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CLINICAL RESEARCH
Arrhythmias

Day-to-day measurement of physical activity and risk of atrial fibrillation

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See the editorial comment for this article 'The ins and outs of physical activity monitoring: implications for atrial fibrillation management', by A. D. Elliott et al., doi:10.1093/eurheartj/ehab520.

Aims The aim of this study was to investigate the association between within-individual changes in physical activity and onset of atrial fibrillation (AF).

Methods and results A total of 1410 participants from the general population (46.2% women, mean age 74.7 ± 4.1 years) with risk factors but with no prior AF diagnosis underwent continuous monitoring for AF episodes along with daily accelerometric assessment of physical activity using an implantable loop recorder during ≈3.5 years. The combined duration of monitoring was ≈1.6 million days, where 10 851 AF episodes lasting ≥60 min were detected in 361 participants (25.6%) with a median of 5 episodes (2, 25) each. The median daily physical activity was 112 (66, 168) min/day. A dynamic parameter describing within-individual changes in daily physical activity, i.e. average daily activity in the last week compared to the previous 100 days, was computed and used to model the onset of AF. A 1-h decrease in average daily physical activity was associated with AF onset the next day [odds ratio 1.24 (1.18–1.31)]. This effect was modified by overall level of activity ($P < 0.001$ for interaction), and the signal was strongest in the tertile of participants with lowest activity overall [low: 1.62 (1.41–1.86), mid: 1.27 (1.16–1.39), and high: 1.10 (1.01–1.19)].

Conclusions Within-individual changes in physical activity are associated with the onset of AF episodes as detected by continuous monitoring in a high-risk population. For each person, a 1-h decrease in daily physical activity during the last week increased the odds of AF onset the next day by ≈25%, while the strongest association was seen in the group with the lowest activity overall.

Clinical Trial Registration ClinicalTrials.gov, identifier: NCT02036450.

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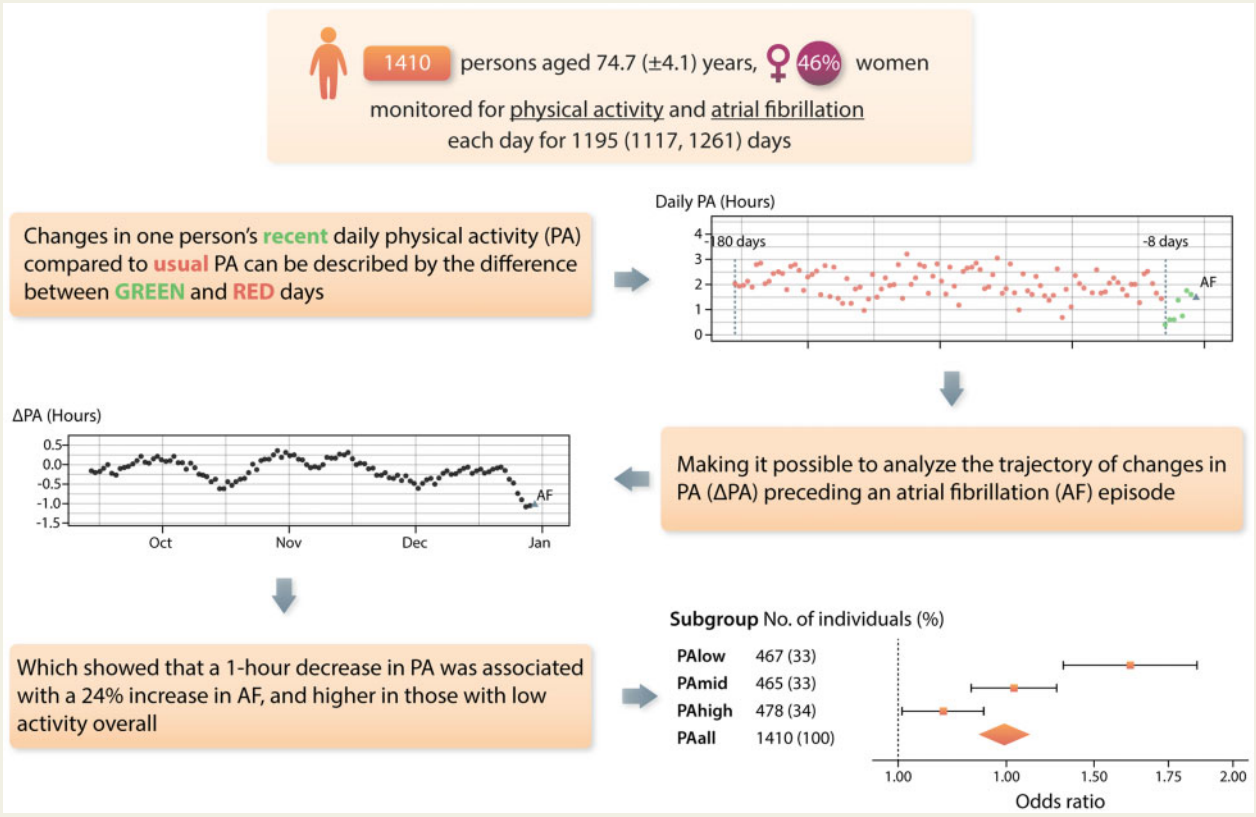
Graphical Abstract



Keywords Atrial fibrillation • Continuous monitoring • Physical activity • Activity patterns • Accelerometry

Introduction

Atrial fibrillation (AF) is the most common cardiac arrhythmia, and the incidence of AF is associated with cardiovascular risk factors such as hypertension, diabetes, and hypercholesterolaemia.[1,2] While physical activity is known to be protective against these risk factors, multiple investigations have focused on physical activity as an either harmful or protective element in AF pathophysiology.[3,4]

So far, the association has proven complex since some studies have linked rigorous physical exercise to AF risk,[5–8] while others found sedentary lifestyle to be an important risk factor for development of AF, and even others have found the association direction to be dependent on age.[9–13] Indeed, exercise-induced and sedentary-induced AF might represent two different entities. In general, the protective impact of moderate physical activity might outweigh the negative impact,[3,14] especially in older individuals.[12] Finally, decreased physical activity could be a marker of conditions leading to AF rather than a causal factor. With the advent of increasingly accessible wearable technology, interest is growing in the potential to measure physical activity and AF on a day-to-day basis.[15–18] Implantable loop recorder (ILR) monitoring provides a unique opportunity to study the association between the two by means of daily objective measurements of movement along with high accuracy for AF detection.

The current study aims to gain insight into the association between objectively measured physical activity and incident AF in patients with risk factors, and to describe whether day-to-day patterns in physical activity (i.e. within-individual changes in physical activity) can be related to AF onset.

Methods

Study design

This analysis is a sub-study of the LOOP study; an on-going randomized controlled trial conducted at four centres in Denmark. Detailed methods have been published previously.[19] Written informed consent was obtained from all participants, and the study was approved by the Danish Regional Ethical Committee (H-4-2013-025) and Data Protection Agency (2007-58-0015), and the trial was registered at ClinicalTrials.gov (NCT02036450).

In short, individuals from the general population were identified by administrative registries and invited by letter to participate. Eligible individuals had to be ≥70 years old and diagnosed with ≥1 of the following stroke risk factors: hypertension, diabetes, heart failure, or previous stroke, while those with any history of AF or cardiac implantable electronic device were excluded. At a baseline visit, a standard ECG was obtained to rule out prevalent AF and confirm study eligibility. Included participants were randomized in a 1:3 ratio to receive an ILR with continuous heart rhythm monitoring (Reveal LINQ®, Medtronic) vs. standard care.

For participants in the ILR group, new AF alerts were reviewed daily by an experienced physician. Any new-onset episode suspicious of AF lasting ≥6 min was independently adjudicated by two senior cardiologists. Any dispute was resolved by majority vote after involving a third senior cardiologist blinded to the previous evaluations. In patients with adjudicated AF, an experienced physician furthermore adjudicated the first episode lasting at least 1, 5.5, and 24 h. The ILR was also used to measure physical activity. The device uses a single axis from an embedded accelerometer to capture movement as an electric signal, by which the number of minutes the person is active is counted, where a minute is considered active if a threshold is reached incorporating both the number and magnitude of deflections. This method has proven responsive in capturing activities of daily living, and these measurements of physical activity have been found to correlate with clinical events.[20–23] Transmission of data from the ILR continued until the end of device battery-life (minimum 3 years), device explantation, or death. All AF episodes and daily physical activity totals in minutes were retrieved for each day for each participant during the study.

The current study comprised all participants in the LOOP study receiving ILR and for whom ILR assessments of AF and physical activity could be retrieved.

Data handling and statistical analysis

All information was registered in and acquired from an online database specific to the LOOP study. All AF episodes occurring before the first adjudicated episode were discarded. Characteristics such as age, sex, medication, and disease history were obtained at the baseline visit.

For summary statistics, continuous variables were presented as mean ± standard deviation for normally distributed variables compared by *t*-tests, and median (interquartile range) for non-normally distributed variables compared by Wilcoxon rank-sum tests, while categorical variables were presented as frequency and percentage compared by chi-squared tests. For the analysis of data with more than two groups, the Kruskal–Wallis method was used and in case of significance, the inter-group significance was assessed using Tukey and Kramer method.

AF episodes lasting at least 1 h were used as the outcome in the main analyses. Association between physical activity and AF was analysed first using time-to-event and second using within-individual changes.

For the time-to-event analysis, the average daily physical activity in the first 100 days of monitoring was calculated, which was then used as the independent variable with new-onset AF after 100 days as the dependent variable. Cumulative incidences were calculated, and a Cox proportional-hazards model was tested. The proportional-hazards assumption was assessed with Schoenfeld residuals and any violations were reported. Multivariate models were tested including age, sex, hypertension, diabetes, heart failure, previous stroke, systemic arterial embolism or transient ischaemic attack, and previous myocardial infarction, percutaneous coronary intervention, or coronary artery bypass graft. The final model included all of these variables.

For the within-individual analysis, changes in daily physical activity (ΔPA) were computed by comparing 'recent' daily physical activity with the preceding 'usual' daily physical activity. Here, recent daily physical activity was defined as the average physical activity during the previous week up (PA_{mean7d}) until but not including the day used to determine the outcome (AF onset or not), and usual physical activity was defined as the average physical activity during the prior 100 days ($PA_{mean100d}$). To avoid overlap, $PA_{mean100d}$ had a lag of 7 days. ΔPA was then defined by $PA_{mean100d}$—PA_{mean7d} and was calculated for each day for each participant moving one day at a time. In this way, several time epochs were defined, and the data were extended to include one data point per monitoring day per participant, except for the first 100 days per participant. A graphical example of how ΔPA was computed can be seen in *Figure 1*.

Logistic regression was then used to estimate the association between AF episode onset and within-individual changes in physical activity for all days in the data set. Three models were tested: M1, M2, and M3. M1 was adjusted for the total number of prior AF episodes. M2 was further adjusted for age, sex and annual season; spring, summer, fall, winter (defined by date cut-offs; 1 June, 1 September, 1 December, and 1 March). M3 was further adjusted for baseline risk factors: hypertension, diabetes, heart failure, previous stroke, systemic arterial embolism or transient ischaemic attack, and previous myocardial infarction, percutaneous coronary intervention, or coronary artery bypass graft.

A supplementary analysis was conducted using the relative change in physical activity (PAmean100d/PAmean7d) instead of absolute change. In this analysis, a maximum value of 100 (i.e. factor 100 increase) was defined, as it tended to rapidly increase towards infinity on days with low PAmean100d.

Sub-analyses were performed after stratifying by overall level of physical activity; PA_{low}, PA_{mid}, and PA_{high} based on tertiles of average daily physical activity during the first 100 days for the time-to-event analysis, and over the entire study period for the within-individual analysis. The within-individual analysis included test for interaction between overall level of physical activity and ΔPA.

Two sets of sensitivity analyses were applied. The first set investigated AF episodes lasting at least 6 min, 5.5 h, or 24 h instead of 1 h and was applied for both the time-to-event analysis and the within-individual analysis. The second set was applied only for the within-individual analysis as it defined ΔPA by different time windows than PAmean100d—PAmean7d, i.e. $PA_{mean100d}$—PA_{mean2d}, $PA_{mean30d}$—PA_{mean7d}, and $PA_{mean30d}$—PA_{mean2d} . A *P*-value <0.05 was considered statistically significant. Data handling and analysis were performed using R version 4.0.1 [https://www.R-project.org/, R Core Team (2019)] including *tidyverse* version 1.3.0.[24]

Results

Study population and data overview

A total of 1420 participants in the LOOP study had an ILR implanted, and of these, technical data retrieval was successful in 1410, comprising the current sub-study population. Baseline characteristics can be found in *Table 1*. The combined duration of monitoring was 1 636 824 days, with a median of 1195 (1117, 1261) days per participant available for the current study. A total of 54 persons (3.83%) died during or within one month from end of monitoring [event rate, 0.73 (0.55, 0.95) per 100 person-years].

A total of 41 709 AF episodes lasting at least 6 min were found across 429 participants (30.4%) having a median number of 21 (4, 82), mean 97 ± 209, episodes per person. A total of 10 851 AF episodes lasting at least 1 h (the outcome in the main analysis) were

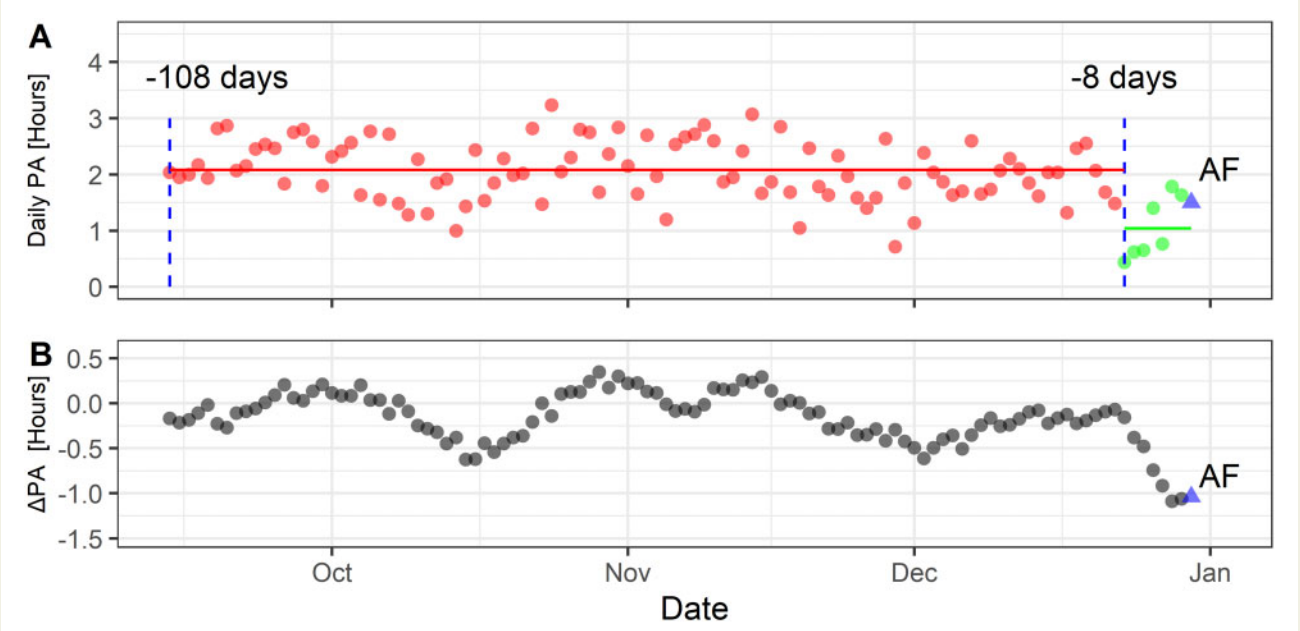


Figure 1 Graphical example of changes in recent compared to usual physical activity (ΔPA) and a pattern of ΔPA leading up to an AF episode. (*A*) Daily physical activity used to calculate ΔPA leading up to the day of AF onset (blue triangle): recent physical activity (during the most recent week, with a horizontal line illustrating the mean, PA_{mean7d}, green), and usual physical activity (during the prior 100 days, with a horizontal line illustrating the mean, $PA_{mean100d}$, red). (*B*) The pattern of ΔPA values leading up to an AF episode. Each day, ΔPA is calculated by subtracting PA_{mean7d} from $PA_{mean100d}$, where PA_{mean7d} is defined as the average daily physical activity in the week leading up to but not including that particular day, and $PA_{mean100d}$ is defined as the average daily physical activity in the 100 days prior to that week. AF, atrial fibrillation.

found across 361 participants (25.6%) having a median number of 5 (2, 25), mean 30 ± 67, episodes per person.

Of the 429 patients with AF episodes lasting at least 6 min, 50 (11.7%) were symptomatic at debut of AF, 19 (4.4%) received any antiarrhythmic therapy (class Ic or III drugs, or ablation, or cardioversion) during monitoring, 4 (0.9%) underwent ablation and 14 (3.3%) cardioversion. Of the 361 patients with AF episodes lasting at least 1 h, 46 (12.7%) were symptomatic at debut, 17 (4.7%) received any antiarrhythmic therapy during monitoring, 4 (1.1%) underwent ablation, and 12 (3.3%) cardioversion. In general, patients with AF were older, more frequently male, and had slower sinus heart rate at baseline (Supplementary material online, *Table S1*).

Physical activity

The median daily physical activity for the participants was 112 (66, 168) min/day during all of monitoring, with tertiles 80 min/day and 141 min/day, used to define physical activity groups: PA_{low}, PA_{medium}, and PA_{high}. Male sex, age ≥75 years, previous transient ischaemic attack or stroke, diabetes, and heart failure were all associated with lower physical activity (*Tables 2* and *3*). The distribution of physical activity for all days in the data set is shown in *Figure 2A* and the distribution of 'recent' compared to 'usual' physical activity (ΔPA) are shown in *Figure 2B*. The 95th and 99th percentiles for ΔPA were at -45 and -76 min. A total of 33 108 days (2.2%) had a ΔPA of -1 h or more, with a median of 25 (9.52) days per person.

Physical activity and AF

The time-to-event analysis found that higher daily physical activity during the first 100 days was associated with lower risk of AF thereafter [hazard ratio 0.88 (0.81, 0.96) per hour, $P < 0.01$]. The effect remained significant after adjustment for all variables but age, and there was no signal in the final model [hazard ratio 0.95 (0.86, 1.04) per hour, $P = 0.23$]. Time-to-event curves and hazard ratios for shorter and longer AF episodes according to physical activity are shown in Supplementary material online, *Table S2* and Supplementary material online, *Figure S1*.

The fraction of participants with AF per day is illustrated in *Figure 3A*, which differed across physical activity groups; PA_{low}, PA_{mid}, and PA_{high} ($P < 0.01$) (*Figure 3B*). In average, physical activity differed by 0.08 ± 0.69 h on days with and without AF for each participant (1.83 ± 1.15 vs. 1.75 ± 1.32 h, $P = 0.01$). In a multivariate model adjusting for the same covariates as M3, lower physical activity on any given day was associated with AF being present on the same day (odds ratio 1.003 per hour, $P < 0.01$).

The within-individual analysis found that a decrease in recent (the previous week) compared to usual (the prior 100 days) physical activity (ΔPA) was associated with AF onset in all models (*Table 4*). For M3, the odds increased by factor 1.24 (1.18, 1.31) per hour decline in physical activity. The association between ΔPA and AF onset was modified by the overall physical activity ($P < 0.001$ for interaction), and the odds ratio for ΔPA was higher in the low-activity group; PA_{low} odds ratio 1.62 (1.41, 1.86), PA_{mid} odds ratio 1.27 (1.16, 1.39),

and PA_{high} odds ratio 1.10 (1.01, 1.19) (*Figure 4*). The supplementary analysis using relative change in physical activity ($PA_{mean100day}$/$PA_{mean7day}$), instead of absolute change, showed that a reduction of 10% increased the odds of AF event onset by factor 1.09 (1.07, 1.10). When grouped by overall activity this was only statistically significant for participants in the low (PA_{low}) and medium (PA_{mid}) activity group in which a reduction of 10% increased the odds of AF onset by factor 1.11 (1.09, 1.12) and 1.06 (1.02, 1.09), respectively. The sensitivity analyses defining AF by a cut-off of 6 min, 5.5 h, or 24 h showed similar findings, albeit the effect size of decreased physical activity was larger with regard to the longer AF episodes (Supplementary material online, *Table S3*). The sensitivity analyses defining ΔPA by different time windows showed similar findings, albeit the signal was weaker when looking at short-term changes in PA (Supplementary material online, *Table S4*).

Discussion

We used long-term monitoring of physical activity and AF in 1410 individuals without known AF but with risk factors to associate physical activity and day-to-day changes in physical activity with AF episodes. The key findings were (i) a low level of physical activity overall was associated with development of AF, but this was confounded by age; (ii) low physical activity on any given day was slightly associated with AF onset on that day; (iii) within-individual changes in physical activity was strongly associated with AF onset; and (iv) the magnitude of the association between within-individual changes in physical activity and AF onset was dependent on the general level of physical activity (*Graphical abstract*).

Physical activity and AF

The association between physical activity and AF has been found to follow different shapes such as linear, J-shaped, or U-shaped, dependently on the age and characteristics of the study population.[9,12] This has created the hypothesis that underlying mechanisms responsible for an increased risk of AF are different from those responsible for a reduced risk of AF. Factors protecting against AF could be linked to the positive effects of physical activity on well-known epidemiological cardiovascular risk factors such as hypertension, diabetes, hypercholesterolaemia, and obesity, while more specific effects could include reduced epicardial fat, lower burden of sleep apnoea, and lower age-related decline in arterial elasticity.[25–27] Factors predisposing to AF could be linked to left atrial dilatation, left ventricular hypertrophy, and increased parasympathetic tone, although mainly investigated in athletes.[28]

Numerous studies have investigated the association between physical activity and AF, but the focus has mainly been on young to middle-aged adults and rigorous exercise opposed to activities of daily living.[7,11,29] Albeit studies such as the Cardiovascular Health Study and the Rotterdam Study looked at leisure-time activity and development of AF in populations aged ≥65 and ≥55 years, physical activity was, however, based on subjective values estimated through questionnaires, and AF detection on occasional ECG measurements.[4,9] While one study found an association between low baseline physical activity and risk of AF,[9] the other did not.[4] More recently, self-reported physical activity and wrist-worn accelerometry data from the UK Biobank have strongly supported the notion that lower levels of daily physical activity at baseline are associated with higher risk of a receiving a diagnosis of AF.[3,14] In the current study, the link between baseline physical activity and incident AF was confounded by age, while traditional risk factors were associated both with lower physical activity and with AF (*Tables 3* and *4*), corresponding to previous findings linking physical activity to risk factors for AF.[10,13]

Table 1 Baseline characteristics ($n = 1410$)

Female sex	626 (44.0)
Age, years	74.7 ± 4.1
Alcohol consumption, U/week	5 [1, 10]
Smoking pack years	7 [0, 28]
Hypertension	1301 (93.0)
Diabetes	407 (29.4)
Heart failure	56 (4.0)
Previous stroke, TIA, or SAE	296 (21.0)
Previous AMI, CABG, or PCI	166 (11.8)
Valvular heart disease	61 (4.3)
CHA_2DS_2-VASc score	
2	193 (13.7)
3	487 (34.5)
4	392 (27.8)
5	229 (16.2)
≥6	109 (7.7)
Treatment with	
Beta-blockers	336 (23.8)
Calcium channel blockers	528 (37.4)
Renin–angiotensin inhibitors	931 (66.0)
Statins	829 (58.8)
Diuretics	462 (32.8)
Platelet inhibitors	665 (47.2)
Insulin	119 (8.4)
Other antidiabetic drugs	310 (22.0)
Systolic blood pressure, mmHg	150.5 ± 19.1
Diastolic blood pressure, mmHg	84.7 ± 11.1
Pulse rate, b.p.m.	71.6 ± 12.1
Body mass index, kg/m^2	27.9 ± 4.6
eGFR, mL/min	76 ± 19.3

Missing data: blood pressure ($n = 1$), pulse rate ($n = 1$), and eGFR ($n = 8$). Values are presented as *n* (%), mean ± SD, or median [Q1, Q3].
AMI, acute myocardial infarction; CABG, coronary artery bypass grafting; COPD, chronic obstructive pulmonary disease; eGFR, estimated glomerular filtration rate; PCI, percutaneous coronary intervention; SAE, systemic arterial embolism; SD, standard deviation; TIA, transient ischaemic attack.

Day-to-day changes in physical activity and AF onset

While we did find an association between lower physical activity in the first part of monitoring and development of AF episodes thereafter, the effect was small and not robust to multivariate adjustment. Also, although lower activity on any given day was associated with AF on the same day, the odds only increased with 0.3% per hour of physical activity.

Table 2 Number of participants grouped by baseline risk factors and physical activity

Variable	All ($n = 1410$)	PA_{low} ($n = 463$)	PA_{mid} ($n = 469$)	PA_{high} ($n = 478$)	*P*-value
Age (years)					<0.01
<75	626 (44)	159 (34)	202 (43)	265 (55)	
≥75	784 (56)	304 (66)	267 (57)	213 (45)	
Sex					<0.01
F	662 (49)	162 (35)	210 (45)	280 (59)	
M	758 (56)	301 (65)	259 (55)	198 (41)	
Hypertension					<0.01
No	99 (7)	34 (7)	36 (8)	39 (8)	
Yes	1301 (93)	429 (93)	433 (92)	439 (92)	
Diabetes					<0.01
No	1003 (71)	269 (58)	345 (74)	389 (81)	
Yes	407 (29)	194 (42)	124 (26)	89 (19)	
Heart failure					0.9
No	1354 (96)	431 (93)	457 (97)	466 (97)	
Yes	56 (4)	32 (6)	12 (2)	12 (3)	
Previous stroke, SAE or TIA					<0.01
No	1114 (79)	343 (74)	377 (80)	394 (82)	
Yes	296 (21)	120 (26)	92 (20)	84 (18)	

Overview of number of participants grouped by risk factors and physical activity groups; PAlow, PAmid, and PAhigh. Values are presented as *n* (%). The *P*-value is based on a test for difference across the physical activity groups.
PA, physical activity; Q1, Q3, quartiles 1 and 3; SAE, systemic arterial embolism; TIA, transient ischaemic attack.

Table 3 Average daily physical activity in minutes grouped by baseline risk factors and physical activity

Variable	All ($n = 1410$)	PA_{low} ($n = 463$)	PA_{mid} ($n = 469$)	PA_{high} ($n = 478$)	*P*-value
Age (years)					<0.01
<75	137 ± 76	50 ± 19	110 ± 18	210 ± 52	
≥75	111 ± 72	45 ± 21	111 ± 17	205 ± 53	
Sex					<0.01
F	140 ± 81	45 ± 22	111 ± 18	216 ± 58	
M	108 ± 65	48 ± 20	111 ± 17	196 ± 43	
Hypertension					<0.01
No	126 ± 78	45 ± 23	115 ± 14	207 ± 63	
Yes	122 ± 74	47 ± 21	111 ± 18	207 ± 51	
Diabetes					<0.01
No	132 ± 75	48 ± 21	111 ± 18	209 ± 52	
Yes	99 ± 68	46 ± 21	110 ± 17	201 ± 55	
Heart failure					0.6
No	124 ± 75	47 ± 21	111 ± 18	208 ± 98	
Yes	94 ± 71	47 ± 19	109 ± 15	204 ± 65	
Previous stroke, SAE or TIA					<0.01
No	126 ± 75	48 ± 20	111 ± 17	205 ± 54	
Yes	111 ± 73	45 ± 23	112 ± 19	205 ± 48	

Overview of average daily physical activity in minutes during the monitoring-period grouped by risk factors and physical activity; PA_{low}, PA_{mid}, and PA_{high}. Values are listed as mean ± SD. The *P*-value is based on a test for difference across the physical activity groups.
PA, physical activity; Q1, Q3, quartiles 1 and 3; SAE, systemic arterial embolism; SD, standard deviation; TIA, transient ischaemic attack.

Interestingly, the within-individual day-to-day changes in physical activity (ΔPA) proved effective at mapping the association between activity and onset of AF episodes, since a 1-h reduction in a person's average daily physical activity in the recent week compared to usual physical activity was independently associated with a ≈ 25% increase in odds of AF onset the next day. The strong association between a

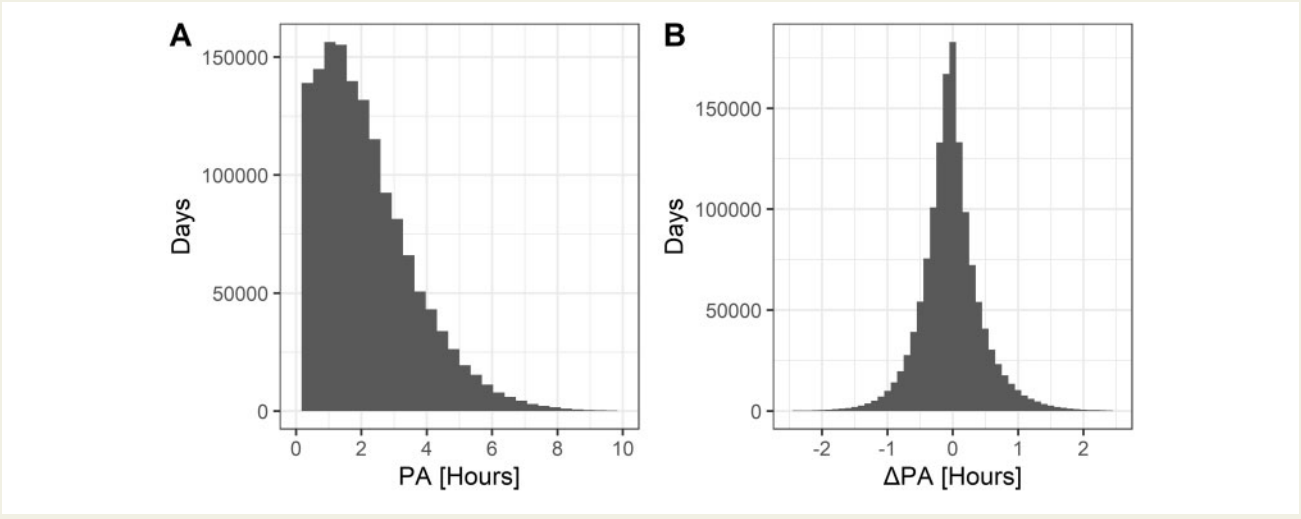


Figure 2 Subplots illustrating physical activity and day-to-day change in physical activity in the study population. (*A*) Distribution of physical activity for all data points; one for each day for each participant. (*B*) Distribution of day-to-day change in physical activity, defined as average physical activity during the prior 100 days ($PA_{mean100d}$) subtracted by average physical activity in the recent week (PA_{mean7d}). To avoid overlap, a lag of 7 days was included between the two. PA, physical activity.

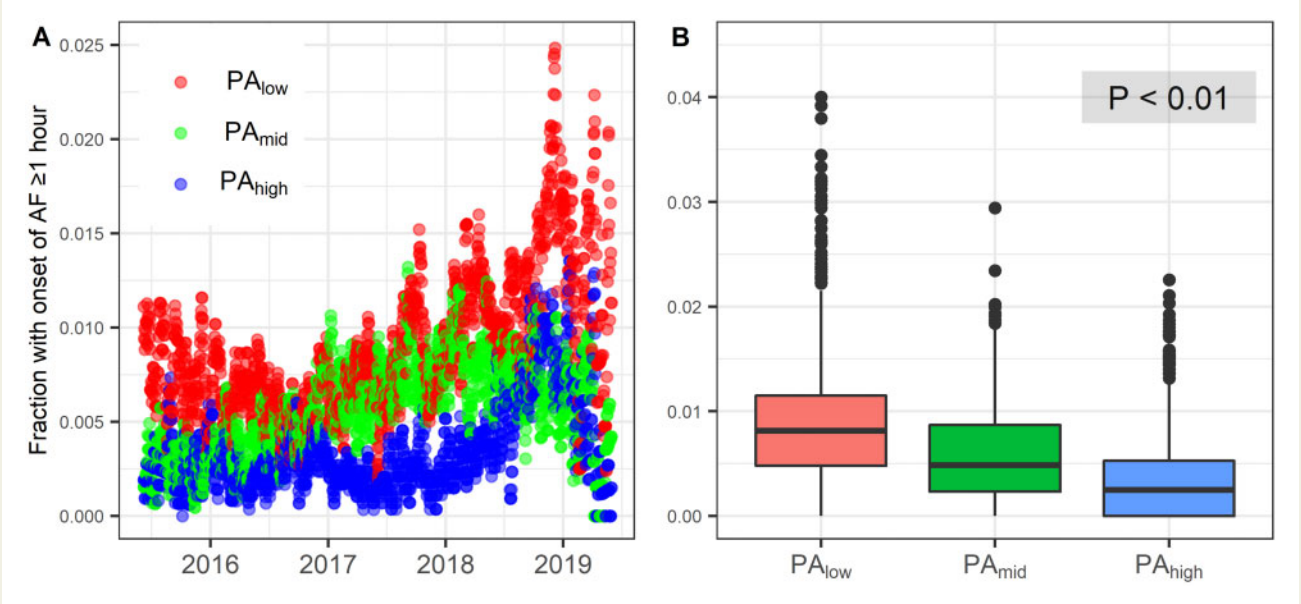


Figure 3 Subplots illustrating atrial fibrillation episodes in the study population. (*A*) Fraction of participants with AF onset on each day during the study period, with participants stratified into physical activity groups. (*B*) Overall percentage of days with AF onset for each participant, stratified by activity group. A Kruskal–Wallis test showed a significant difference between groups ($P < 0.01$) and a Tukey–Kramer analysis showed that all groups were significantly different from each other ($P < 0.01$). AF, atrial fibrillation; PA, physical activity.

decline in physical activity and onset of AF could to some extent be due to lack of exercise leading to AF in itself, while another possible explanation could be the presence of unknown, subclinical conditions leading to both decreased physical activity and then to AF. The interaction analysis illustrated that the dynamic relationship between physical activity and AF was strongest among persons with low activity overall, as a 1-h reduction in an individual's physical activity increased the odds of AF by ≈60% among the third of the population with the least activity. Few previous studies have investigated day-to-day changes in some exposure and association with AF. Linz *et al.*[27]

Table 4 Association between within-individual changes in physical activity and atrial fibrillation onset

Coefficient	M1			M2			M3		
	Estimate	95% CI	*P*-value	Estimate	95% CI	*P*-value	Estimate	95% CI	*P*-value
ΔPA	1.22	1.16–1.28	<0.01	1.21	1.18–1.24	<0.01	1.24	1.18–1.3 1	<0.01
$Episodes_{prior}$ [#]	1.02	1.02–1.02	<0.01	1.02	1.02–1.02	<0.01	1.02	1.02–1.02	<0.01
$Season_{spring}$				1.09	1.02–1.17	<0.01	1.11	1.04–1.19	<0.01
$Season_{summer}$				0.96	0.89–1.02	0.2	0.98	0.92–1.05	0.2
$Season_{winter}$				1.09	1.02–1.16	<0.01	1.13	1.06–1.20	<0.01
Age (years)				1.03	1.02–1.04	<0.01	1.03	1.03–1.04	<0.01
Sex (male)				1.37	1.30–1.43	<0.01	1.17	1.12–1.23	<0.01
Diabetes							1.01	0.96–1.07	0.6
Hypertension							1.92	1.72–2.13	<0.01
Previous stroke, SAE, or TIA							1.21	1.14–1.28	<0.01
Previous AMI, PCI, or CABG							1.64	1.54–1.74	<0.01
Heart failure							1.35	1.23–1.48	<0.01

Results from the logistic regression models: M1, M2, and M3, regarding the association between ΔPA and the onset of AF episodes lasting at least 1 h. The estimate for ΔPA represents a 1-h decrease in activity. $Season_{fall}$ was used as a reference for the annual season parameter.
AF, atrial fibrillation; AMI, acute myocardial infarction; CABG, coronary artery bypass grafting; CI, confidence interval; ΔPA, change in daily physical activity; PCI, percutaneous coronary intervention; SAE, systemic arterial embolism; TIA, transient ischaemic attack.

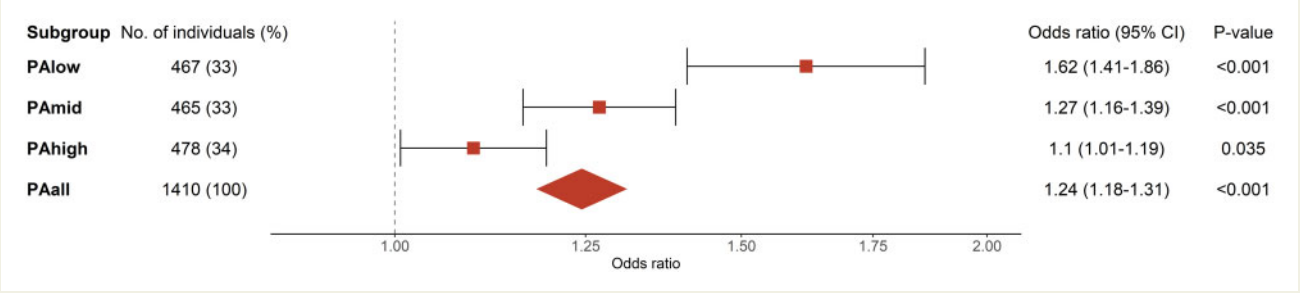


Figure 4 Association between changes in recent compared to usual physical activity (ΔPA) and onset of atrial fibrillation grouped by overall physical activity after multivariate adjustment (M3). M3, model 3 adjusted for age, sex, hypertension, diabetes, heart failure, previous stroke, systemic arterial embolism or transient ischaemic attack, and previous myocardial infarction, percutaneous coronary intervention, or coronary artery bypass graft, the total number of prior atrial fibrillation episodes, and annual season.

investigated 72 patients undergoing 21 ± 8 weeks of pacemaker-mediated monitoring for both AF and respiratory disturbances and reported that nights with more sleep-disordered breathing conferred a higher risk of AF.

Future perspectives

One of the traits of the digital age is the promise of individual risk estimation on a day-to-day basis. Our findings illustrate the potential utility of day-to-day monitoring of physical activity as a biomarker for forthcoming AF. The recent years have seen an explosion in so-called 'wearables', both developed for clinical use and for the consumer market. The technology is continuously improving with regards to monitoring activities of daily life and exploring risk factors or even detecting clinical disease. Many such devices are capable of accelerometry and are thus able to measure physical activity, making this a topic of interest.[15–18] The clinical utility and possible health benefits for patients are far from fully understood. Patient-initiated health monitoring with digitally delivered feedback imposes new challenges to health care systems as concerns remain when it comes to validity and reliability of the data. Potential benefits from the utilization of patient data from devices or 'wearables' include facilitated preventive care and aid in monitoring ongoing illness, whereas potential harms include increased workload on health care givers, risk of over- and underestimating signs of disease, and a psychological burden.[17]

Limitations

Limitations of the study adhere to the population under study and the device used. The study population was recruited by letter invitation and could be affected by healthy user bias. Persons with mobility disorders were not actively excluded. The eligibility criteria required all participants to be without a diagnosis of AF but to have at least

one comorbidity which impeded the ability to investigate the impact of individual comorbidities.

Also, the multivariate model included comorbidities at baseline, not interim conditions occurring during the approximately 3 years of monitoring. We did not have data on sleep apnoea. The absolute risk of AF onset on any given day was limited.

As the ILR used a single axis accelerometer, it was only capable of detecting movement in a binary way (active or inactive) and it was not possible to categorize physical activity by type (walking, running, biking, etc.) or intensity levels (leisure, moderate, vigorous exercise, etc.), which is arguably inferior to more advanced tri-axial accelerometry.[14] Furthermore, the ILR algorithm used for AF detection in the current study has significant false-positive rates. Mittal *et al.* reported that in patients with stroke risk factors but without known AF only 39% of AF alerts lasting ≥6 min would be deemed true AF, while for alerts lasting ≥1 h, the proportions were ∼91–97%.[30] For this reason, we applied a rigorous adjudication regimen for new-onset AF and then focused our analysis on the longer episodes.

Conclusion

Using data from long-term, continuous heart rhythm monitoring and accelerometry in 1410 individuals with stroke risk factors we demonstrated an association between physical activity and AF onset on a day-to-day basis. Specifically, a 1-h reduction in recent compared to usual daily activity accounted for a 25% increase in the odds of AF the next day. These findings illustrate the potential of day-to-day monitoring of physical activity as a biomarker for the risk of AF.

Supplementary material

Supplementary material is available at *European Heart Journal* online.

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Conflict of interest: M.P.B. reports to be an employee of Cortrium, not related to this work. K.J.H. reports travel and educational grants from Medtronic, Abbott, and Biotronik and speaker honoraria from Boehringer Ingelheim not related to this work. L.K. reports speaker honoraria from Bayer, Astra-Zeneca, Orion Pharma, Novartis, and Sanofi, not related to this work. D.K. reports being a Medtronic Focus Group member. A.B. reports a research grant from Theravance and the Regions of Southern Denmark and Zealand, and speaker honoraria from Bayer, Boehringer Ingelheim, and Bristol-Myers Squibb not related to this work. J.H.S. reports to be a member of the Medtronic advisory boards and to have received speaker honoraria and research grants from Medtronic concerning this work, in addition to a research grant from Gilead not related to this work. S.Z.D. reports to be a part-time employee of Vital Beats, not related to this work.

Data availability

The data underlying this article cannot be shared publicly for ethical reasons, but the methodology will be shared upon reasonable request to the corresponding author.

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