

Digital Connectedness in the Framingham Heart Study

Caroline S. Fox, MD, MPH; Shih-Jen Hwang, PhD; Kenneth Nieto, MA; Maureen Valentino, BA; Karen Mutalik, BS; Joseph M. Massaro, PhD; Emelia J. Benjamin, MD, MSc; Joanne M. Murabito, MD, MSc

Background—New avenues of data collection such as eHealth and mobile technology have the potential to revolutionize the way large populations can be assessed and managed outside of standard research and clinical settings.

Methods and Results—A digital connectedness survey was administered within the Framingham Heart Study from 2014 to 2015. The exposure was usage of the Internet, email, cell phones, and smartphones in relation to demographic and cardiovascular disease risk factors; all results were adjusted for age and sex. Among 8096 living study participants, 6503 (80.3%) completed the digital survey. Among survey responders, 5678 (87.4%) reported regular Internet use. Participants reporting regular Internet use were younger (aged 59.1 versus 76.5 years, $P<0.0001$), were more likely to be employed (70.3% versus 23.7%, $P=0.002$), and had more favorable cardiovascular disease risk factors than those who did not use the Internet (all $P\leq 0.05$). Overall, 5946 (92.1%) responders reported using cell phones. Among cell phone users, 3907 (67.8%) had smartphones. Smartphone users were younger (aged 55.4 versus 68.5 years, $P<0.0001$), more likely to be employed (81.1% versus 43.9%, $P<0.0001$) and to have a college education, and less likely to have hypertension (27.9% versus 55.7%, $P=0.0002$) than those who did not use smartphones.

Conclusions—Digital connectedness varies substantially by age; connected persons tend to be younger and better educated and to have more favorable cardiovascular disease risk factor profiles. Less than two-thirds of study participants who completed the survey had a smartphone. The generalizability of studies focused on digitally connected persons may have limitations. (*J Am Heart Assoc.* 2016;5:e003193 doi: 10.1161/JAHA.116.003193)

Key Words: cardiovascular risk • eHealth • epidemiology • mHealth • smartphones • technology

Traditional cohort epidemiology has been the mainstay of population-based science for several decades; however, classical cohort epidemiology is costly and time consuming^{1–3} and has been criticized for incremental findings, lack of

validation, and lack of flexibility.⁴ New models of scalable population-based data collection are necessary.⁵ The digital health revolution may have the potential to transform health care by offering larger scale phenotyping performed outside of standard research clinic settings.^{6–9} New avenues for collecting population-level data, such as eHealth and mobile (mHealth) technology, are potentially exciting and may improve clinicians' and researchers' abilities to assess risk factors and health behaviors in vivo (ie, data are collected in participants' true environments).¹⁰ Use of these new modalities requires access to technology including the Internet, email, cell phones, and smartphones. The overall penetrance of digital technology within an existing cohort study and associations with cardiovascular disease (CVD) risk burden remain largely unknown.

The purpose of our study was to assess the digital connectedness, which we defined as usage of digital technologies, of Framingham Heart Study (FHS) participants, using a recently administered digital connectedness survey. In addition to overall connectivity, we examined the CVD risk factor profiles associated with technology usage. We hypothesized that those who used digital technologies would be younger and would have less adverse CVD risk factor profiles than their counterparts who did not use such technologies.

From the National Heart, Lung, and Blood Institute Center for Population Studies, National Institutes of Health, Framingham, MA (C.S.F., S.-J.H.); Division of Endocrinology, Hypertension, and Metabolism, Brigham and Women's Hospital, Harvard Medical School, Boston, MA (C.S.F.); Framingham Heart Study, Framingham, MA (K.N., M.V., K.M., E.J.B., J.M. Murabito); Department of Mathematics and Statistics, Boston University, Boston, MA (J.M. Massaro); Department of Epidemiology, Boston University School of Public Health, Boston, MA (E.J.B.); Sections of Cardiology and Preventive Medicine (E.J.B.) and General Internal Medicine (J.M. Murabito), Department of Medicine, Boston University School of Medicine, Boston, MA.

An accompanying Data S1 is available at <http://jaha.ahajournals.org/content/5/4/e003193/DC1/embed/inline-supplementary-material-1.pdf>

Correspondence to: Caroline S. Fox, MD, MPH, Framingham Heart Study, National Heart, Lung, and Blood Institute, 73 Mount Wayte Avenue, Suite 2, Framingham, MA 01702. E-mail: foxca@nhlbi.nih.gov

Received January 1, 2016; accepted March 12, 2016.

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Methods

Study Sample

In 1948, 5209 women and men aged 28 to 62 years enrolled in the FHS Original cohort. Because <100 participants from the Original cohort are living, that cohort was not included in the present report. The offspring and spouses of the offspring of the Original cohort were enrolled in the Offspring study.^{11,12} In 2002, 4095 Third Generation participants with at least 1 parent in the Offspring cohort were enrolled. From

1994 to 1998, Omni Group 1 (n=506) was recruited to reflect the contemporary diversity of the town of Framingham, Massachusetts. From 2002 to 2005, the Omni Group 2 cohort (n=410) was recruited to parallel recruitment of the Third Generation cohort. The standard research clinical examination typically included physician-administered medical history interviews, physical examinations, and laboratory tests. The study was approved by the institutional review board of Boston University Medical Center, and participants provided written informed consent.

Table 1. Study Sample Characteristics Among Framingham Heart Study Participants by Internet, Cell Phone, or Smartphone Usage

	Internet (n=5678)	No Internet (n=806)	P Value	Cell Phone (n=5946)	No Cell Phone (n=517)	P Value	Smartphone (n=3907)	No Smartphone (n=1857)	P Value*
Age, y	59.1 (13.0)	76.5 (10.2)	<0.0001	60.0 (13.4)	75.5 (11.0)	<0.0001	55.4 (11.8)	68.5 (11.9)	<0.0001
Age groups, y			<0.0001			<0.0001			<0.0001
25 to 34	178 (3.1)	—		178 (3.0)	—		165 (4.2)	13 (0.7)	
35 to 44	663 (11.7)	2 (0.3)		659 (11.1)	3 (0.6)		615 (15.7)	43 (2.3)	
45 to 54	1378 (24.3)	31 (3.9)		1383 (23.3)	22 (4.3)		1153 (29.5)	214 (11.5)	
55 to 64	1495 (26.3)	80 (9.9)		1515 (25.5)	60 (11.6)		1105 (28.3)	378 (20.4)	
65 to 74	1321 (23.3)	199 (24.7)		1362 (22.9)	151 (29.2)		676 (17.3)	626 (33.7)	
75 to 84	537 (9.5)	318 (39.5)		687 (11.6)	165 (31.9)		179 (4.6)	449 (24.2)	
≥85	106 (1.9)	176 (21.8)		162 (2.7)	116 (22.4)		14 (0.36)	134 (7.2)	
Women (%)	3166 (55.8)	464 (57.6)	0.44	3319 (55.8)	293 (56.7)	0.78	2156 (55.2)	1060 (57.1)	0.12
Race/ethnicity			0.09			0.99			0.02
White	5168 (91.1)	730 (90.6)		5401 (90.9)	479 (92.7)		3505 (89.8)	1734 (93.4)	
Black	142 (2.5)	19 (2.4)		148 (2.5)	12 (2.3)		105 (2.7)	35 (1.9)	
Hispanic	142 (2.5)	45 (5.6)		170 (2.9)	17 (3.3)		123 (3.2)	39 (2.1)	
Asian	128 (2.3)	8 (1.0)		132 (2.2)	4 (0.8)		96 (2.5)	33 (1.8)	
Other	95 (1.7)	4 (0.5)		92 (1.6)	5 (1.0)		75 (1.9)	16 (0.9)	
BMI, kg/m ²	28.1 (5.6)	28.6 (5.6)	0.88	28.1 (5.6)	28.8 (6.1)	0.64	27.9 (5.5)	28.5 (5.7)	0.59
Smoking (%)	404 (8.2)	80 (13.0)	<0.0001	442 (8.7)	41 (10.0)	0.004	281 (8.3)	147 (9.4)	<0.0001
Currently employed (%)	3320 (70.3)	132 (23.7)	0.002	3351 (68.5)	99 (26.7)	0.0005	2630 (81.1)	657 (43.9)	<0.0001
Education			<0.0001			<0.0001			<0.0001
Less than high school (%)	31 (0.6)	54 (7.9)		57 (1.1)	28 (6.3)		16 (0.45)	36 (2.2)	
High school (%)	779 (15.2)	318 (46.7)		939 (17.6)	153 (34.4)		399 (11.3)	492 (29.8)	
Some college (%)	1552 (30.3)	202 (29.7)		1606 (30.0)	137 (30.8)		1031 (29.1)	522 (31.6)	
College and higher (%)	2767 (54.0)	107 (15.7)		2746 (51.4)	127 (28.5)		2093 (59.1)	601 (36.4)	
Hypertension (%)	1746 (35.5)	451 (73.2)	0.0009	1907 (37.4)	276 (67.3)	0.35	946 (27.9)	869 (55.7)	0.0002
Hyperlipidemia (%)	2743 (55.9)	442 (72.9)	0.002	2884 (56.7)	289 (71.2)	0.01	1726 (51.0)	1044 (67.3)	0.15
Diabetes (%)	726 (15.0)	181 (30.6)	0.05	784 (15.6)	121 (30.7)	0.07	421 (12.6)	326 (21.3)	0.61
CVD (%)	443 (7.8)	213 (26.4)	0.0002	531 (8.9)	122 (23.6)	0.26	215 (5.5)	277 (14.9)	0.16
Atrial fibrillation (%)	249 (4.4)	101 (12.6)	0.79	282 (4.8)	66 (12.8)	0.79	104 (2.7)	157 (8.5)	0.07

BMI indicates body mass index; CVD, cardiovascular disease.

*P value is adjusted for age and sex.

Digital Connectedness Survey

We created a digital connectedness survey to administer to all living FHS participants without significant cognitive impairment (n=8096). The full survey appears in Data S1. Briefly, we asked participants about their usage of the Internet, email, cell phones, smartphones, social networks, computer games, and health applications (“apps”). The survey was estimated to take about 3 minutes to complete. The survey was first administered in REDCap (<http://project-redcap.org>) to all participants with a unique email address on file. The link was re-sent twice, weekly, and if the participant still did not respond, a telephone call was placed. Up to 3 attempts were made to reach the participant by telephone. During the telephone call, the participant was given the opportunity to complete the survey over the telephone, to receive the REDCap link again, or to complete the survey using a mailed

paper version. For participants who did not have an email address on file or who shared email accounts (n=2922), attempts were made to call participants to retrieve their email addresses. Finally, paper surveys were mailed to all participants who did not complete the survey either by REDCap or by telephone. Overall, 2649 Offspring, 3321 Third Generation, and 533 Omni participants completed the survey. The survey was administered between study examinations. Compared with survey responders, survey nonresponders (n=1593) were younger (aged 57.4 versus 61.3 years), were less likely to have attended a recent examination (54.8% versus 85.3%), had a higher body mass index (in kg/m²; 28.6 versus 28.2), were more likely to smoke cigarettes (13.1% versus 8.7%), were less likely to have completed college (38.3% versus 49.5%), and had higher rates of hypertension (42.6% versus 39.8%) and diabetes (20.4% versus 16.7%; all *P*<0.02).

Table 2. Study Sample Characteristics Among Framingham Heart Study Offspring Participants by Internet, Cell Phone, or Smartphone Usage

	Internet (n=1947)	No Internet (n=620)	<i>P</i> Value	Cell Phone (n=2164)	No Cell Phone (n=392)	<i>P</i> Value	Smartphone (n=909)	No Smartphone (n=1128)	<i>P</i> Value*
Age, y	71.5 (7.7)	79.6 (7.8)	<0.0001	72.4 (8.0)	78.9 (8.3)	<0.0001	69.1 (7.0)	74.7 (7.9)	<0.0001
Age groups, y			<0.0001			<0.0001			<0.0001
45 to 54	24 (1.2)	4 (0.6)		25 (1.2)	3 (0.8)		18 (2.0)	7 (0.6)	
55 to 64	330 (16.9)	17 (2.7)		334 (15.4)	14 (3.6)		224 (24.6)	97 (8.6)	
65 to 74	1013 (52.0)	150 (24.2)		1041 (48.1)	117 (29.8)		498 (54.7)	495 (43.9)	
75 to 84	489 (25.1)	282 (45.5)		617 (28.5)	150 (38.3)		158 (17.4)	405 (35.9)	
≥85	91 (4.7)	167 (26.9)		148 (6.8)	108 (27.6)		12 (1.3)	124 (11.0)	
Women (%)	858 (44.1)	251 (40.5)	0.09	944 (43.6)	165 (42.1)	0.95	419 (46.0)	471 (41.8)	0.03
Race/ethnicity									
White	1946 (100)	620 (100)	NA	2165 (100)	392 (100)		909 (100)	1128 (100)	NA
BMI, kg/m ²	28.4 (5.3)	28.6 (5.5)	0.03	28.4 (5.3)	28.9 (5.9)	0.01	28.5 (5.1)	28.3 (5.4)	0.98
Smoking (%)	112 (6.9)	46 (9.7)	<0.0001	131 (7.4)	27 (8.8)	0.005	43 (5.8)	79 (8.6)	<0.0001
Currently employed (%)	574 (35.6)	66 (13.9)	0.01	602 (34.0)	39 (12.7)	0.34	362 (48.5)	213 (23.1)	<0.0001
Education									
Less than high school (%)	18 (1.0)	50 (8.7)	<0.0001	40 (2.0)	28 (7.8)	<0.0001	5 (0.6)	30 (2.9)	<0.0001
High school (%)	369 (20.6)	260 (45.1)		495 (24.8)	131 (36.4)		120 (14.3)	335 (32.2)	
Some college (%)	540 (30.1)	169 (29.3)		594 (29.7)	108 (30.0)		237 (28.1)	317 (30.5)	
College and higher (%)	867 (48.5)	97 (16.8)		871 (43.6)	93 (25.8)		480 (57.0)	357 (34.4)	
Hypertension (%)	958 (59.4)	371 (78.4)	0.001	1093 (61.8)	228 (74.5)	0.43	399 (53.4)	627 (68.2)	0.01
Hyperlipidemia (%)	1224 (76.3)	349 (75.2)	0.11	1341 (76.4)	227 (74.7)	0.32	557 (75.1)	704 (77.52)	0.95
Diabetes (%)	354 (22.2)	140 (30.6)	0.004	400 (23.0)	93 (31.1)	0.02	159 (21.5)	214 (23.8)	0.67
CVD (%)	289 (14.8)	178 (28.7)	0.001	362 (16.7)	105 (26.8)	0.12	111 (12.2)	218 (19.3)	0.23
Atrial fibrillation (%)	192 (9.9)	91 (14.7)	0.86	221 (10.2)	60 (15.3)	0.8	70 (7.7)	132 (11.7)	0.41

BMI indicates body mass index; CVD, cardiovascular disease.

**P* value is adjusted by age and sex.

Cardiovascular Risk Assessment

CVD risk factors were measured at the most recently attended examination. Overall, 81% of participants attended Offspring examination 9 (2011–2014), and 88% of participants attended the second examination of the Third Generation (2008–2011). Body mass index was defined as weight (in kilograms) indexed to height squared (in meters). Plasma glucose and total cholesterol were measured in fasting samples. Hyperlipidemia was defined as total cholesterol ≥ 200 mg/dL or lipid treatment. Diabetes was defined as fasting glucose ≥ 126 mg/dL or treatment with a hypoglycemic agent or insulin. Participants were classified as current smokers if they smoked at least 1 cigarette per day in the prior year. Hypertension was defined as

systolic blood pressure ≥ 140 mm Hg or diastolic blood pressure ≥ 90 mm Hg or being on treatment. CVD events were adjudicated by 3 investigators and included myocardial infarction, coronary insufficiency, atherothrombotic infarct, transient ischemic attack, intermittent claudication, and congestive heart failure. Atrial fibrillation was confirmed, as described previously.¹³

Statistical Analysis

Data were tabulated by frequency across different survey components. CVD risk factor profiles were examined by survey response (yes versus no). Chi-square *P* values for

Table 3. Study Sample Characteristics Among Framingham Heart Study Third Generation Participants by Internet, Cell Phone, or Smartphone Usage

	Internet (n=3216)	No Internet (n=96)	<i>P</i> Value	Cell Phone (n=3225)	No Cell Phone (n=80)	<i>P</i> Value	Smartphone (n=2606)	No Smartphone (n=585)	<i>P</i> Value*
Age, y	51.4 (8.9)	59.6 (7.7)	<0.0001	51.4 (8.9)	59.0 (7.6)	<0.0001	50.3 (8.6)	56.2 (8.7)	<0.0001
Age groups, y			<0.0001			<0.0001			<0.0001
20 to 34	148 (4.5)	—		148 (4.6)	—		136 (5.2)	12 (2.1)	
35 to 44	609 (18.9)	2 (2.1)		606 (18.8)	3 (3.8)		564 (21.6)	41 (7.0)	
45 to 54	1275 (39.6)	25 (26.0)		1278 (39.6)	18 (22.5)		1067 (40.9)	197 (33.7)	
55 to 64	1007 (31.3)	52 (54.2)		1018 (31.6)	40 (50.0)		754 (28.69)	250 (42.7)	
65 to 74	174 (5.4)	14 (14.6)		169 (5.2)	19 (23.8)		82 (3.1)	82 (14.0)	
75 to 84	3 (0.1)	3 (3.1)		6 (0.2)	—		3 (0.1)	3 (0.5)	
Women (%)	1439 (44.7)	56 (58.3)	0.02	1447 (44.9)	45 (56.3)	0.06	1157 (44.4)	276 (47.2)	0.25
Race/ethnicity									
White	3162 (98.4)	93 (96.9)	0.18	3172 (98.4)	76 (95.0)	0.01	2565 (98.5)	573 (97.9)	0.26
Black	3 (0.1)	—		3 (0.1)	—		2 (0.1)	1 (0.2)	
Asian	1 (0.01)	—		1 (0.009)	—		1 (0.005)	—	
Others	48 (1.5)	3 (3.1)		47 (1.5)	4 (5.0)		36 (1.4)	11 (1.9)	
BMI, kg/m ²	27.8 (5.8)	28.6 (5.5)	0.03	27.8 (5.7)	28.7 (7.3)	0.48	27.6 (5.6)	28.7 (6.4)	0.02
Smoking (%)	274 (9.6)	46 (9.7)	<0.0001	289 (10.1)	13 (13.8)	0.02	220 (9.6)	64 (12.3)	0.015
Currently employed (%)	2456 (86.2)	56 (69.1)	0.0009	2461 (86.3)	49 (69.0)	0.019	2027 (88.2)	404 (77.4)	<0.0001
Education									
Less than high school (%)	13 (0.4)	4 (4.2)	<0.0001	17 (0.5)	—	0.06	11 (0.4)	6 (1.0)	<0.0001
High school (%)	389 (12.1)	52 (54.7)		420 (13.1)	19 (24.4)		269 (10.4)	143 (24.5)	
Some college (%)	1002 (31.3)	32 (33.7)		1001 (31.1)	29 (37.2)		787 (30.3)	203 (34.8)	
College and higher (%)	1802 (56.2)	7 (7.4)		1778 (55.3)	30 (38.5)		1532 (58.9)	231 (39.6)	
Hypertension (%)	605 (21.3)	35 (43.2)	0.32	609 (21.4)	28 (39.4)	0.83	425 (18.5)	169 (32.4)	0.02
Hyperlipidemia (%)	1262 (44.3)	48 (59.3)	0.9	1268 (44.5)	38 (54.3)	0.22	990 (43.1)	257 (49.2)	0.17
Diabetes (%)	272 (9.7)	18 (23.1)	0.39	272 (9.7)	18 (26.5)	0.09	194 (8.6)	75 (14.6)	0.32
CVD (%)	109 (3.4)	9 (9.4)	0.19	109 (3.4)	6 (7.5)	0.76	73 (2.8)	33 (5.6)	0.34
Atrial fibrillation (%)	48 (1.5)	2 (2.1)	0.32	47 (1.5)	3 (3.8)	0.92	28 (1.1)	17 (2.9)	0.06

BMI indicates body mass index; CVD, cardiovascular disease.

**P* value is adjusted for age and sex.

dichotomous CVD risk factors or F test *P* values for continuous risk factors were calculated using logistic or general linear models that were adjusted for age and sex. All statistics were performed using SAS v9.3 (SAS Institute). A 2-sided $P < 0.05$ was considered statistically significant.

Results

Among 8096 living FHS participants, 6503 (80.3%) completed the survey: Overall, 3902 completed the survey by REDCap (60.0%), 883 completed the survey by mail (13.5%), and 1718 completed it by telephone (26.5%). Participants who completed the survey by telephone were older (69.1 years) on average compared with those who completed the survey by REDCap (58.2 years) or by mail (59.4 years, $P < 0.0001$).

Among survey responders, 5678 (87.4%) reported Internet usage, 5121 (91.1%) reported home Wi-Fi, 5509 (85.0%) reported regular email use, 5946 (92.1%) reported using a cell phone, and 3907 (67.8%) of cell phone users reported having a smartphone. When queried regarding the use of apps and social networks, 1426 (24.4%) reported using health apps, 2746 (42.4%) reported using computer games, and 3163 (48.8%) reported using social networks. Social network users predominantly accessed Facebook ($n = 2944$), LinkedIn ($n = 1244$), Google+ ($n = 347$), and Twitter ($n = 478$).

Participants reporting Internet usage were younger (aged 59.1 versus 76.5 years), were more likely to be employed, and had more favorable CVD risk factors compared with those who did not use the Internet (Table 1). Tables 2 through 4 stratify the sample by FHS cohort (Offspring, Third Generation, Omni).

Table 4. Study Sample Characteristics Among Framingham Heart Study Omni Participants by Internet, Cell Phone, or Smartphone Usage*

	Internet (n=459)	No Internet (n=73)	<i>P</i> Value	Cell Phone (n=496)	No Cell Phone (n=33)	<i>P</i> Value	Smartphone (n=364)	No Smartphone (n=112)	<i>P</i> Value [†]
Age, y	58.6 (13.2)	71.7 (8.6)	<0.0001	59.6 (13.3)	71.9 (9.4)	<0.0001	56.4 (12.8)	67.9 (10.5)	<0.0001
Age groups, y			<0.0001			<0.0001			<0.0001
20 to 34	30 (6.5)	—		30 (6.0)	—		29 (8.0)	1 (0.9)	
35 to 44	54 (11.8)	—		53 (10.7)	—		51 (14.0)	2 (1.8)	
45 to 54	79 (17.2)	2 (2.7)		80 (16.1)	1 (3.0)		68 (18.7)	10 (8.9)	
55 to 64	139 (30.3)	11 (15.1)		144 (29.0)	6 (18.2)		115 (31.6)	24 (21.4)	
65 to 74	116 (25.3)	35 (47.9)		135 (27.2)	14 (42.4)		85 (23.4)	43 (38.4)	
75 to 84	33 (7.2)	18 (24.7)		44 (8.9)	8 (24.2)		15 (4.1)	25 (22.3)	
≥85	8 (1.7)	7 (9.6)		10 (2.0)	4 (12.1)		1 (0.3)	7 (6.3)	
Women (%)	190 (41.4)	27 (37.0)	0.48	206 (41.5)	11 (33.3)	0.06	160 (44.0)	36 (32.1)	0.02
Race/ethnicity									
White	6 (1.2)	—	0.98	6 (1.2)	—	0.01	5 (1.4)	1 (0.9)	0.23
Black	139 (30.3)	19 (26.0)		145 (29.2)	12 (36.4)		103 (28.3)	34 (30.4)	
Hispanic	142 (30.9)	45 (61.6)		170 (34.3)	17 (51.5)		123 (33.8)	39 (34.8)	
Asian	127 (27.7)	8 (11.0)		131 (26.4)	4 (12.1)		95 (26.1)	33 (29.5)	
Others	45 (9.8)	1 (1.4)		44 (8.9)	—		38 (10.4)	5 (4.5)	
BMI, kg/m ²	28.1 (5.7)	28.9 (6.6)	0.41	28.2 (5.8)	27.6 (6.1)	0.48	28.4 (5.8)	27.7 (5.5)	0.17
Smoking (%)	18 (4.4)	5 (10.0)	0.056	22 (5.1)	1 (4.0)	0.02	18 (5.6)	4 (4.3)	0.72
Currently employed (%)	266 (65.0)	9 (18.0)	0.03	264 (61.3)	10 (40.0)	0.019	228 (70.8)	30 (32.3)	0.72
Hypertension (%)	169 (41.3)	38 (76.0)	0.07	189 (43.9)	15 (60.0)	0.83	115 (35.7)	64 (68.8)	0.02
Hyperlipidemia (%)	225 (55.1)	37 (75.5)	0.84	242 (56.3)	17 (70.8)	0.22	164 (51.1)	66 (71.0)	0.92
Diabetes (%)	93 (23.3)	21 (45.7)	0.26	103 (24.5)	10 (45.5)	0.09	64 (20.2)	32 (36.0)	0.56
CVD (%)	36 (7.8)	18 (24.7)	0.04	49 (9.9)	5 (15.2)	0.76	28 (7.7)	18 (16.1)	0.73
Atrial fibrillation (%)	5 (1.1)	3 (4.4)	0.31	7 (1.5)	1 (3.3)	0.92	4 (1.2)	3 (2.9)	0.65

BMI indicates body mass index; CVD, cardiovascular.

*Education information incompletely ascertained and therefore not included in this table.

[†]*P* value is adjusted for age and sex.

The figure presents CVD risk factor data by Internet use and cell phone status (Figure).

Cell phone users tended to be younger (aged 60.0 versus 75.5 years), were more likely to be currently employed (68.5% versus 26.7%, $P=0.0005$), were less likely to smoke (8.7% versus 6.1%, $P=0.004$), and were less likely to have hyperlipidemia (56.7% versus 71.2%, $P=0.01$, Table 1). We did not observe differences in hypertension, diabetes, CVD, or atrial fibrillation by cell phone use.

Slightly less than two-thirds (60.1%) of survey responders had a smartphone. Among smartphone users, 2689 had an iPhone (Apple Inc) and 1548 had an Android-based (Google Inc) smartphone. Smartphone users were younger (aged 55.4 versus 68.5 years, $P<0.0001$), less likely to smoke (8.3% versus 9.4%, $P<0.0001$), more likely to be currently employed (81.1% versus 43.9%, $P<0.0001$), more likely to have a college education, and less likely to have hypertension (27.9% versus 55.7%, $P=0.0002$). We did not observe differences in hyperlipidemia, diabetes, CVD, or atrial fibrillation by smartphone use. Additional details can be found in Table 1.

In the Offspring cohort (Table 2), Internet users tended to be 8 years younger on average than those who did not use the Internet ($P<0.0001$). Internet users were less likely to smoke and had lower rates of hypertension, diabetes, and CVD. Similar but less striking trends were observed for cell and smartphone usage in this cohort as well as in the Third Generation (Table 3) and Omni (Table 4) cohorts.

Discussion

Digital connectedness, when assessed on the basis of access to the Internet, email, Wi-Fi, cell phones, or smartphones, was fairly high among FHS participants. Despite this, important differences existed among those who use technology and those who do not, with marked differences in age, educational attainment, and CVD risk factor profiles. Finally, those with smartphones represented less than two-thirds of survey respondents.

With the increasing ubiquity of home Internet, Wi-Fi, and smartphones, paired with the rapid development of wearable devices, there is increased focus on collecting biomedical

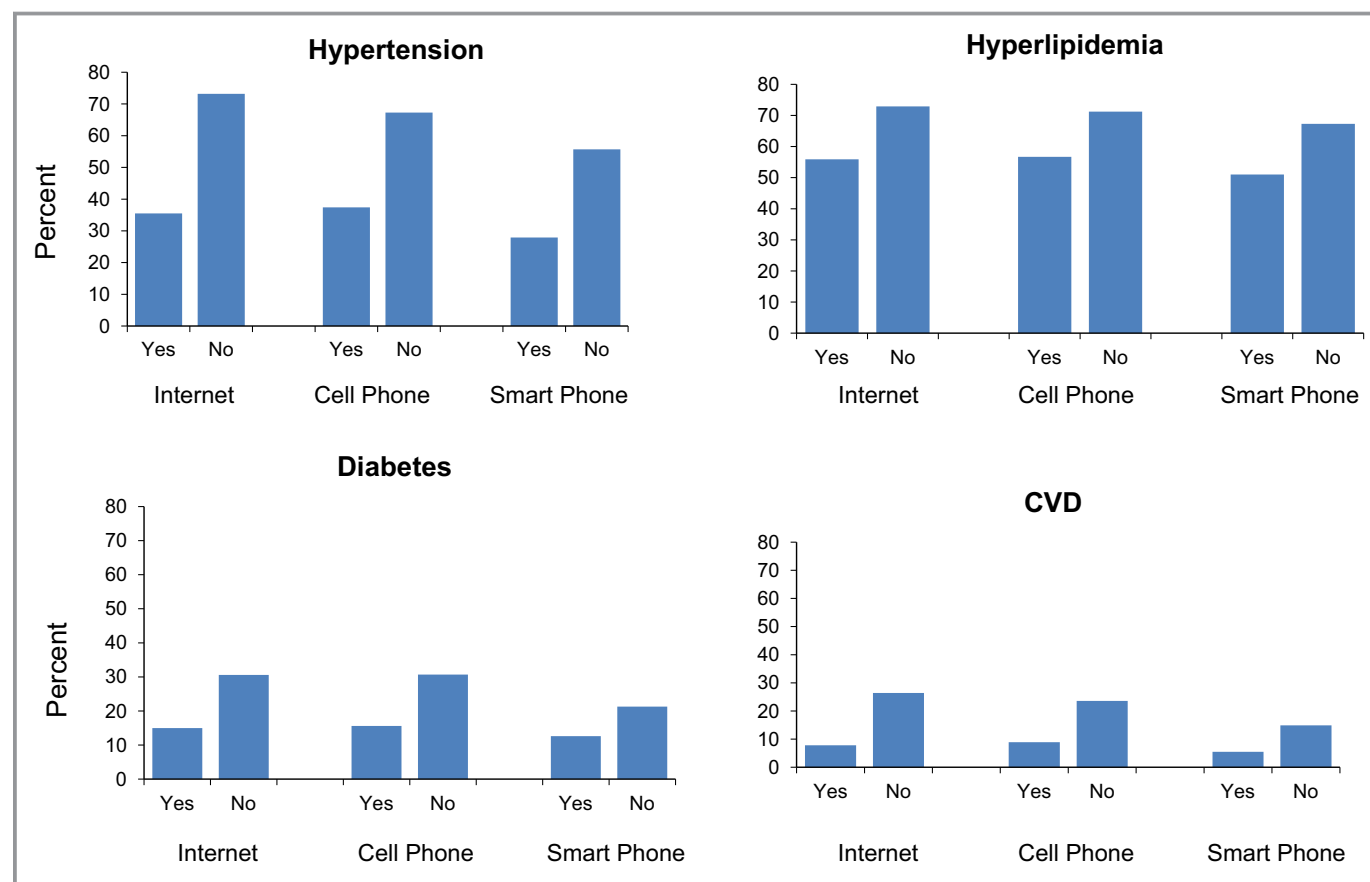


Figure. Prevalence of hypertension, hyperlipidemia, diabetes, and cardiovascular disease (CVD) among those with Internet, cell phone, and smartphone access compared with those without access. CVD was defined as myocardial infarction, angina pectoris, coronary insufficiency, cerebrovascular accident, transient ischemic attack, intermittent claudication, and heart failure. All cell counts can be found in Table 1.

data from participants in their home environments. The digital health trend has been hailed as potentially revolutionary in transforming health care.^{6–9} The eHealth and mHealth technologies have been advanced as convenient, resource-effective, and efficient ways to collect health data from individual persons in their everyday lives to inform both clinical care and research. A key component of the success and ultimate transformative power of this new technology is whether people have access to the technology and are willing to use it. Mobile digital health data collection is fairly new and remains largely untested in established population-based cohorts and in clinical research.¹⁴

Our findings highlight potential opportunities and challenges of reaching study participants through technology. Within an existing cohort, there might be limited reach ($\approx 60\%$ of eligible participants) with smartphones. An alternative approach is to recruit a de novo cohort based on access to technology. Whereas de novo targeted recruitment would increase the number of participants within any given study, generalizability is an important consideration, given the demographics of those who use technology. In addition, participants who report technology usage tend to be younger and to have more favorable CVD risk factor profiles, potentially biasing cohorts that ascertain participants using these modalities. Our findings also have implications for users of clinical technology applications, suggesting that similar biases may exist. Leveraging social networks to reach potential participants through technology is an important future opportunity. The social network of the Offspring cohort of the FHS has been mapped,¹⁵ and it may be possible to leverage this network in the future to promote the uptake and use of technology.

Strengths of our work include the use of the well-characterized FHS cohort. Some limitations warrant mention. The generalizability of the FHS may be limited; however, our findings mirrored those in a recent report from the Pew Research Center that noted 64% of US respondents have a smartphone¹⁶ and 84% of US respondents use the Internet.¹⁷ The FHS consists predominantly of white participants; generalizability to other ethnicities and races is uncertain. Finally, even though our connectedness survey was administered recently (2014–2015), continued penetrance of digital connectedness and smartphone technology will occur over time. Nonetheless, our findings remain applicable to studies wishing to recruit technology-enabled cohorts in the present, such as cohorts being considered through the Precision Medicine Initiative (<http://www.nih.gov/precision-medicine/09172015-pmi-working-group-report.pdf>).

Digital connectedness varies substantially by age; those who are connected tend to be younger and to have more favorable CVD risk factor profiles. Less than two-thirds of FHS participants responding to the survey had a smartphone. The generalizability of studies focused on digitally connected persons may have limitations.

Sources of Funding

The National Heart, Lung, and Blood Institute's Framingham Heart Study is supported by contract N01-HC-25195 and HHSN268201500001I; 2R01HL092577; 1R01HL128914; 1P50HL120163.

Disclosures

Dr Caroline S. Fox became an employee of Merck Research Labs as of December 14, 2015. None of the additional authors report any relevant conflicts of interest.

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SUPPLEMENTAL MATERIAL

Framingham Heart Study Participant Tracking Update

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Framingham Heart Study investigators are thinking about using new electronic tools to conduct research on your heart and general health. We are interested in finding out what kind of electronic tools you use, including computers, internet and cell phones.

Please take a few minutes to respond to this survey.

Internet

Do you use the internet at least occasionally?

☐ **Yes**

☐ **No**

If yes, please continue....

How do you access the internet?
(check all that apply)

- ☐ Cell phone
- ☐ Tablet
- ☐ Computer or laptop

On average, how many hours a day do
you use the internet

_____ # of hours

Email

Do you use email?

☐ **Yes**

☐ **No**

If yes please continue

Can you ...
(check all that apply)

- ☐ Read new emails ?
- ☐ Use the reply feature?
- ☐ Send an email?
- ☐ Open a file attached to an email?

Framingham Heart Study Participant Tracking Update

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Cell Phones

Do you use a cell phone?

☐ Yes ☐ No

If yes, please continue ...

1. **Some cell phones are called “smartphones” because of certain features they have. Is your cell phone a smartphone, such as an iPhone, Android, Blackberry or Windows phone?**

☐ Yes ☐ No

2. **What type of cell phone do you use?**

(check all that apply)

- ☐ Android
- ☐ iPhone
- ☐ Blackberry
- ☐ Window phone
- ☐ Other *(describe)* _____

3. **Please tell us if you ever use your cell phone to do any of the following things.**

(check all that apply)

- ☐ Send or receive email
- ☐ Send or receive text messages
- ☐ Take a picture
- ☐ Access the internet
- ☐ None of the above

4. **On your cell phone, do you have any software applications or “apps” that help you track or manage your health?**

☐ Yes ☐ No

If yes, please continue...

Health apps you currently have on your phone... *(check all that apply)*

- ☐ Exercise, fitness, pedometer or heart rate monitoring (includes specific types of exercise like running, workouts, yoga, etc.)
- ☐ Diet, food, calorie counter
- ☐ Weight
- ☐ Blood pressure
- ☐ Blood sugar or diabetes
- ☐ Medication management (tracking, alerts, etc.)
- ☐ Mood
- ☐ Sleep
- ☐ Other *(describe)* _____

Framingham Heart Study Participant Tracking Update

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Computer Games

Do you use computer games?

☐ Yes

☐ No

If yes please continue

Do you play game on ...?

(check all that apply)

☐ Computer

☐ Tablet

☐ Cell phone

☐ Other (describe)

Social Networks

Do you use a social network to keep in touch with friends and family?

☐ Yes

☐ No

If yes please continue

Check all that apply

☐ Facebook

☐ LinkedIn

☐ Google Plus

☐ Twitter

☐ Other (describe)

Contact Information

May we please have your updated email address where you would prefer to be contacted by the Framingham Heart Study:

_____@_____

Will you please list your cell phone: ____ - ____ - ____