Comparative effectiveness. Effective Health Care Program, Agency for Healthcare Research and Quality. https://effectivehealthcare.ahrq.gov/products/measuring-blood-pressure/research

Uhlig K, Patel K, Ip S, Kitsios GD, & Balk EM (2013). Self-measured blood pressure monitoring in the management of hypertension: A systematic review and meta-analysis. Annals of Internal Medicine, 159, 185–194. 10.7326/0003-4819-159-3-201308060-00008 [PubMed: 23922064]

U.S. Department of Health and Human Services, & Centers for Disease Control and Prevention. (2014). Self-measured blood pressure monitoring: Action steps for public health practitioners. CreateSpace Independent Publishing Platform.

Waalen J, Peters M, Ranamukhaarachchi D, Li J, Ebner G, Senkowsky J, Topol EJ, & Steinhubl SR (2019). Real world usage characteristics of a novel mobile health self-monitoring device: Results from the Scanadu Consumer Health Outcomes (SCOUT) Study. PLoS ONE, 14, e0215468. 10.1371/journal.pone.0215468 [PubMed: 30990860]

Westerlund H, Vahtera J, Ferrie JE, Singh-Manoux A, Pentti J, Melchior M, Leineweber C, Jokela M, Siegrist J, Goldberg M, Zins M, & Kivimaki M (2010). Effect of retirement on major chronic conditions and fatigue: French GAZEL occupational cohort study. BMJ, 341, c6149. 10.1136/bmj.c6149 [PubMed: 21098617]

Wood S, Greenfield SM, Sayeed Haque M, Martin U, Gill PS, Mant J, Mohammed MA, Heer G, Johal A, Kaur R, Schwartz C, & McManus RJ (2016). Influence of ethnicity on acceptability of method of blood pressure monitoring: A cross-sectional study in primary care. British Journal of General Practice, 66, e577–e586. 10.3399/bjgp16X685717

Ye T, Zhang P, Ouyang Z, Yang J, Xu C, Pan Z, Wu Z, Zhang L, & Li B (2018). Multi-trajectory modeling of home blood pressure telemonitoring utilization among hypertensive patients in China: A latent class growth analysis. International Journal of Medical Informatics, 119, 70–74. 10.1016/j.ijmedinf.2018.09.005

Zheng Y, Sereika SM, Burke LE, Olgin JE, Marcus GM, Aschbacher K, Tison GH, & Pletcher MJ (2019). Temporal patterns of self-weighing behavior and weight changes assessed by consumer purchased scales in the Health eHeart Study. Journal of Behavioral Medicine, 42, 873–882. 10.1007/s10865-018-00006-z [PubMed: 30649648]

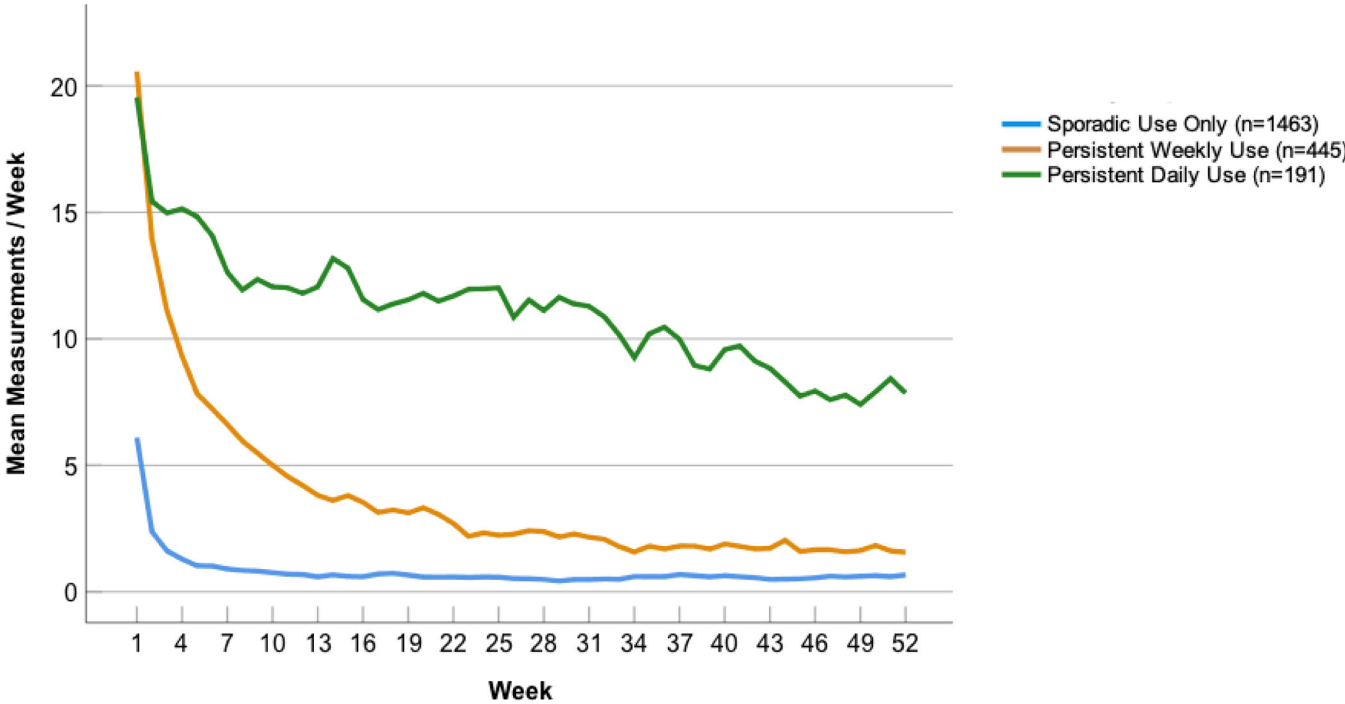
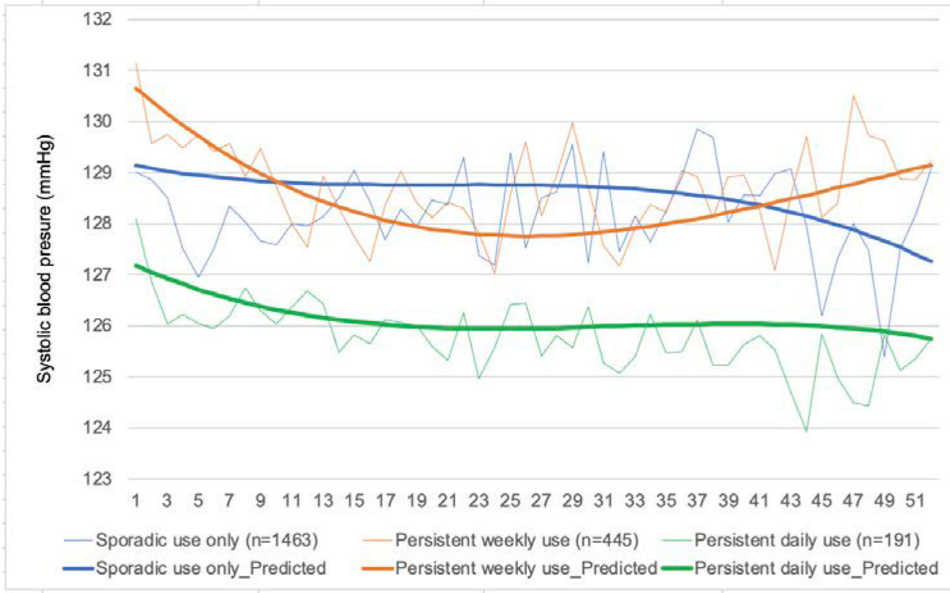


Figure 1.

One-year Patterns of Self-Monitoring of Blood Pressure

Author Manuscript
Author Manuscript
Author Manuscript



P values:
Time-linear: p<.001
Time-quadratic: p<.001
Time-cubic: p<.001
Group: p=.001
Group x time-linear: p<.001
Group x time-quadratic: p<.001

Figure 2a.
Differences in systolic blood pressure by SMBP groups over 1 year.

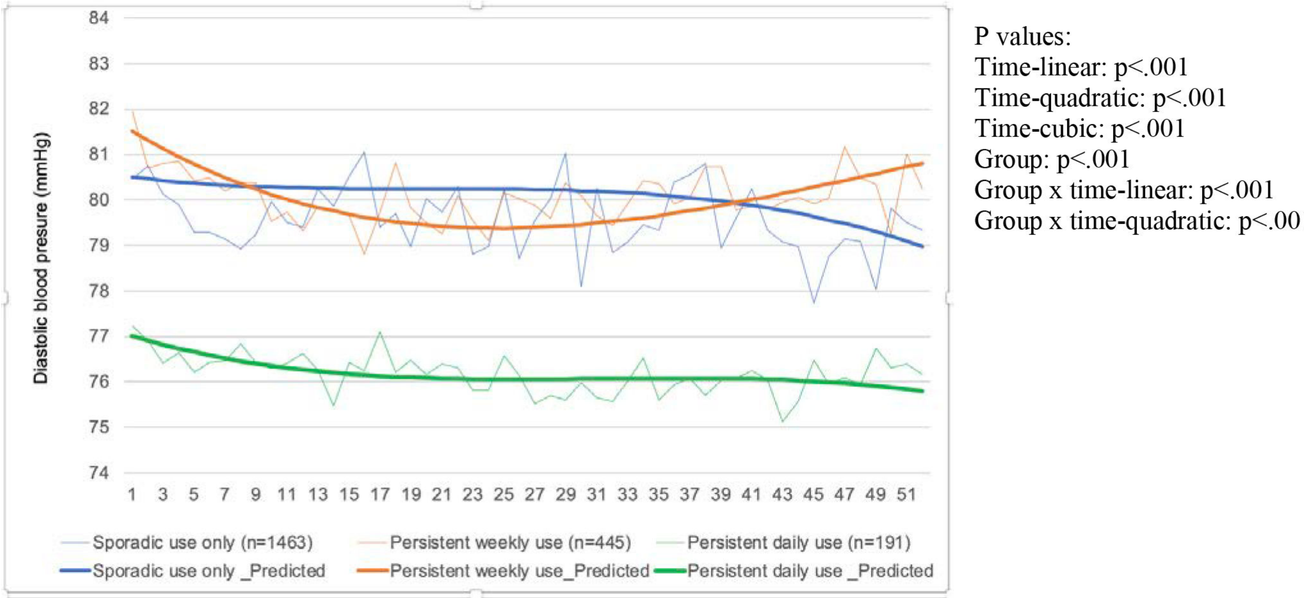


Figure 2b.

Differences in diastolic blood pressure by SMBP groups over 1 year

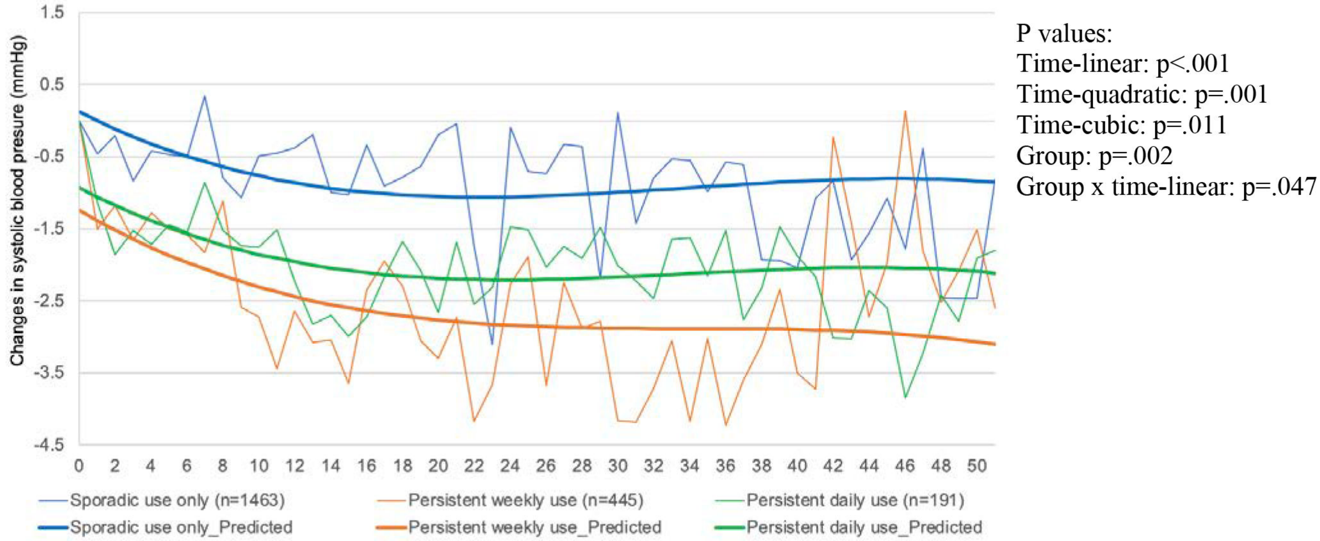


Figure 3a.

Differences in changes in systolic blood pressure relative to week 1 by SMBP groups over 1 year.

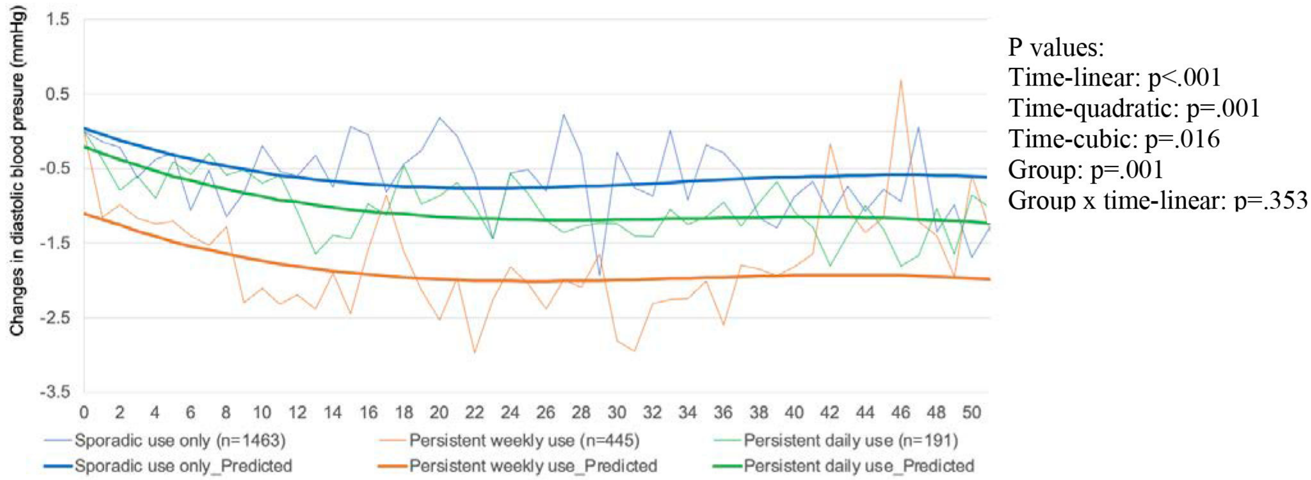


Figure 3b.

Differences in changes in diastolic blood pressure relative to week 1 by SMBP groups over 1 year.

Table 1

Predictors of SMBP Groups

	Persistent daily use (*n*=191)	Persistent weekly use (*n*=445)	Sporadic use only (n=1463)	*p*-values		
				Univariate model	Multivariate Full model	Multivariate Parsimonious model
Demographic						
Characteristics						
Age, years	61.1±11.6	53.4±11.6	50.4±11.5	<.001	.0011	<.001
BMI (kg/m^2)	28.4±9.0	28.7±5.9	29.0±6.3	.576	.488	
Age (n, %)						
<45	16 (8.4)	103 (23.2)	474 (32.4)	<.001		
45–65	93 (48.7)	256 (57.5)	779 (53.3)			
≥ 65	82 (42.9)	86 (19.3)	210 (14.4)			
Gender						
Male	179 (93.7)	392 (88.1)	1299 (88.8)	.091	.505	
Female	12 (6.28)	53 (11.9)	164 (11.2)			
Race						
White (non-Hispanic)	167 (90.3)	386 (89.6)	1244 (88.1)	.535	.203	
Non-White	18 (9.7)	45 (10.4)	168 (11.9)			
Education						
≤ High school	17 (10.6)	27 (7.1)	103 (8.7)	.739	.095	
High school/college	31 (19.4)	79 (20.7)	238 (20.0)			
≥ College	112 (70.0)	275 (72.2)	849 (71.3)			
Employment						
Employed[d]	99 (61.1)	293 (75.3)	976 (80.9)	<.001	.748	
Unemployed	63 (38.9)	96 (24.7)	230 (19.1)			
Income						
< $50,000	34 (24.6)	62 (18.1)	135 (12.6)	.001	.702	
$50,000 – < $100,000	36 (26.1)	98 (28.7)	293 (27.4)			
≥ $100,000	68 (49.3)	182 (53.2)	640 (60.0)			
Marital status				.005	.180	0.01
Married or living with partner	61 (62.2)	214 (74.1)	698 (77.0)			
Widowed, divorced, separated, other	37 (37.8)	75 (25.9)	209 (23.0)			
Medical Conditions						
Hypertension	96 (67.3)	185 (60.5)	401 (47.6)	<.001	.243	
Hyperlipidemia	75 (53.2)	150 (49.0)	372 (44.3)	.083	.247	
Diabetes	26 (18.2)	30 (9.8)	76 (9.0)	.004	.419	
Coronary heart disease	29 (20.6)	34 (11.3)	45 (5.4)	<.001	.531	
Myocardial infarction	18 (12.8)	16 (5.3)	26 (3.1)	<.001	.639	
Congenital heart disease	6 (4.29)	8 (2.62)	20 (2.4)	.434	.136	

	Persistent daily use (*n*=191)	Persistent weekly use (*n*=445)	Sporadic use only (n=1463)	*p*-values		
				Univariate model	Multivariate Full model	Multivariate Parsimonious model
Stroke (n, %)	6 (4.23)	10 (3.3)	26 (3.1)	.780	.271	
Congestive heart failure	3 (2.14)	1 (0.33)	12 (1.4)	.207	.166	
Other factors						
Week 1 SMBP frequency	19.5±12.3	20.5±12.2	6.1±5.4	<.001	<.001	<.001
Week 1 systolic BP	128.1±12.8	131.2±14.4	129.0±13.8	.007	.999	
Week 1 diastolic BP	77.2±10.0	81.9±10.7	80.4±9.6	<.001	.521	.0002
Type of device				<.001	.194	
Withing	110 (57.6)	234 (52.6)	1046 (71.5)			
iHealth	48 (25.1)	135 (30.3)	317 (21.7)			
Qardio	33 (17.3)	76 (17.1)	100 (6.8)			

Note. SMBP = self-monitoring of blood pressure. Full model included all demographic factors, medical conditions, and other factors. Parsimonious model included factors of age, marital status, week 1 diastolic blood pressure, and week 1 SMBP frequency.

Table 2

Systolic Blood Pressure by SMBP Groups (3 groups) over Time

	No adjustment			Adjusted for demographic variables		
Parameter	***b***	**SE**	***p*-value**	***b***	**SE**	***p*-value**
Time	−0.277	0.559	<.001	−0.269	0.22	<.001
$Time^2$	0.007	0.001	<.001	0.007	0.001	<.001
$Time^3$	−0.0001	0.001	<.001	−0.001	0.0001	<.001
Group			.001			.006
Persistent daily use vs. Persistent weekly use	−2.526	1.010	.012	−3.957	1.618	.015
Persistent daily use vs. Sporadic use only	−2.397	0.902	.008	−3.774	1.508	.012
Persistent daily use	126.30	0.845	<.001	125.44	1.648	<.001
Persistent weekly use	128.83	0.554	<.001	129.39	1.249	<.001
Sporadic use only	128.70	0.316	<.001	129.21	1.064	<.001
Group*Time			<.001			<.001
$Group*Time^2$			<.001			<.001

Note. b= parameter estimate; SE = standard error. Demographic variables include baseline BMI, age, gender, race, education, employment, income and marital status.

Author Manuscript

Author Manuscript

Author Manuscript

Table 3

Diastolic Blood Pressure by SMBP Groups (3 groups) over Time

	No adjustment			Adjusted for demographic variables		
Parameter	***b***	**SE**	***p*-value**	***b***	**SE**	***p*-value**
Time	−0.212	0.420	<.001	−0.189	0.015	<.001
$Time^2$	0.006	0.0001	<.001	0.006	0.001	<.001
$Time^3$	−0.001	0.001	<.001	−0.001	0.0001	<.001
Group			<.001			.0003
Use daily vs. Use weekly	−3.891	0.761	<.001	−4.057	1.235	.001
Use daily vs. Use sporadically	−3.852	0.679	<.001	−3.853	1.150	.001
Use daily	76.318	0.636	<.001	76.527	1.256	<.001
Use weekly	80.209	0.418	<.001	80.380	0.808	<.001
Use sporadically	80.170	0.418	<.001	80.380	0.951	<.001
Group*Time			<.001			<.001
$Group*Time^2$			<.001			<.001

Note. b= parameter estimate; SE = standard error. Demographic variables include baseline BMI, age, gender, race, education, employment, income and marital status.