

Quantifying Physical Activity Characteristics with Accelerometry Data: Application to the National Health and Nutrition Examination Survey (NHANES)

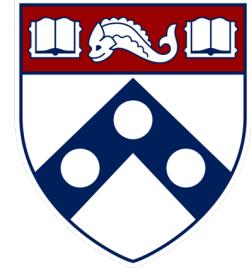
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Background



Memorial Sloan Kettering
Cancer Center™



Overview

- **Goals:**
 - Process accelerometry National Health and Nutrition Examination Survey (NHANES) data from CDC
 - Investigate sample NHANES to create a pipeline for clinical development
- **Dataset:** minute-level accelerometry data from NHANES
- **Approach:**
 - Process minute-level accelerometry NHANES data:
 - Parse data into subject-level datasets
 - Obtain minute-level timestamps when measurements were taken
 - Quantify minute-level physical activity characteristics with an open-source package
 - Characterize physical actigraphy, demographic, and medical characteristics of NHANES dataset
- **Primary Findings:**
 - Quantified subject-level and day-level physical activity characteristics with *Arctools* package
 - Generated exploratory visualizations and statistical analysis of NHANES characteristics and physical activity

Agenda

Accelerometry Data

- Overview of data from wearable devices
- Key challenges and opportunities

Process Data

- Quantification of physical activity characteristics with **Arctools**
- Summary statistics and graphics of physical activity

NHANES

- Overview of NHANES
- Quantification minute-level accelerometry data from NHANES

Analysis

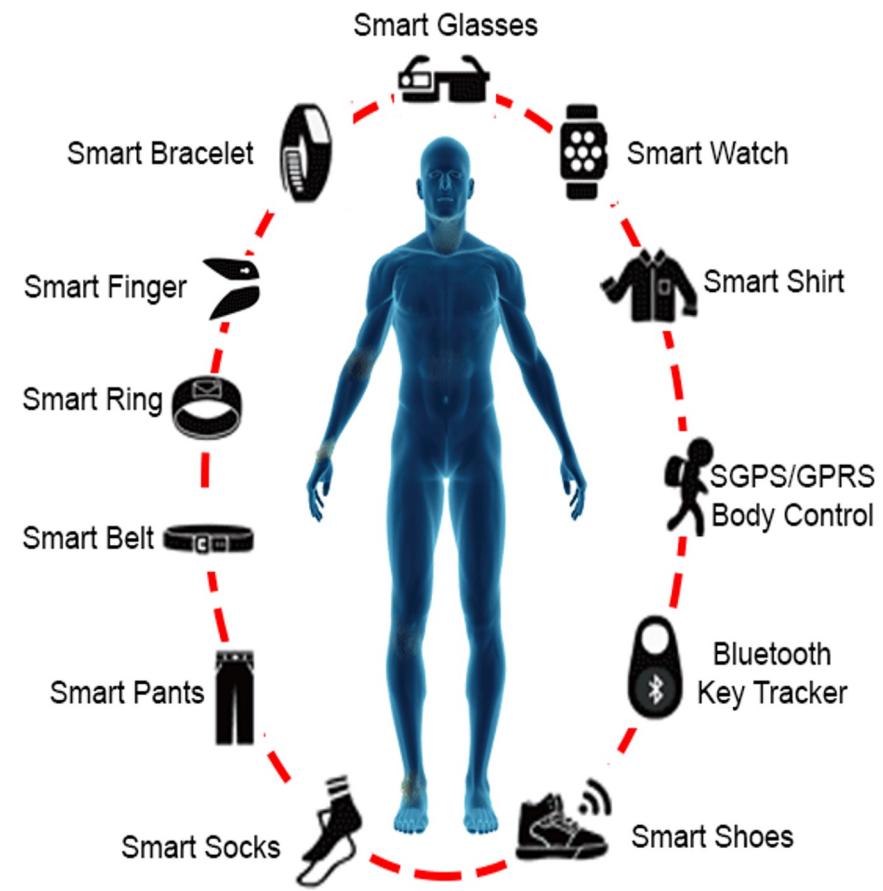
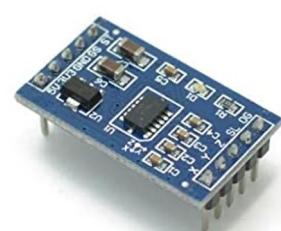
- Characterization of NHANES with respect to physical activity
- Exploratory visualizations and statistical analysis

Conclusion

- Limitations of current approach
- Future research

Accelerometry data present challenges and opportunities

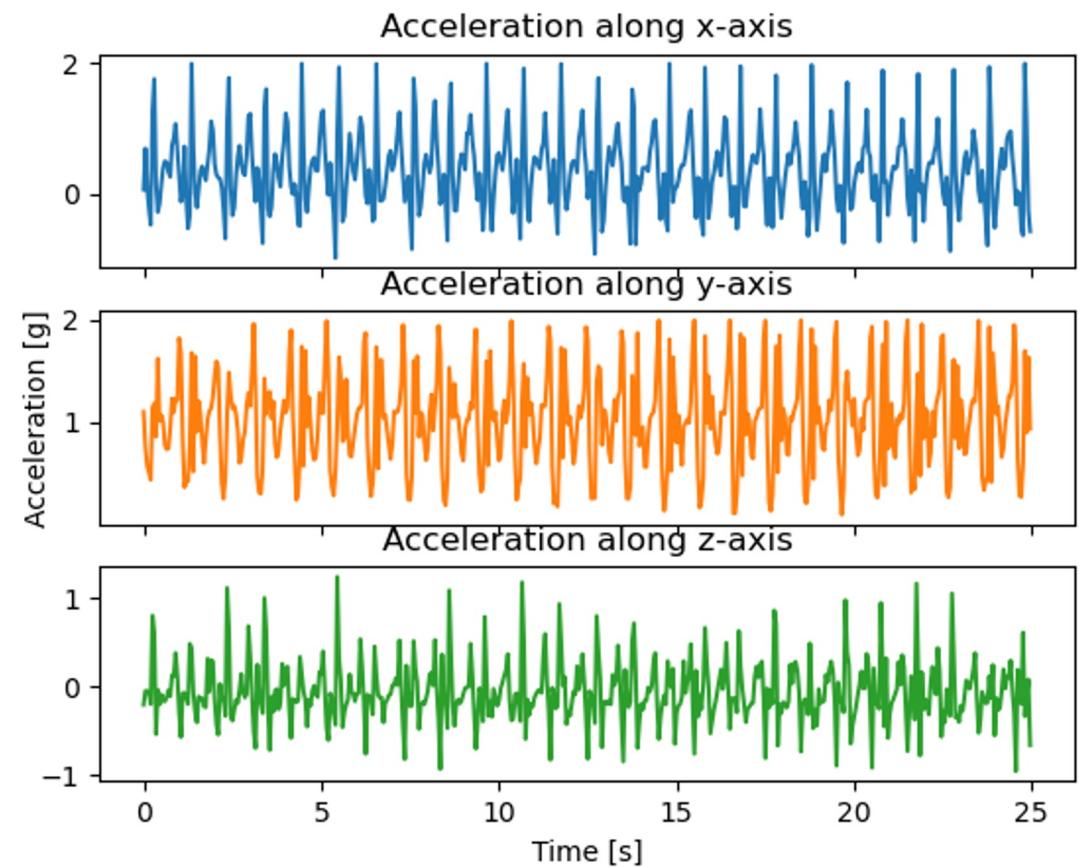
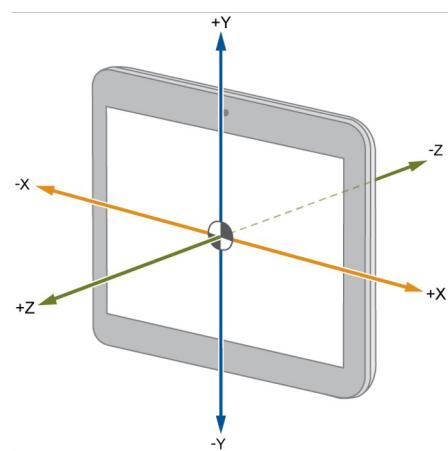
- **Objective measurements** of physical activity in both controlled and free-living environment
- Accelerometer measures **acceleration** amplitude relative to the Earth gravity
- **Challenges** with data heterogeneity:
 - Sensor location: hip, wrist, ear, thigh, etc.
 - Device rotation
 - Sampling frequency
 - Device calibration
- **Opportunities** in health research:
 - Digital biomarker development
 - Pattern of human movement



Rodrigues, Joel JPC, et al. "Enabling technologies for the internet of health things." *IEEE Access* 6 (2018): 13129-13141.

Raw accelerometry data is collected in a 3D time series format

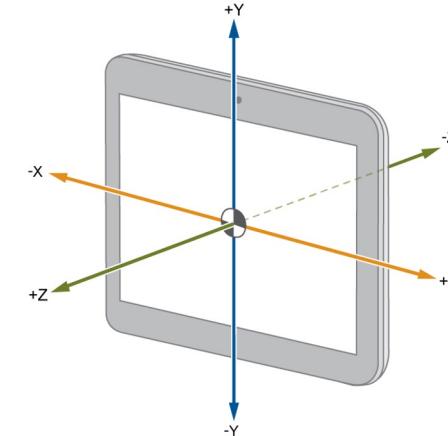
- Raw data collected along **three orthogonal axes XYZ**
- **Universal** acceleration measurements comparable across devices
- Output is **three-dimensional time series accelerations** in gravitational units ($1g = 9.8 \text{ m/s}^2$)
- Device's frame of reference: up-down, left-right, backward-downward



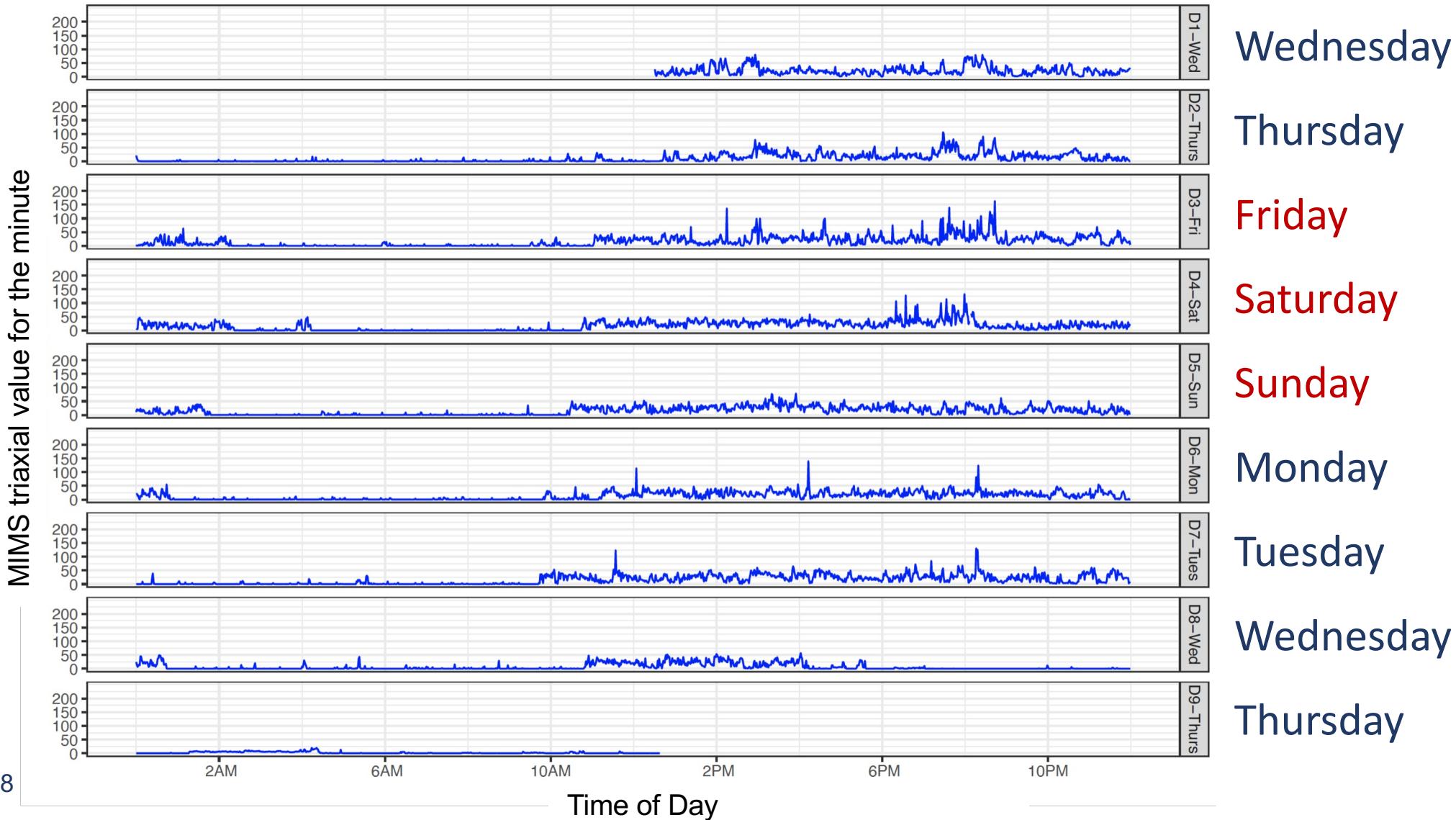
Peter Hausmann, "Activity recognition from accelerometer data" (2020)

Raw data can be collapsed into minute-level data

- Acceleration times series $\{x(t), y(t), z(t)\}$ sampled at frequency f
- Raw data from XYZ tri-axes are **collapsed** into one value, called **minute-level**
- **Minute-level** accelerometry data most popular for **digital biomarker development**
- Well-defined, **open-source, reproducible** methods to summarize minute-level accelerometry data, **non-overlapping** time window
 - Monitor Independent Movement Summary (MIMS)

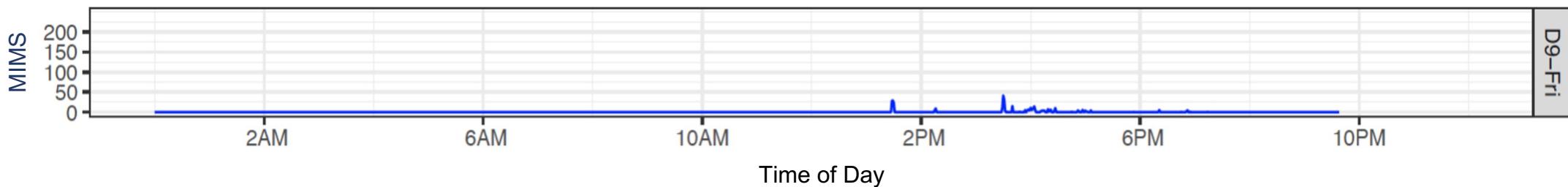


Weekly physical activity patterns suggest active and sedentary time within a day, and differences between weekdays and **weekends**

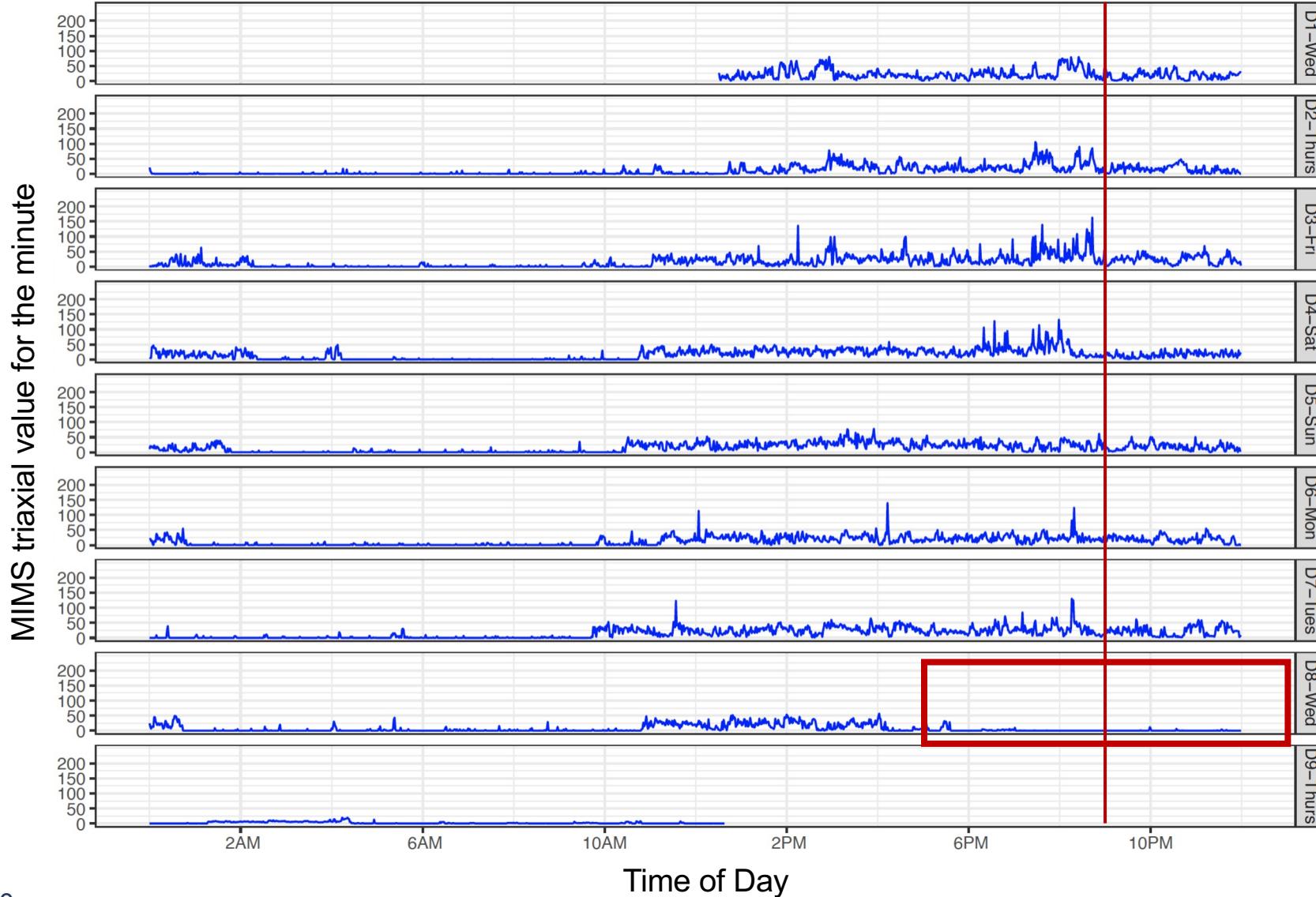


Arctools R package computes physical activity summaries

- *Arctools* R package processes accelerometry **minute-level data** to quantify physical activity characteristics:
 - Control data quality (1)
 - Impute missing data (2)
- (1) *Arctools* algorithm to **classify wear/non-wear**:
 - 90 or more minutes of consecutive 0's: non-wear
 - 144 or more minutes of consecutives 0's: invalid day
 - 2 or fewer valid days: non-representative subject



Arctools package imputes missing data with median physical activity

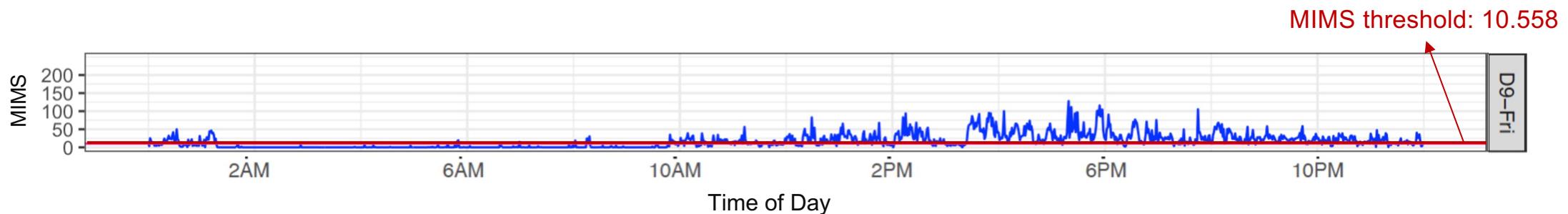


- (2) *Arctools* imputes missing data with median physical activity value from valid days within one person

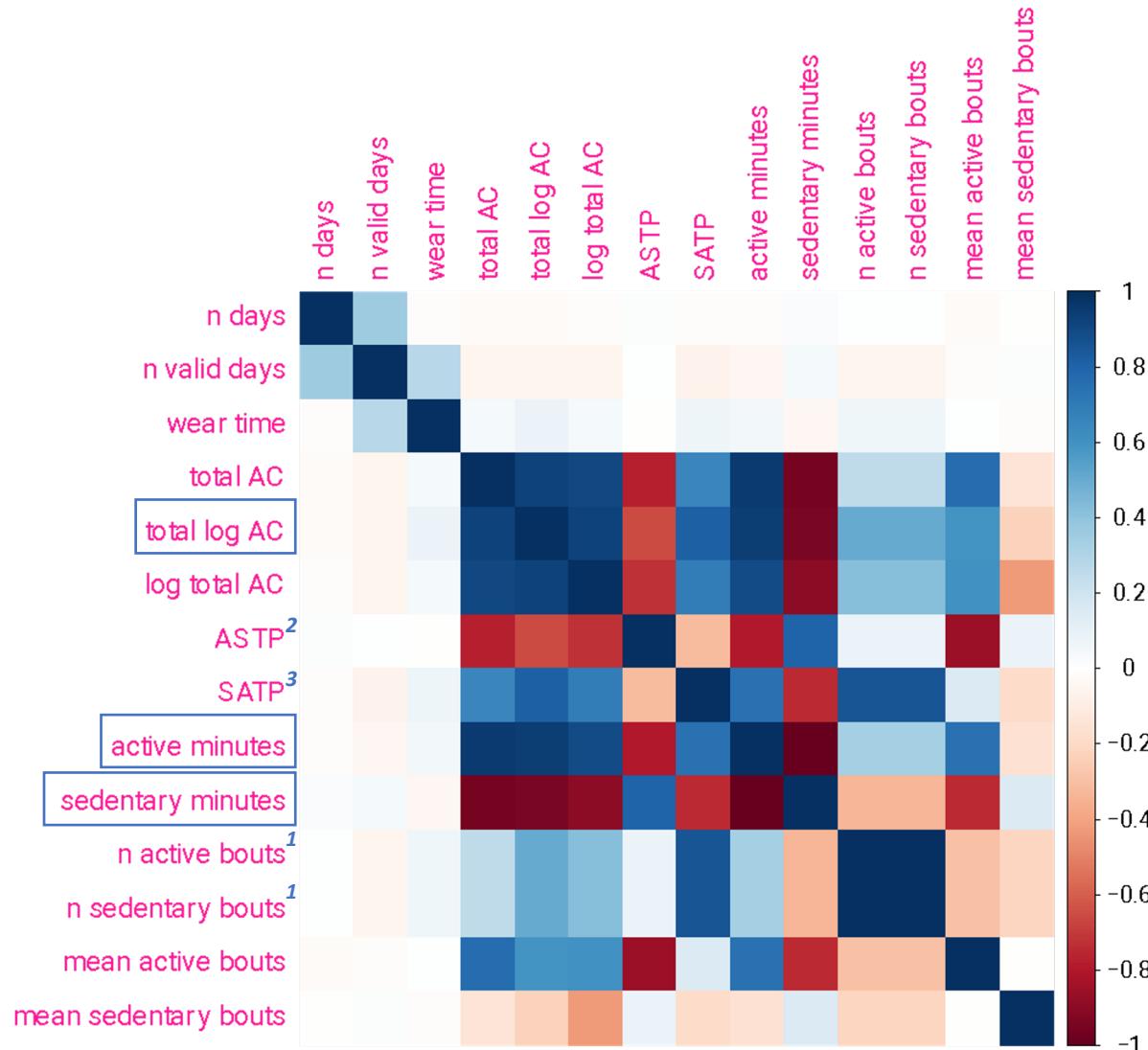
Missing data

Arctools quantifies physical activity characteristics

- ***Arctools* output:**
 - Minute-level metric of physical activity (PA) volume (AC, MIMS, ENMO, etc.)
 - **Active minute:** a minute with AC equal or above a fixed universal threshold
 - **Sedentary minute:** a minute with AC below a fixed universal threshold
 - N valid days: number of days with $\leq 10\%$ of non-wear time
 - N days: number of unique day dates in the data collection
 - Wear time on valid days: average number of wear time minutes across valid days



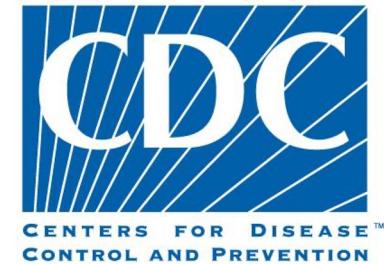
PA metrics from *Arctools* package contain much of the same information with minor variations



- (1) Active/sedentary bout: a sequence of one or more consecutive active/sedentary minutes
- (2) ASTP: active to sedentary transition probability
- (3) SATP: sedentary to active transition probability
- **Our focus: Total log Activity Count**

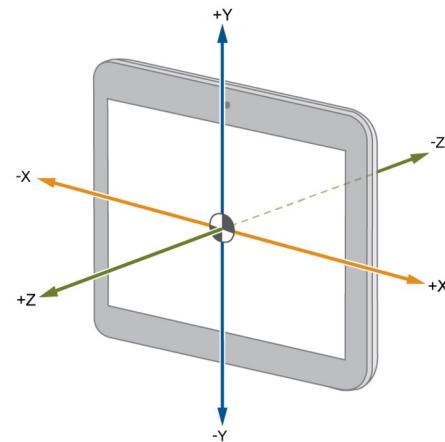
National Health and Nutrition Examination Survey (NHANES)

- National CDC survey conducted every 2 years
- Designed to assess health and nutritional status of adults and children in the US
- Survey takes form of interviews and physical examinations
- Oversampled traditionally underrepresented groups
- Includes demographic, socioeconomic, medical history and examination data
- NHANES is free and open access!



Study sample includes two NHANES cohorts 2011-2012 and 2013-2014

- Wear Physical Activity Monitor (PAM)
- Device manufactured by ActiGraph LLC
- Sampling frequency is at 80 Hz
- PA amplitude recorded on triaxial scale (MIMS scale)

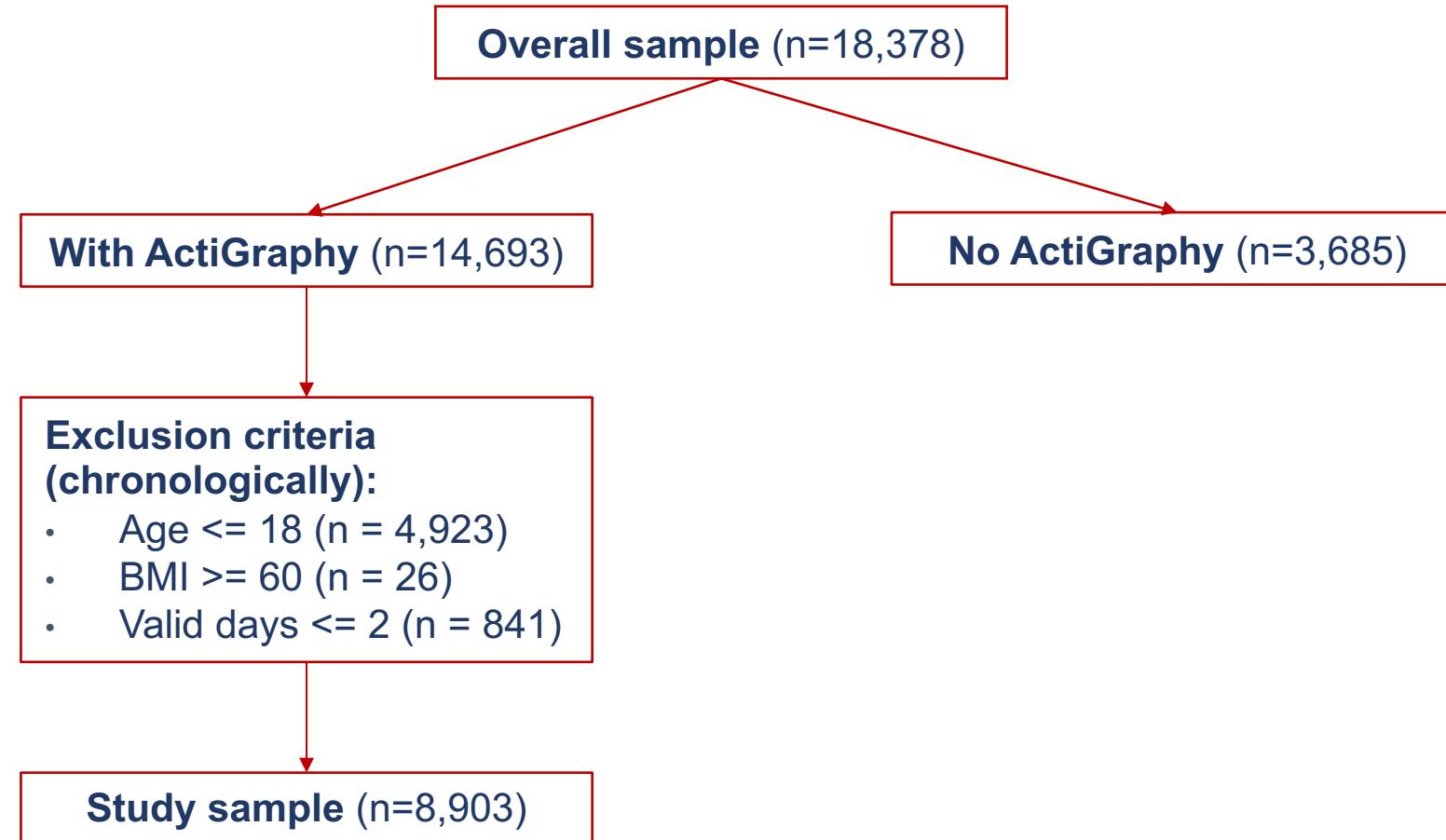


NHANES is a well-characterized data source

- **Demographics information**
 - Body Mass Index (kg/m²)
 - Biological Sex
 - Age
 - Race
 - Highest education level
 - Marital status for people 20+
 - Pregnancy status
 - Annual household income groups
 - Number of people in the participant's household
- **Medical history**
 - Diabetes
 - Asthma
 - Congestive heart failure
 - Cancer
 - Stroke
 - Liver condition
- **Physical Examination data**
 - Spirometry
 - Audiology
- **And many more!**



NHANES Flow Chart



The two cohorts have similar physical activity estimates

Characteristic	NHANES adults with Actigraphy			
	Cohort	Overall, N = 8,903	2011-2012, N = 4,517	2013-2014, N = 4,386
Total log AC per valid day				
Mean (SD)		2,231 (438)	2,185 (479)	2,279 (385)
Median (IQR)		2,273 (2,003, 2,519)	2,244 (1,968, 2,491)	2,303 (2,037, 2,545)
Range		29, 3,974	29, 3,974	40, 3,942
Unknown		0 (0%)	0 (0%)	0 (0%)
Average number of active minutes per valid day				
Mean (SD)		482 (148)	471 (153)	492 (141)
Median (IQR)		486 (385, 586)	481 (377, 576)	492 (395, 596)
Range		0, 1,177	0, 1,177	0, 990
Unknown		0 (0%)	0 (0%)	0 (0%)
Average number of sedentary minutes per valid day				
Mean (SD)		957 (147)	968 (153)	947 (141)
Median (IQR)		953 (853, 1,054)	958 (863, 1,062)	947 (844, 1,044)
Range		263, 1,440	263, 1,440	450, 1,440
Unknown		0 (0%)	0 (0%)	0 (0%)

Two cohorts have comparable PA characteristics

Median age was 49 years and approximately 37% of the sample was obese

Characteristic	NHANES adults with Actigraphy		
	Overall, N = 8,903 ¹	2011-2012, N = 4,517 ¹	2013-2014, N = 4,386 ¹
age in years			
Mean (SD)	49 (18)	49 (18)	50 (18)
Median (IQR)	49 (34, 64)	49 (33, 63)	50 (35, 64)
Range	19, 80	19, 80	19, 80
Unknown	0 (0%)	0 (0%)	0 (0%)
BMI Categories			
severely underweight	16 (0.2%)	9 (0.2%)	7 (0.2%)
underweight	159 (1.8%)	88 (1.9%)	71 (1.6%)
normal weight	2,491 (28%)	1,300 (29%)	1,191 (27%)
overweight	2,806 (32%)	1,416 (31%)	1,390 (32%)
obesity class I	1,874 (21%)	930 (21%)	944 (22%)
obesity class II	840 (9.4%)	406 (9.0%)	434 (9.9%)
obesity class III	621 (7.0%)	310 (6.9%)	311 (7.1%)
Unknown	96 (1.1%)	58 (1.3%)	38 (0.9%)
¹ n (%)			

The NHANES study oversampled black individuals

Characteristic	NHANES adults with Actigraphy		
	Cohort		
	Overall, N = 8,903 ¹	2011-2012, N = 4,517 ¹	2013-2014, N = 4,386 ¹
biological sex			
female	4,634 (52%)	2,306 (51%)	2,328 (53%)
male	4,269 (48%)	2,211 (49%)	2,058 (47%)
race			
Asian	1,032 (12%)	585 (13%)	447 (10%)
White	3,599 (40%)	1,677 (37%)	1,922 (44%)
Black	2,124 (24%)	1,222 (27%)	902 (21%)
Hispanic	1,887 (21%)	905 (20%)	982 (22%)
Other Race	261 (2.9%)	128 (2.8%)	133 (3.0%)
Unknown	0 (0%)	0 (0%)	0 (0%)
annual household income groups			
\$0 to \$24,999	2,605 (29%)	1,417 (31%)	1,188 (27%)
\$25,000 to \$44,999	1,779 (20%)	906 (20%)	873 (20%)
\$45,000 to \$74,999	1,467 (16%)	685 (15%)	782 (18%)
\$75,000 to \$99,999	746 (8.4%)	374 (8.3%)	372 (8.5%)
\$100,000 and over	1,509 (17%)	726 (16%)	783 (18%)
Unknown	797 (9.0%)	409 (9.1%)	388 (8.8%)

¹ n (%)

Demographics of two NHANES cohorts

Characteristic	NHANES adults with Actigraphy		
	Overall, N = 8,903 ¹	2011-2012, N = 4,517 ¹	2013-2014, N = 4,386 ¹
highest education level			
less than 9th grade	746 (8.4%)	409 (9.1%)	337 (7.7%)
9-11th grade	1,176 (13%)	599 (13%)	577 (13%)
high school graduate	1,902 (21%)	934 (21%)	968 (22%)
college or AA degree	2,636 (30%)	1,315 (29%)	1,321 (30%)
college graduate or above	2,206 (25%)	1,134 (25%)	1,072 (24%)
Unknown	237 (2.7%)	126 (2.8%)	111 (2.5%)
number of people in the participant's family			
1	1,248 (14%)	638 (14%)	610 (14%)
2	2,594 (29%)	1,383 (31%)	1,211 (28%)
3	1,615 (18%)	823 (18%)	792 (18%)
4	1,470 (17%)	752 (17%)	718 (16%)
5	1,976 (22%)	921 (20%)	1,055 (24%)
number of children aged 5 years or younger			
0	7,150 (80%)	3,658 (81%)	3,492 (80%)
1	1,234 (14%)	611 (14%)	623 (14%)
2	427 (4.8%)	213 (4.7%)	214 (4.9%)
3	92 (1.0%)	35 (0.8%)	57 (1.3%)
¹ n (%)			

The ratio of family income to poverty was ~2:1

Characteristic	NHANES adults with Actigraphy		
	Cohort		
Overall, N = 8,903¹ 2011-2012, N = 4,517¹ 2013-2014, N = 4,386¹			
six-month time period			
May 1 through October 31	4,561 (51%)	2,354 (52%)	2,207 (50%)
November 1 through April 30	4,342 (49%)	2,163 (48%)	2,179 (50%)
pregnancy status, for women 20-44 yrs old			
no	1,689 (19%)	849 (19%)	840 (19%)
yes	85 (1.0%)	40 (0.9%)	45 (1.0%)
Unknown	7,129 (80%)	3,628 (80%)	3,501 (80%)
ratio of family income to poverty			
Mean (SD)	2.44 (1.65)	2.40 (1.67)	2.47 (1.64)
Median (IQR)	1.97 (1.02, 3.97)	1.88 (0.98, 3.97)	2.06 (1.04, 3.93)
Range	0.00, 5.00	0.00, 5.00	0.00, 5.00
Unknown	659 (7.4%)	345 (7.6%)	314 (7.2%)

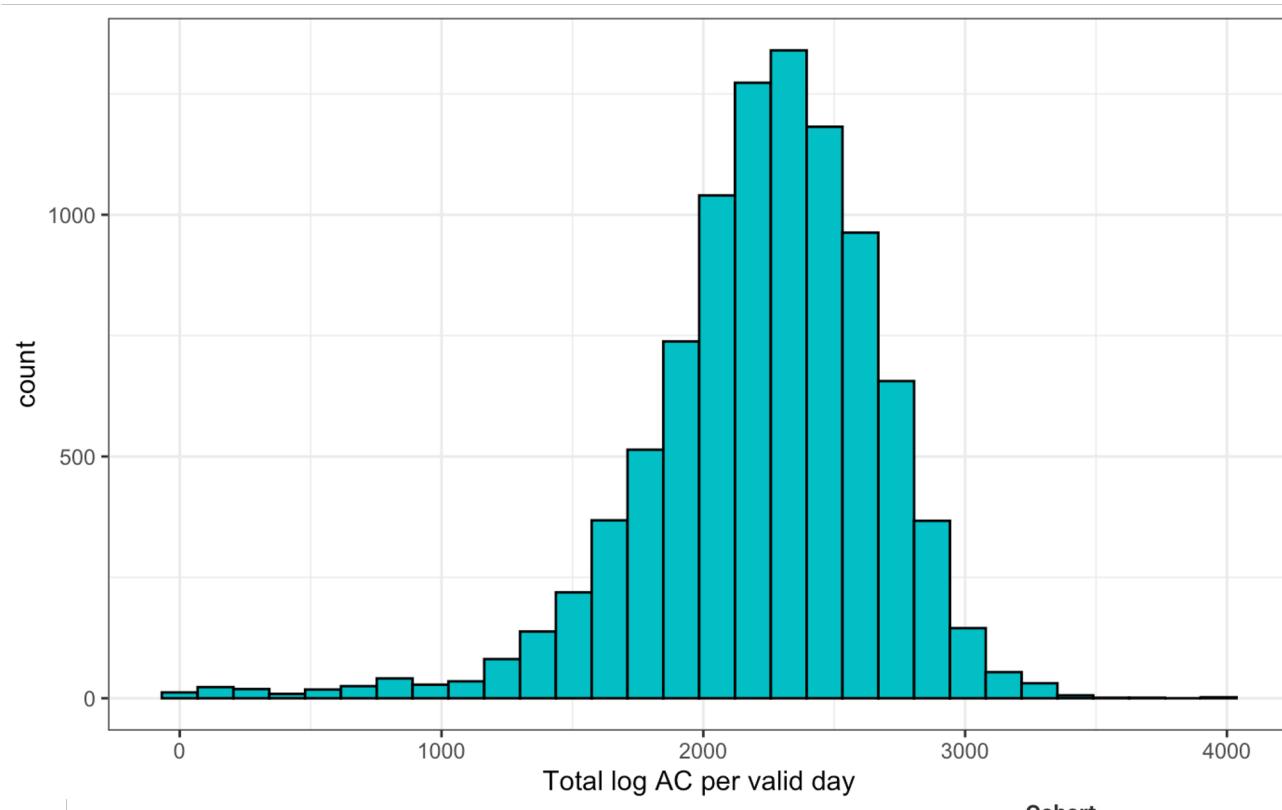
¹ n (%)

Self-reported diabetes, asthma, and cancer were common health conditions in the cohort

NHANES adults with Actigraphy		Cohort			NHANES adults with Actigraphy		Cohort		
Characteristic		Overall, N = 8,903 ¹	2011-2012, N = 4,517 ¹	2013-2014, N = 4,386 ¹	Characteristic		Overall, N = 8,903 ¹	2011-2012, N = 4,517 ¹	2013-2014, N = 4,386 ¹
health condition									
excellent	783 (8.8%)		414 (9.2%)		369 (8.4%)		no	8,356 (94%)	
very good	2,225 (25%)		1,138 (25%)		1,087 (25%)		yes	301 (3.4%)	
good	3,344 (38%)		1,653 (37%)		1,691 (39%)		Unknown	246 (2.8%)	
fair	303 (3.4%)		151 (3.3%)		152 (3.5%)		cancer		
poor	1,648 (19%)		795 (18%)		853 (19%)		no	7,830 (88%)	
Unknown	600 (6.7%)		366 (8.1%)		234 (5.3%)		yes	842 (9.5%)	
diabetes									
no	7,496 (84%)		3,832 (85%)		3,664 (84%)		Unknown	231 (2.6%)	
borderline	238 (2.7%)		100 (2.2%)		138 (3.1%)		stroke		
yes	1,164 (13%)		583 (13%)		581 (13%)		no	8,321 (93%)	
Unknown	5 (<0.1%)		2 (<0.1%)		3 (<0.1%)		yes	346 (3.9%)	
asthma									
no	7,553 (85%)		3,833 (85%)		3,720 (85%)		Unknown	236 (2.7%)	
yes	1,342 (15%)		680 (15%)		662 (15%)		liver condition		
Unknown	8 (<0.1%)		4 (<0.1%)		4 (<0.1%)		no	8,309 (93%)	
							yes	355 (4.0%)	
							Unknown	239 (2.7%)	
								126 (2.8%)	

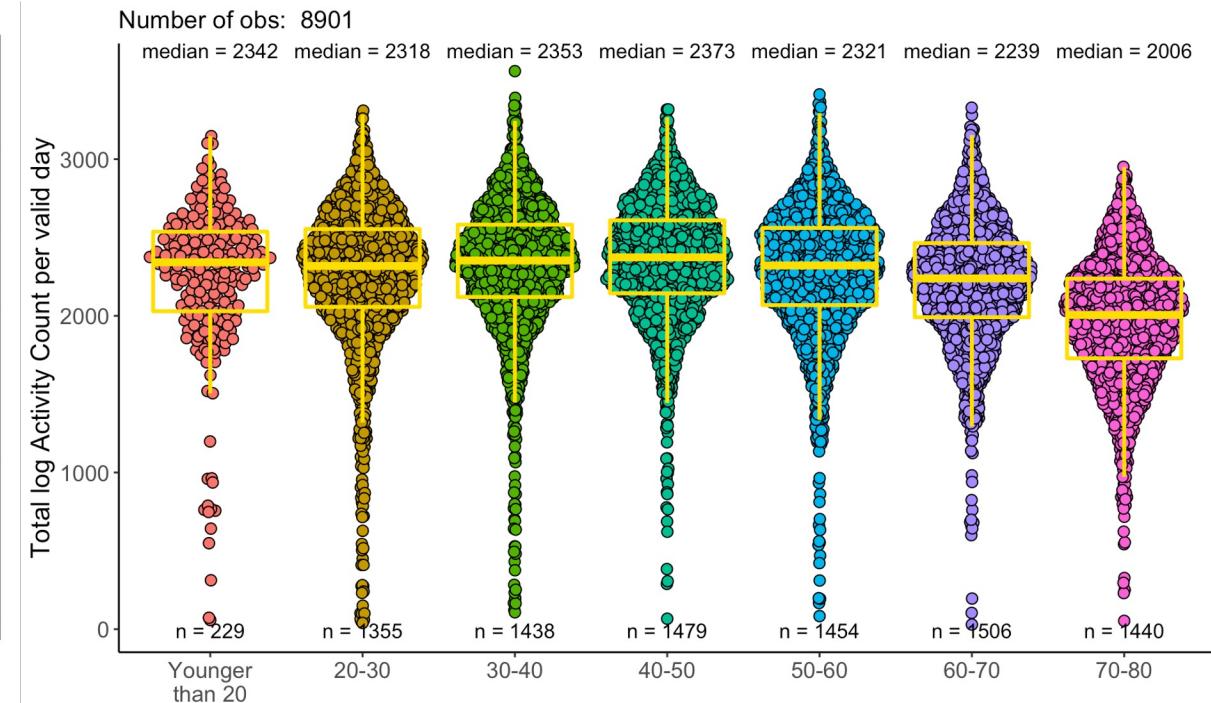
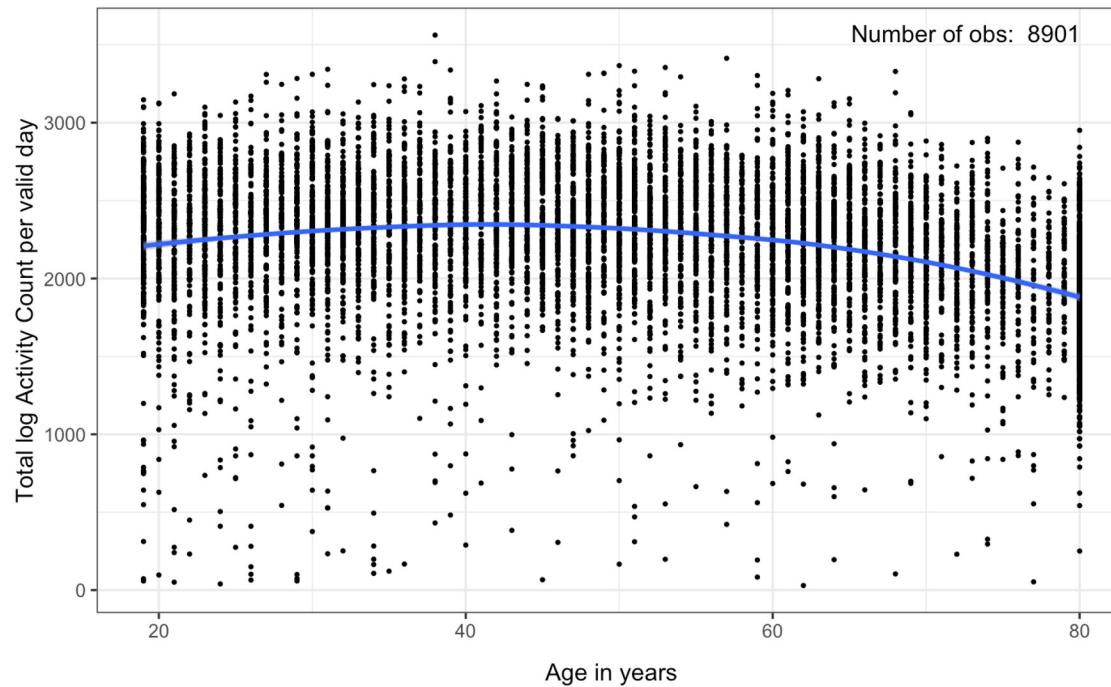
Total log activity counts

Metric of PA volume and it is normally distributed



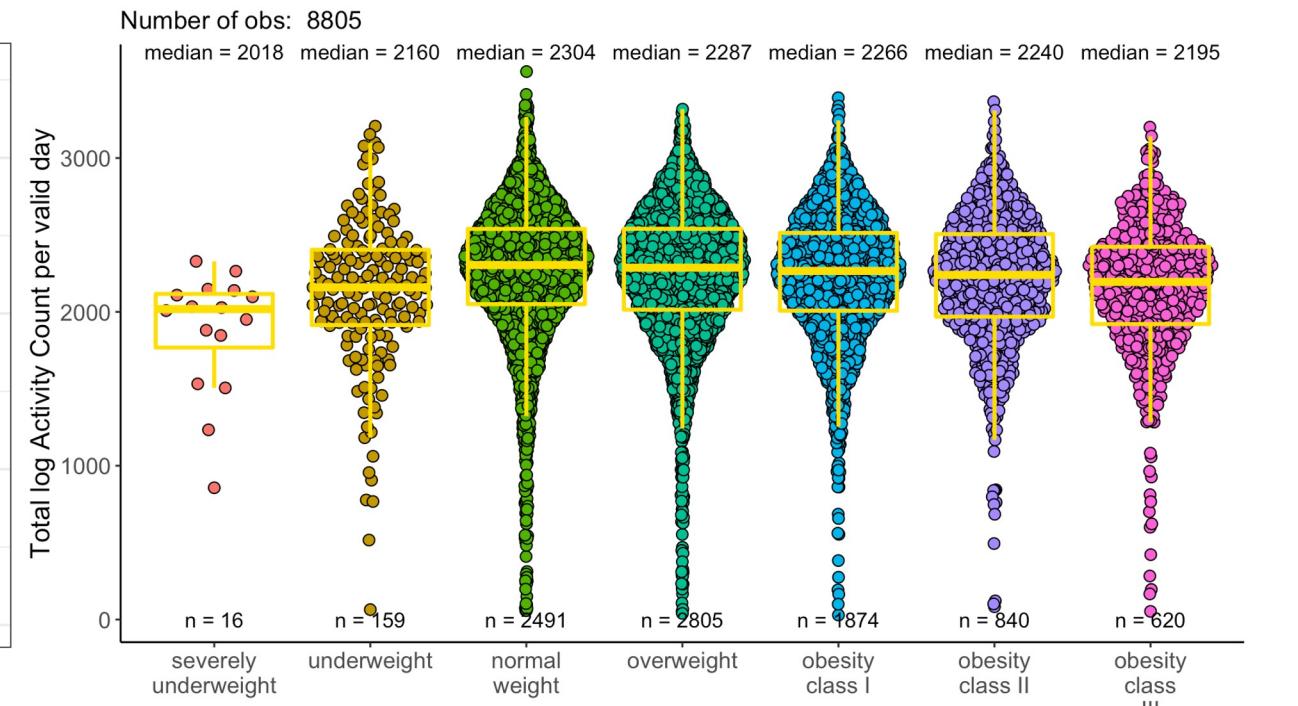
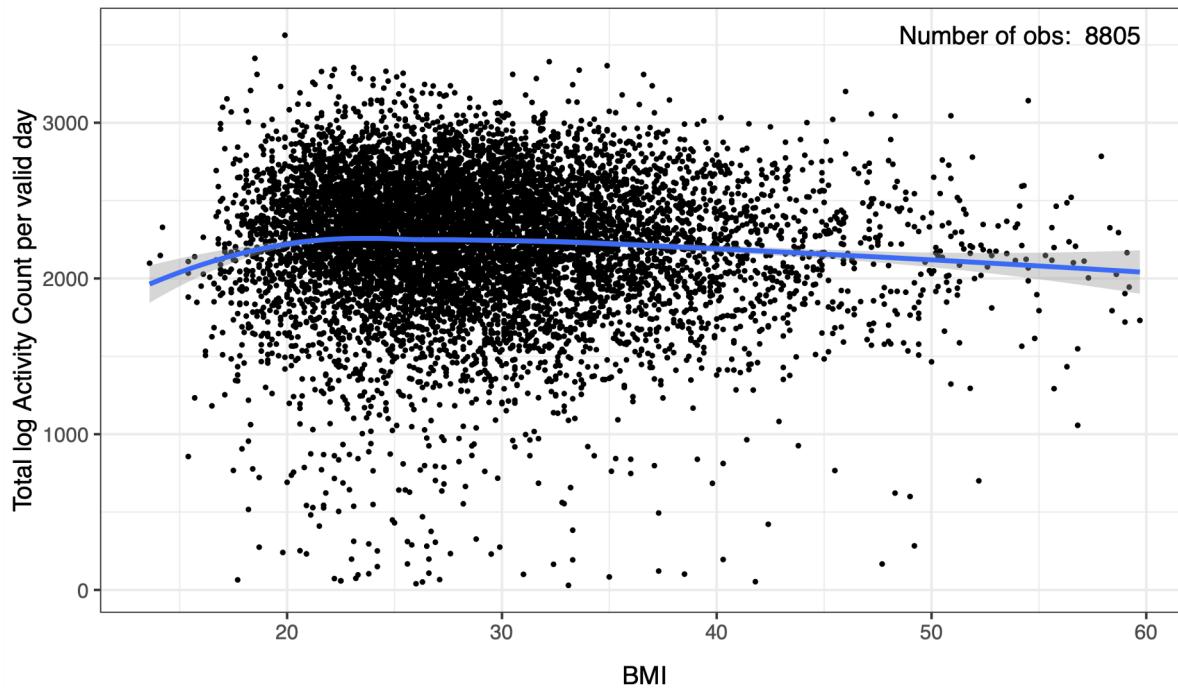
Characteristic	Overall, N = 8,901	2011-2012, N = 4,516	2013-2014, N = 4,385
Total log AC per valid day			
Mean (SD)	2,231 (437)	2,184 (479)	2,278 (384)
Median (IQR)	2,273 (2,003, 2,519)	2,244 (1,968, 2,491)	2,303 (2,037, 2,545)
Range	29, 3,562	29, 3,562	40, 3,343

Scatterplot shows up and downward trend in age



Characteristic	Younger than 20, N = 229 ¹	20-30, N = 1,355 ¹	30-40, N = 1,438 ¹	40-50, N = 1,479 ¹	50-60, N = 1,454 ¹	60-70, N = 1,506 ¹
Total log Activity Count per day						
Mean (SD)	2,234 (510)	2,254 (470)	2,316 (432)	2,349 (386)	2,283 (418)	2,210 (396)
Median (IQR)	2,342 (2,029, 2,537)	2,318 (2,057, 2,554)	2,353 (2,120, 2,582)	2,373 (2,144, 2,610)	2,321 (2,068, 2,561)	2,239 (1,991, 2,464)
Range	58, 3,147	40, 3,310	108, 3,562	67, 3,318	83, 3,413	29, 3,329

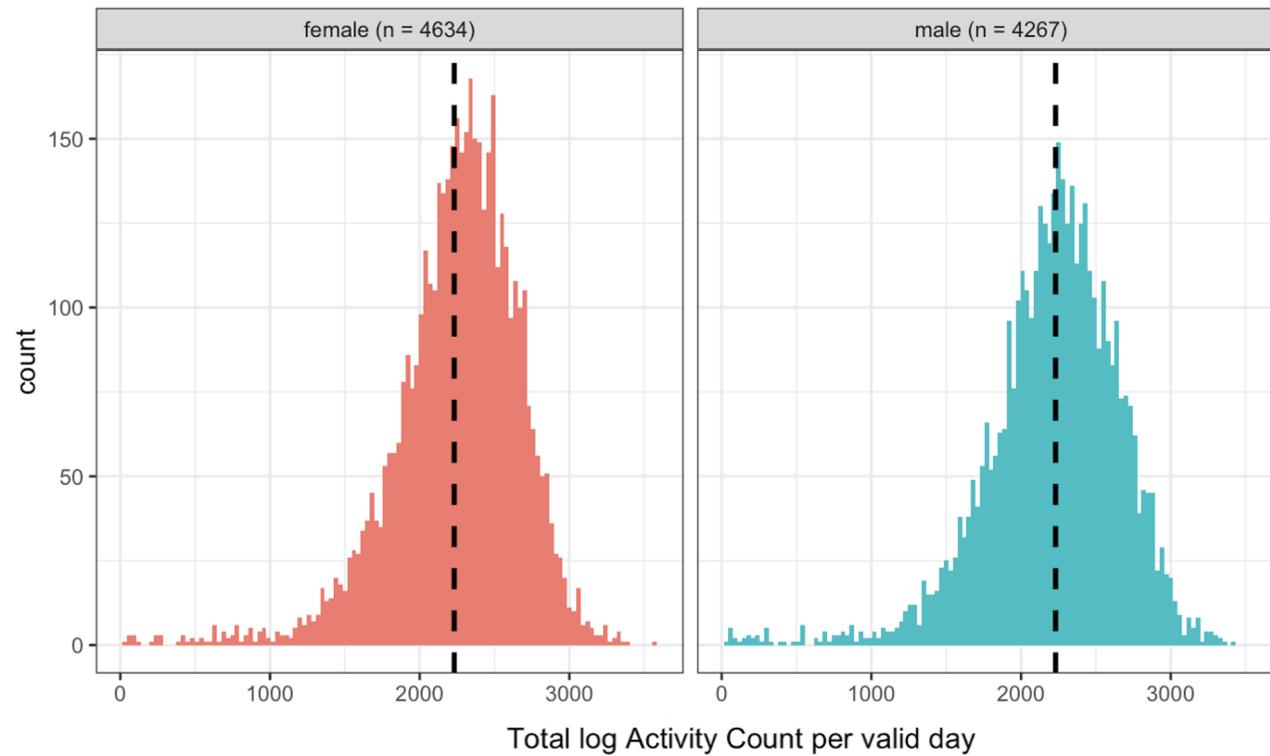
Scatterplot shows U shape of physical activity and BMI



- Severely underweight - BMI < 16.5
- Underweight - BMI under 18.5
- Normal weight - BMI 18.5 to 24.9
- Overweight – BMI 25 to 29.9
- Obesity class I – BMI 30 to 34.9
- Obesity class II – BMI 35 to 39.9
- Obesity class III – BMI > 40

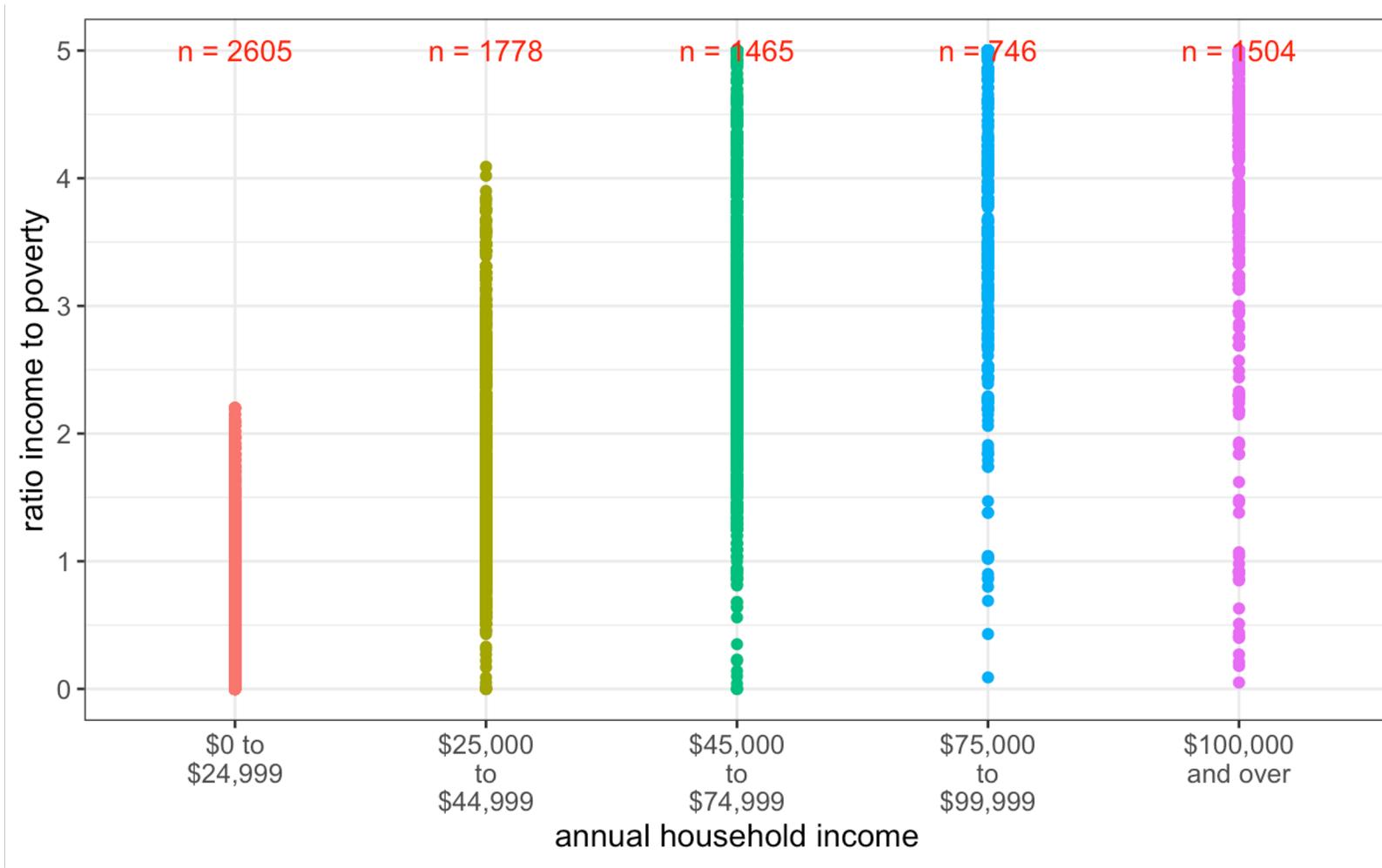
Characteristic	severely underweight, N = 16	underweight, N = 159	normal weight, N = 2,491	overweight, N = 2,805	obesity class I, N = 1,874	obesity class II, N = 840	obesity class III, N = 620
Total log AC per day							
Mean (SD)	1,873 (398)	2,118 (507)	2,256 (447)	2,249 (432)	2,235 (414)	2,210 (425)	2,150 (430)
Median (IQR)	2,018 (1,768, 2,116)	2,160 (1,914, 2,404)	2,304 (2,050, 2,539)	2,287 (2,014, 2,540)	2,266 (2,008, 2,513)	2,240 (1,969, 2,506)	2,195 (1,921, 2,423)
Range	857, 2,329	65, 3,207	58, 3,562	40, 3,318	29, 3,392	83, 3,366	53, 3,201

Men and women have similar physical activity distributions

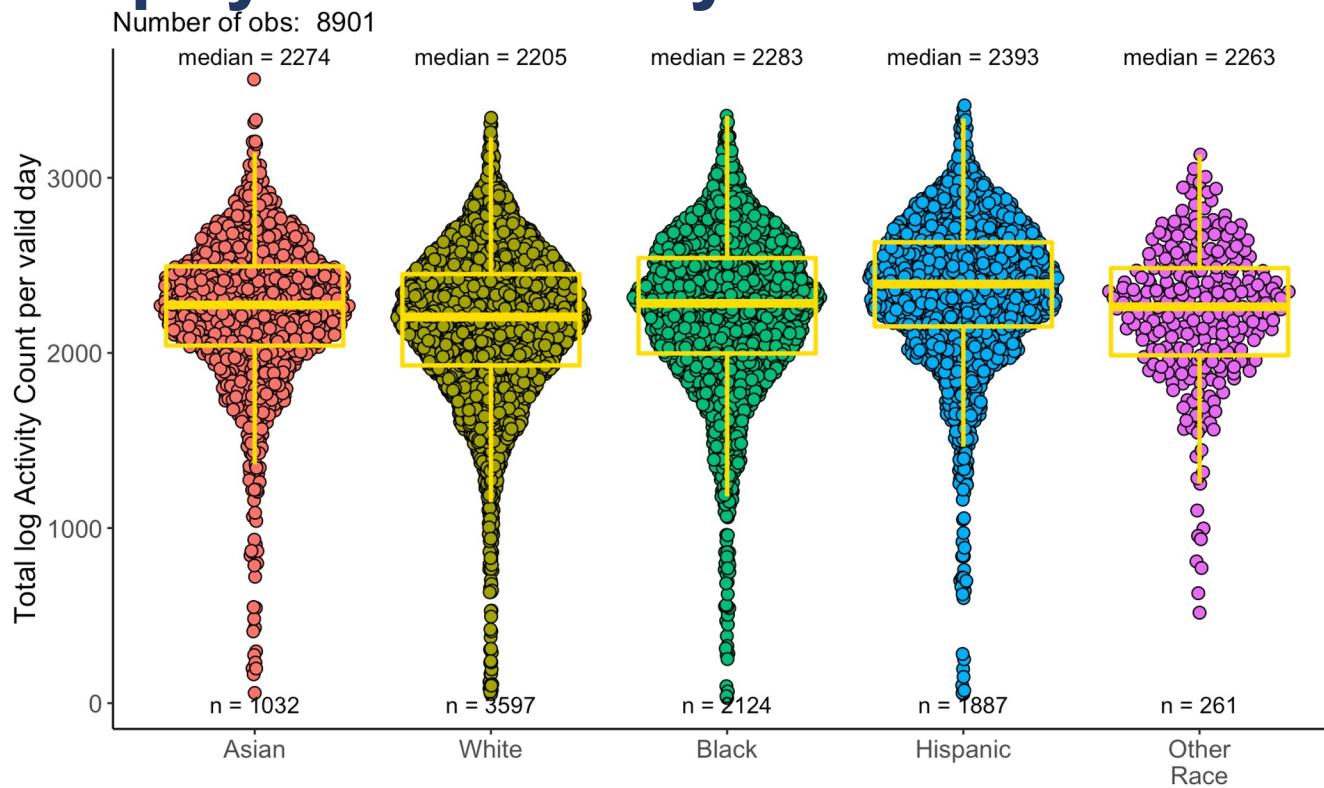


Characteristic	female, N = 4,634	male, N = 4,267
Total log Activity Count per day		
Mean (SD)	2,248 (425)	2,212 (449)
Median (IQR)	2,291 (2,029, 2,529)	2,250 (1,979, 2,507)
Range	29, 3,562	40, 3,413

Ratio of income to poverty strongly associated with income groups

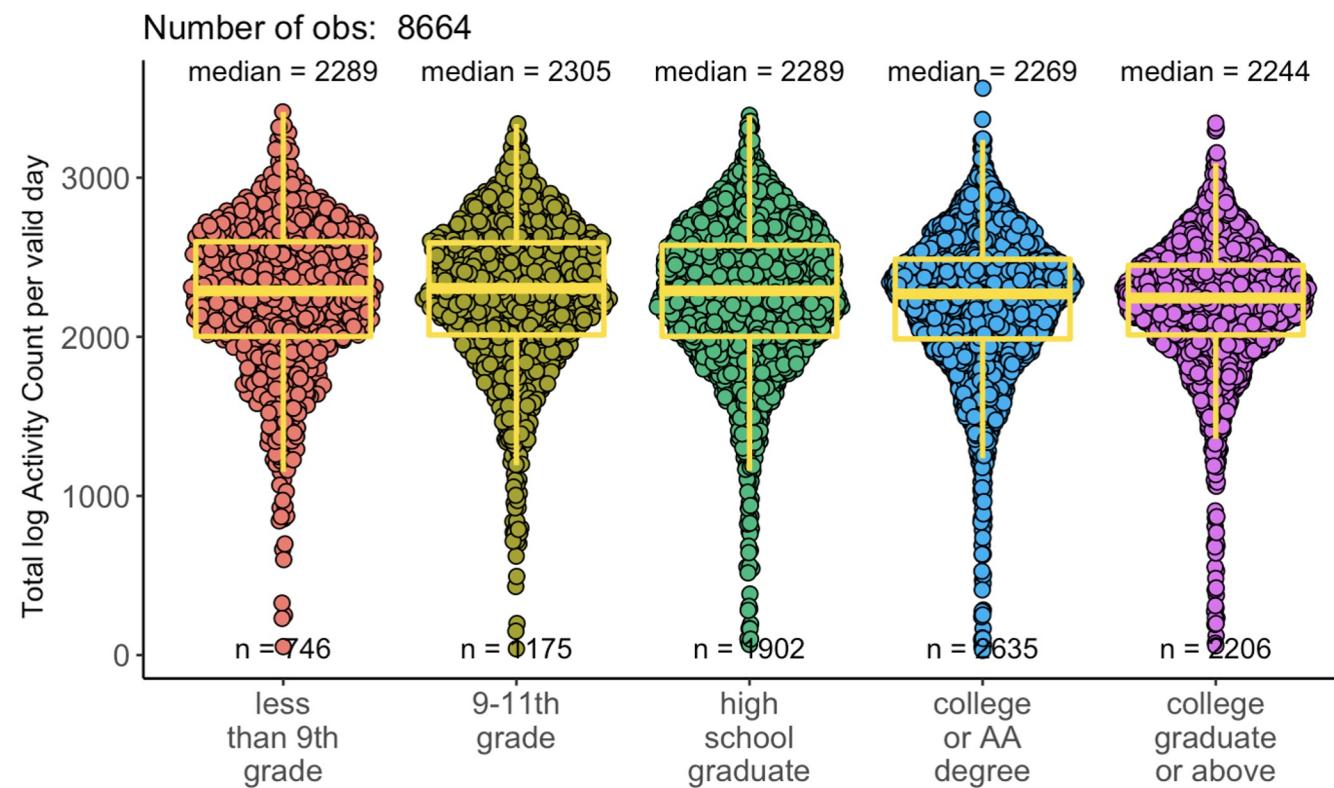


Among ethnic groups, Hispanics have a higher distribution of physical activity



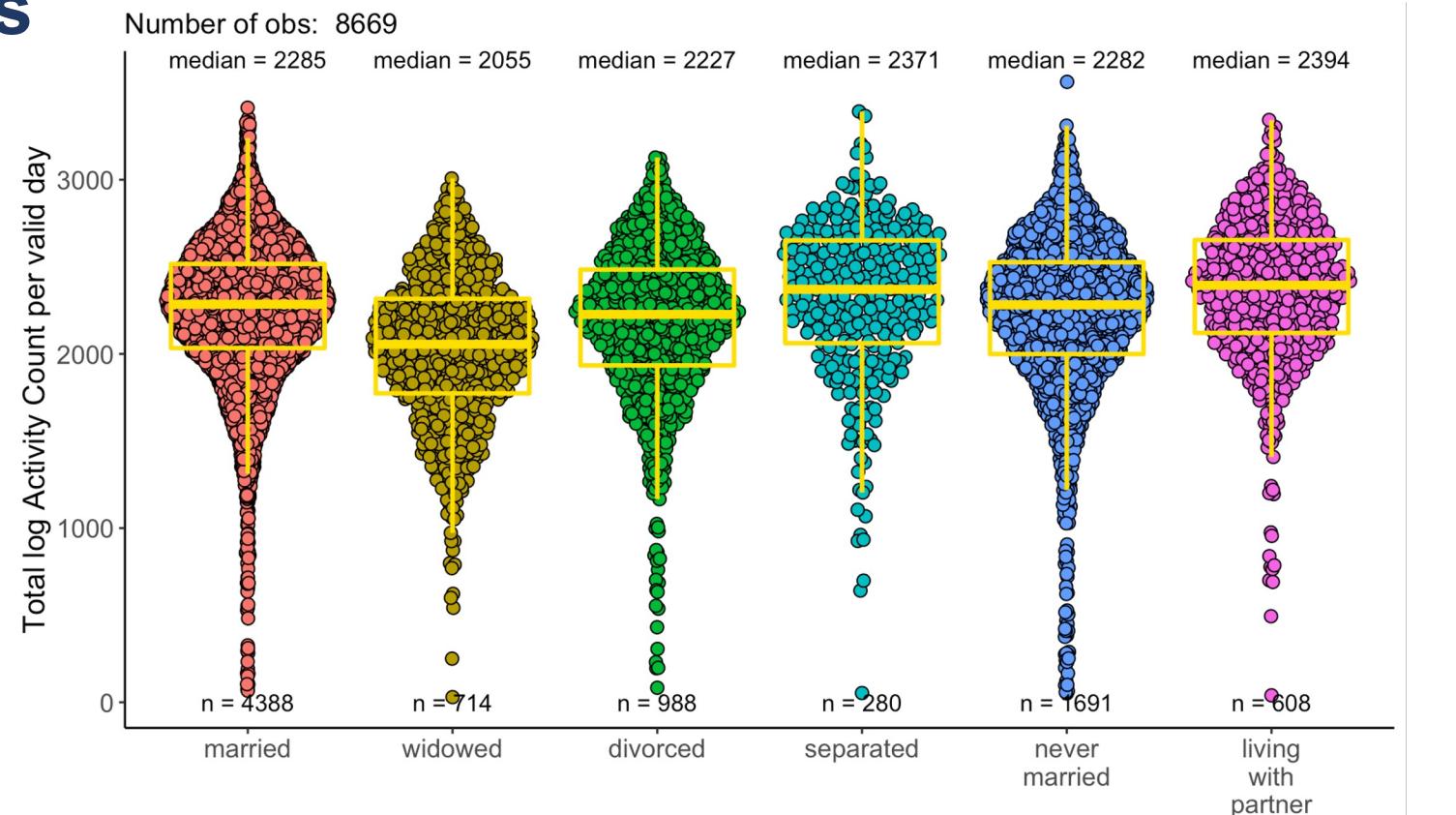
Characteristic	Asian, N = 1,032	White, N = 3,597	Black, N = 2,124	Hispanic, N = 1,887	Other Race, N = 261
Total log Activity Count per day					
Mean (SD)	2,231 (437)	2,166 (423)	2,232 (451)	2,353 (422)	2,218 (429)
Median (IQR)	2,274 (2,042, 2,495)	2,205 (1,929, 2,450)	2,283 (1,997, 2,542)	2,393 (2,151, 2,632)	2,263 (1,986, 2,484)
Range	59, 3,562	51, 3,343	29, 3,354	53, 3,413	517, 3,132

No pattern in physical activity across educational levels



Characteristic	less than 9th grade, N = 746	9-11th grade, N = 1,175	high school graduate, N = 1,902	college or AA degree, N = 2,635	college graduate or above, N = 2,206
Total log Activity Count per day					
Mean (SD)	2,246 (485)	2,263 (464)	2,256 (461)	2,216 (421)	2,205 (388)
Median (IQR)	2,289 (2,002, 2,598)	2,305 (2,012, 2,591)	2,289 (2,002, 2,575)	2,269 (1,987, 2,488)	2,244 (2,012, 2,449)
Range	53, 3,413	40, 3,338	67, 3,392	29, 3,562	50, 3,242

Widowed people move the least, followed by divorced individuals

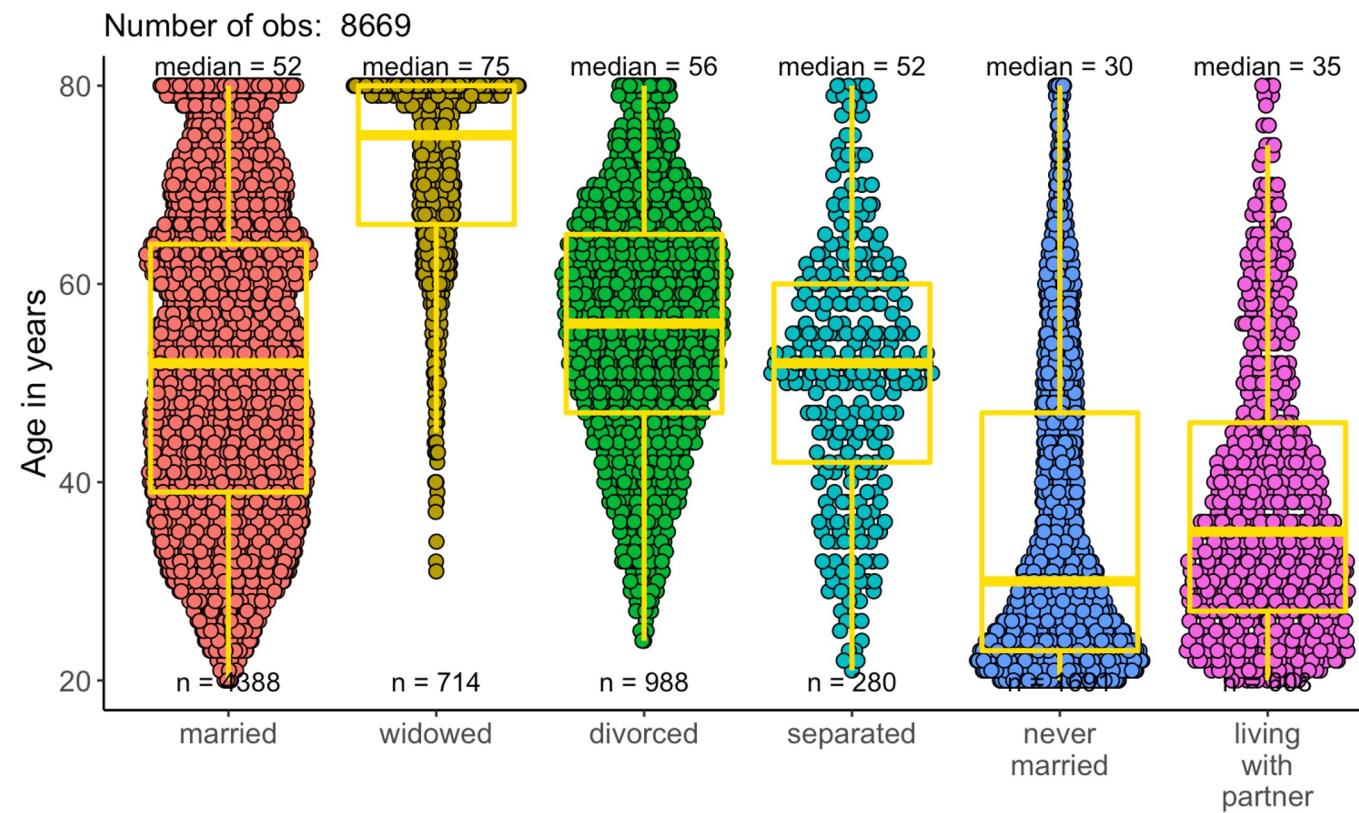


Characteristic	married, N = 4,388	widowed, N = 714	divorced, N = 988	separated, N = 280	never married, N = 1,691	living with partner, N = 608
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Total log Activity Count per day

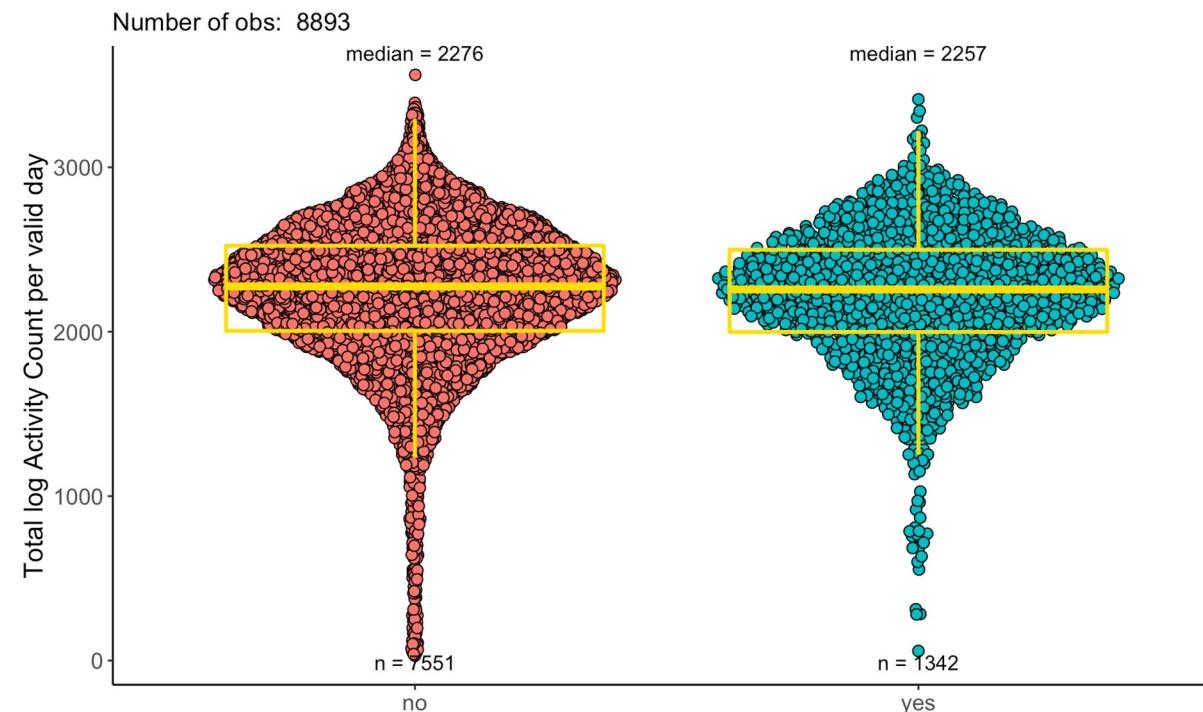
Mean (SD)	2,253 (403)	2,026 (431)	2,184 (447)	2,303 (482)	2,227 (472)	2,363 (426)
Median (IQR)	2,285 (2,034, 2,517)	2,055 (1,774, 2,317)	2,227 (1,934, 2,484)	2,371 (2,062, 2,652)	2,282 (1,999, 2,526)	2,394 (2,120, 2,654)
Range	67, 3,413	29, 3,007	83, 3,127	53, 3,392	51, 3,562	40, 3,343

Age distribution across marital groups



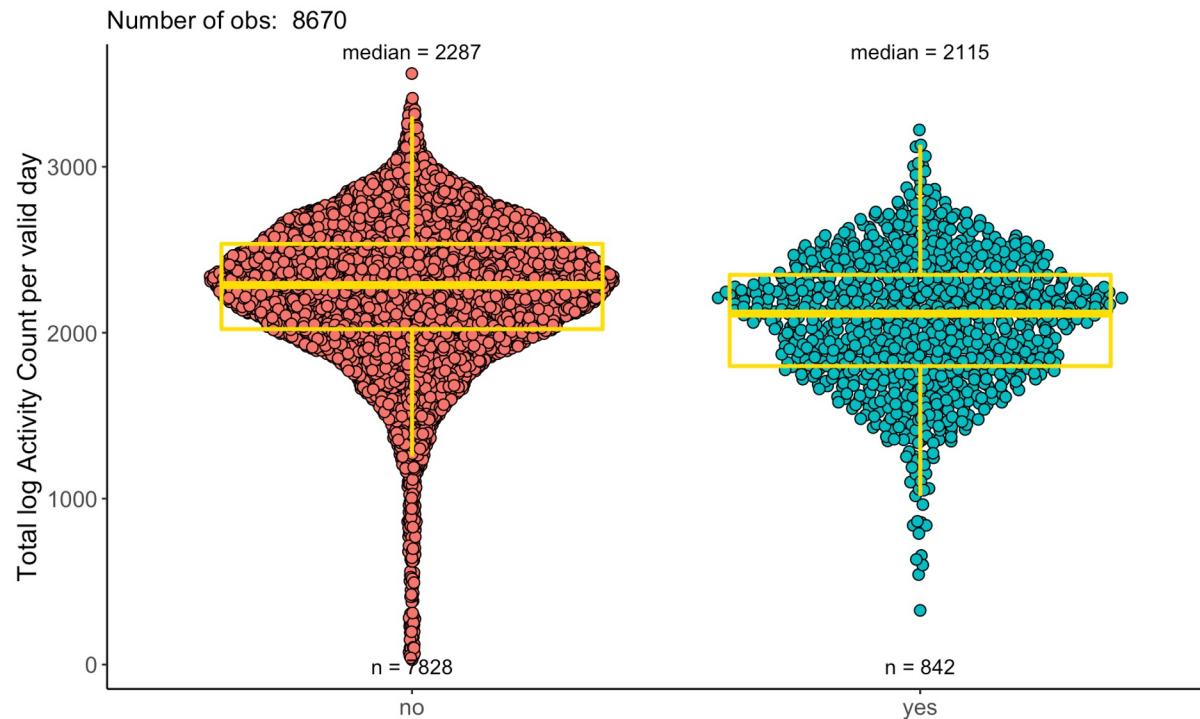
Characteristic	married, N = 4,388	widowed, N = 714	divorced, N = 988	separated, N = 280	never married, N = 1,691	living with partner, N = 608
age in years						
Mean (SD)	52 (16)	72 (10)	56 (12)	51 (14)	36 (15)	38 (14)
Median (IQR)	52 (39, 64)	75 (66, 80)	56 (47, 65)	52 (42, 60)	30 (23, 47)	35 (27, 46)
Range	20, 80	31, 80	24, 80	21, 80	20, 80	20, 80

No physical activity differences by Asthmatic status



Characteristic	no, N = 7,551	yes, N = 1,342
Total log Activity Count per day		
Mean (SD)	2,233 (439)	2,219 (425)
Median (IQR)	2,276 (2,005, 2,523)	2,257 (1,999, 2,498)
Range	29, 3,562	58, 3,413

People with self-reported past Cancer move less



Characteristic	no, N = 7,828	yes, N = 842
Total log Activity Count per day		
Mean (SD)	2,248 (434)	2,070 (411)
Median (IQR)	2,287 (2,022, 2,535)	2,115 (1,799, 2,349)
Range	29, 3,562	327, 3,222

Univariate analysis with activity counts

Significant p-values but small effect size

Significant p-values but the effect size is medium based on AC scale (AC median is 2273)

Univariate Linear Model					
Characteristic	N	Beta	95% CI ¹	p-value	
BMI Categories	8,807		<0.001		
normal weight		—	—		
severely underweight	-384	-597, -170			
underweight	-138	-208, -69			
overweight	-6.5	-30, 17			
obesity class I	-21	-47, 4.8			
obesity class II	-46	-80, -12			
obesity class III	-103	-141, -65			
Body Mass Index (kg/m²)	8,807	-3.0	-4.3, -1.6	<0.001	
biological sex	8,903		<0.001		
female		—	—		
male	-35	-53, -17			

Univariate Linear Model					
Characteristic	N	Beta	95% CI ¹	p-value	
race	8,903		<0.001		
White		—	—		
Asian	64	34, 94			
Black	65	42, 88			
Hispanic	186	161, 210			
Other Race	51	-3.6, 105			
annual household income groups	8,106		<0.001		
\$0 to \$24,999		—	—		
\$25,000 to \$44,999	50	24, 77			
\$45,000 to \$74,999	67	39, 95			
\$75,000 to \$99,999	81	46, 117			
\$100,000 and over	58	30, 85			

¹ CI = Confidence Interval

Univariate analysis with activity counts

Significant p-values but small effect size

Univariate Linear Model				
Characteristic	N	Beta	95% CI ¹	p-value
race	8,903			<0.001
White		—	—	
Asian	64	34, 94		
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\$25,000 to \$44,999	50	24, 77		
\$45,000 to \$74,999	67	39, 95		
\$75,000 to \$99,999	81	46, 117		
\$100,000 and over	58	30, 85		

¹ CI = Confidence Interval

Ratio of family income to poverty is strongly associated with income groups (Spearman Correlation = 0.88)

Univariate Linear Model				
Characteristic	N	Beta	95% CI ¹	p-value
age in 10 years	8,903	-50	-55, -45	<0.001
ratio of family income to poverty	8,244	0.25	-5.5, 6.0	>0.9
six-month time period	8,903			0.046
May 1 through October 31		—	—	
November 1 through April 30		-19	-37, -0.37	
education level among adults	8,666			<0.001
less than 9th grade		—	—	
9-11th grade	18	-22, 58		
high school graduate	9.7	-27, 47		
college or AA degree	-30	-65, 5.7		
college graduate or above	-42	-78, -5.4		

¹ CI = Confidence Interval

Univariate analysis with activity counts

Significant p-values but small effect size

Univariate Linear Model					
Characteristic	N	Beta	95% CI ¹	p-value	
marital status for people > 20 yrs old	8,671			<0.001	
married		—	—		
widowed		-227	-261, -193		
divorced		-69	-98, -39		
separated		51	-1.3, 103		
never married		-23	-47, 0.83		
living with partner	111	74, 147			
pregnancy status, for women 20-44 yrs old	1,774			0.026	
no		—	—		
yes		-107	-201, -13		
number of people in the participant's family	8,903	64	57, 70	<0.001	
number of children aged 5 years or younger	8,903	106	90, 121	<0.001	

Significant p-values, medium effect size based on AC scale (AC median is 2273)

¹ CI = Confidence Interval

Univariate analysis with activity counts

Significant p-values but small effect size

Significant p-values, medium effect size based on AC scale (AC median is 2273)

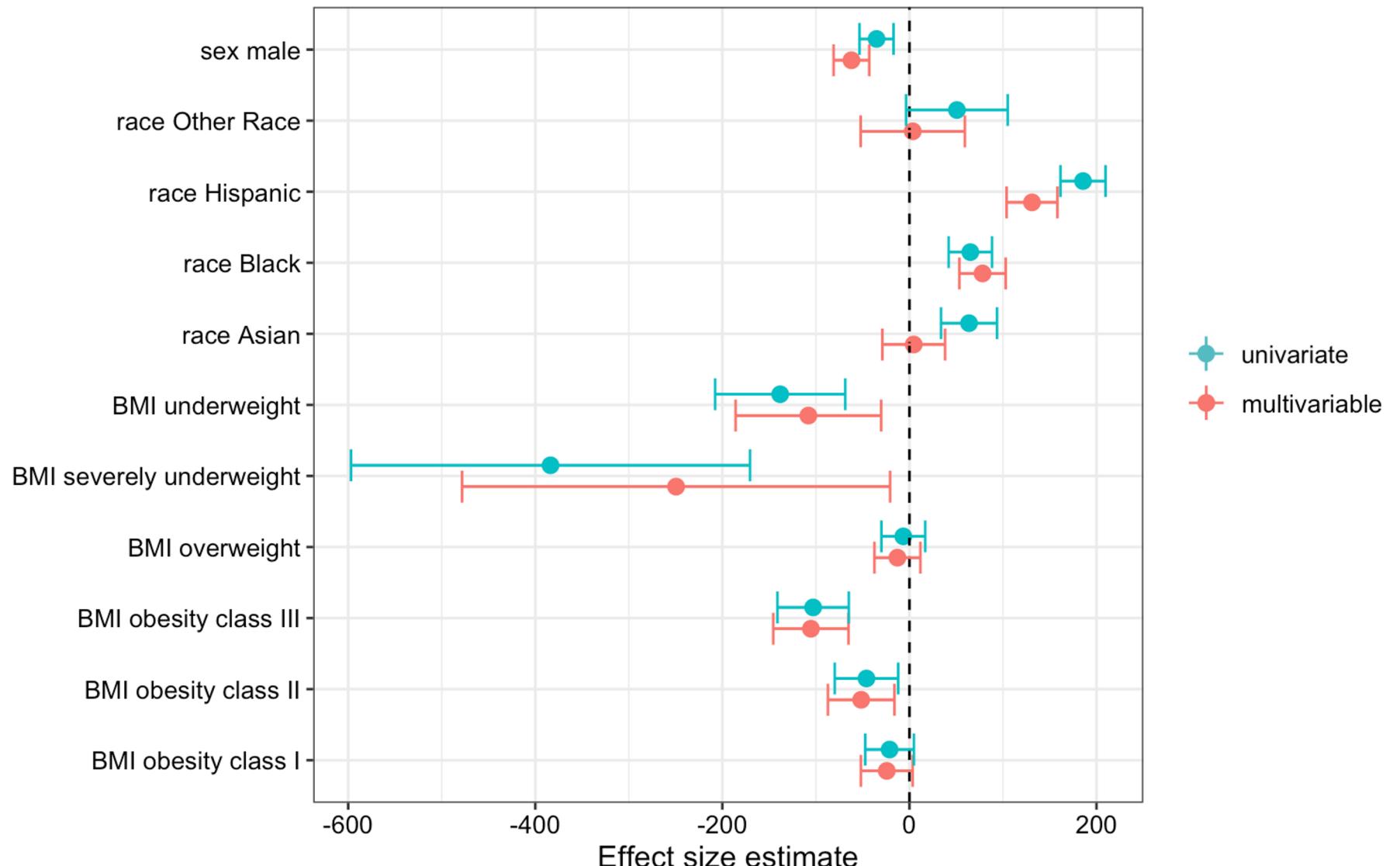
Univariate Linear Model				
Characteristic	N	Beta	95% CI ¹	p-value
health condition	8,303			<0.001
poor		—	—	
excellent	89	52, 125		
very good	66	38, 93		
fair		-151	-204, -98	
good	48	22, 73		
asthma	8,895		0.3	
no		—	—	
yes		-15	-40, 11	
cancer	8,672			<0.001
no		—	—	
yes		-178	-209, -147	

¹ CI = Confidence Interval

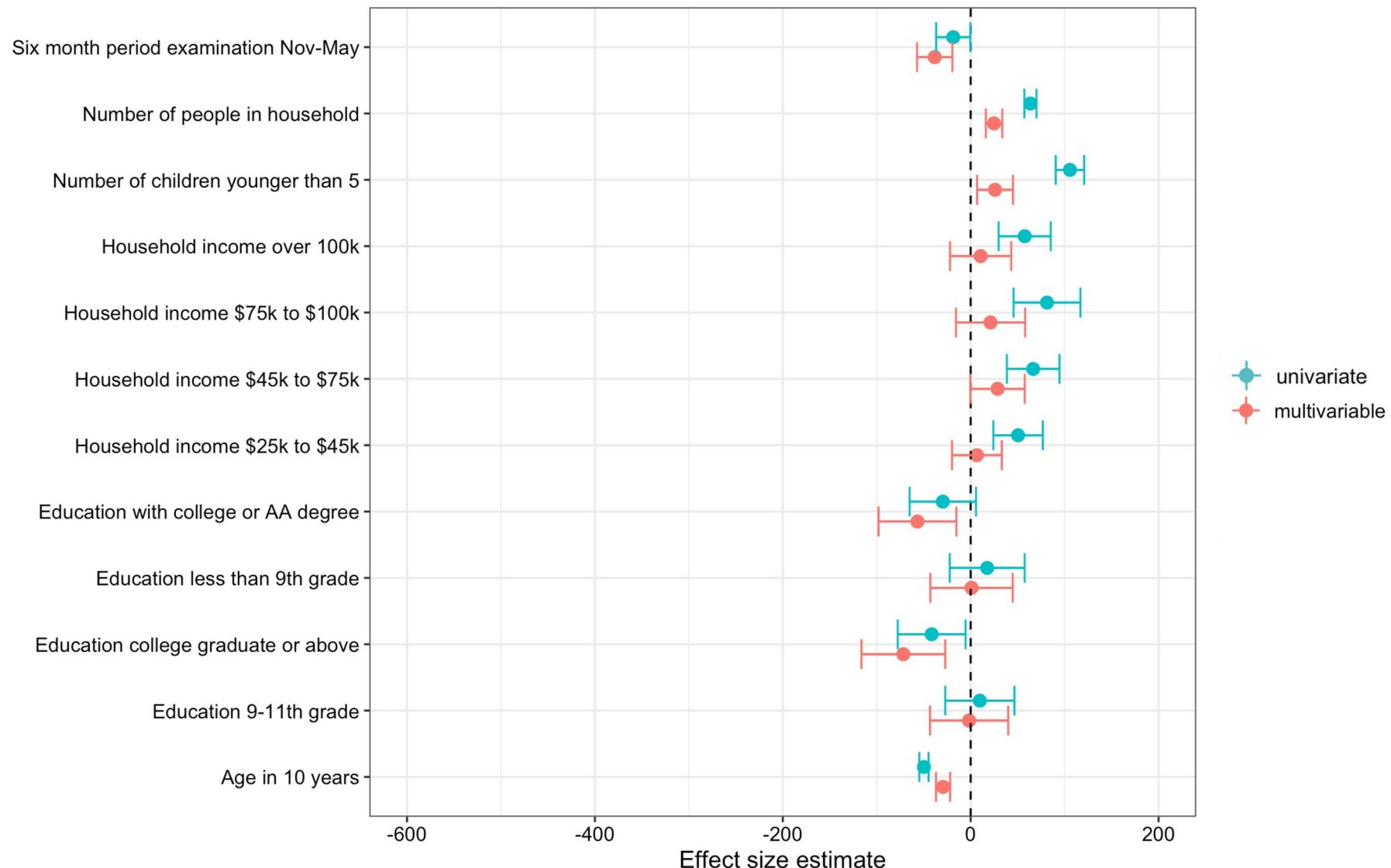
Univariate Linear Model				
Characteristic	N	Beta	95% CI ¹	p-value
diabetes	8,898			<0.001
no		—	—	
borderline		-39	-94, 17	
yes		-179	-206, -153	
congestive heart failure	8,657			<0.001
no		—	—	
yes		-267	-317, -217	
stroke	8,667			<0.001
no		—	—	
yes		-314	-360, -267	
liver condition	8,664			0.13
no		—	—	
yes		-36	-82, 11	

¹ CI = Confidence Interval

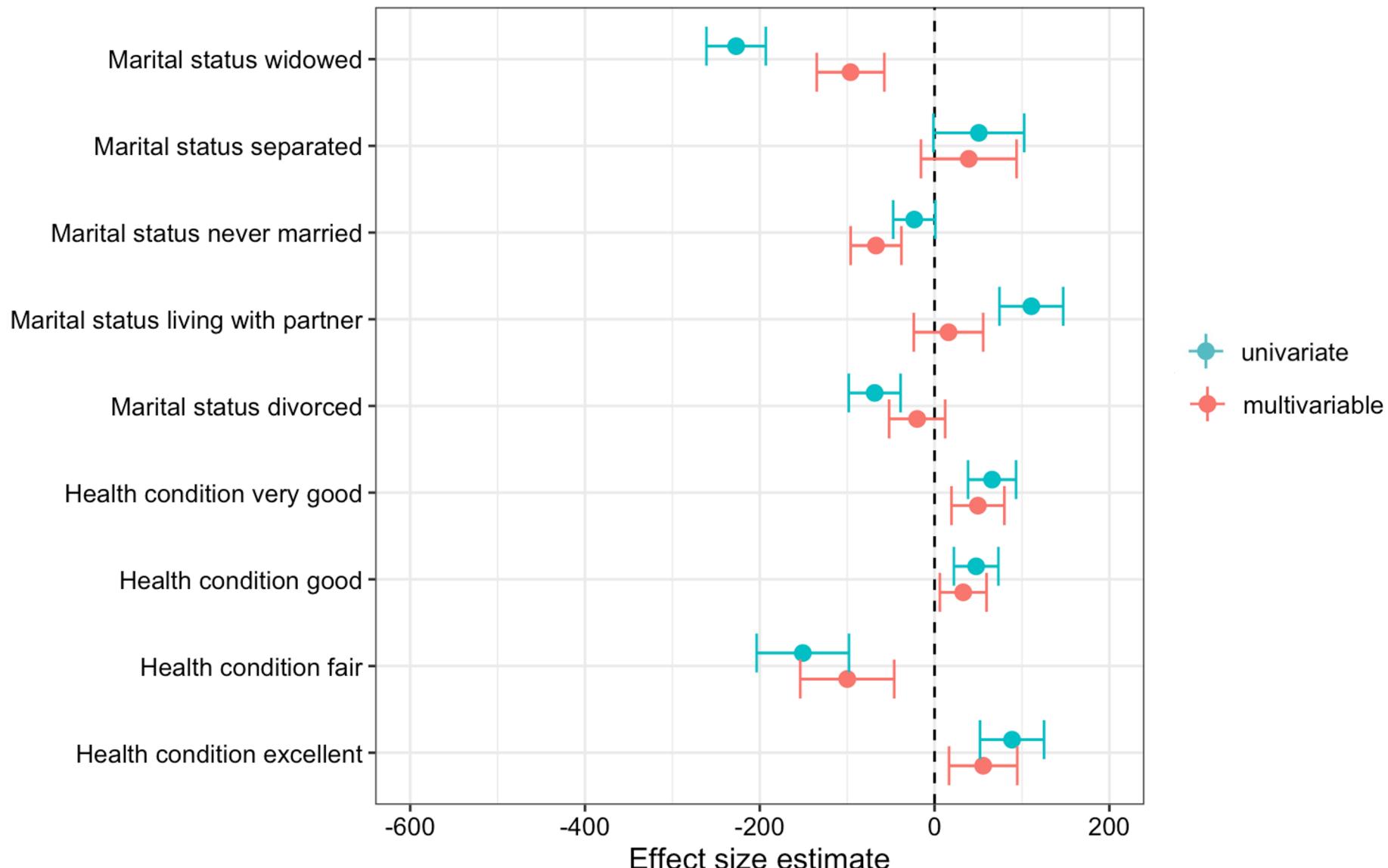
Forest plot of effect size for activity counts



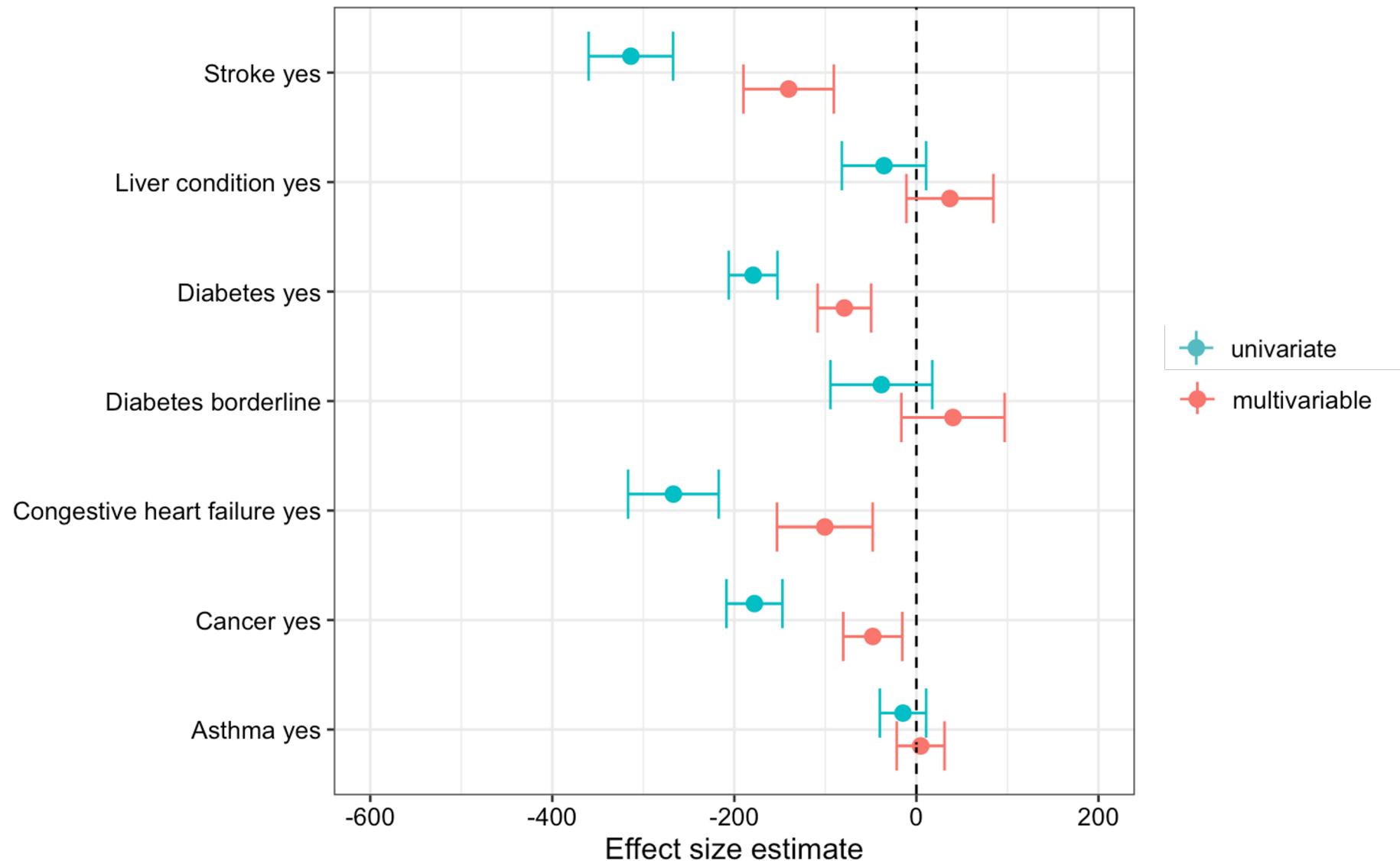
Forest plot of effect size for activity counts



Forest plot of effect size for activity counts



Forest plot of effect size for activity counts



Conclusion

- Accelerometry data is very challenging to work with
 - Complex data structure – there's still a lot to unfold
 - Complex data processing procedure with many steps
- Only medium to low association with TLAC determined despite statistical significance
 - Physical activity volume *might* not be an ideal digital biomarker
 - Further work is warranted

Future Work

- Research on alternative physical activity characteristics
- Continue exploring the NHANES
- Create an R shiny app
- Expand functionality of ***Arctools*** to incorporate more biomarkers
- Understand day-to-day variability of physical activity
- Develop a framework for using NHANES data as baseline for drug development

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- Regeneron Biostatistics and Data Management

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Thank you

Question?