Physical activity monitor (accelerometer)

Version 2.0

http://www.ukbiobank.ac.uk/

August 2025

This document details the procedure for processing of the accelerometer data and the creation of derived summary variables performed by the Physical Activity Expert Working Group for UK Biobank. Version 2.0 was produced in August 2025 to include details of the seasonal repeat study as the invitation response fields from this follow-up were added to Showcase.

Contents

1. Introduction

1.1: Interpreted levels of accelerometer measured physical activity can vary, as many data processing approaches can be taken to extract summary information from raw device data. This document describes the process used to generate derived data-fields of accelerometer measured physical activity. This has been developed by the UK Biobank Physical Activity Expert Working Group, the members of which are listed at the end of this document.

The overall approach to processing the data is summarised in Figure 1 (as published in Doherty et al. 2017). This analysis is freely available and hosted as an open source software project[1].

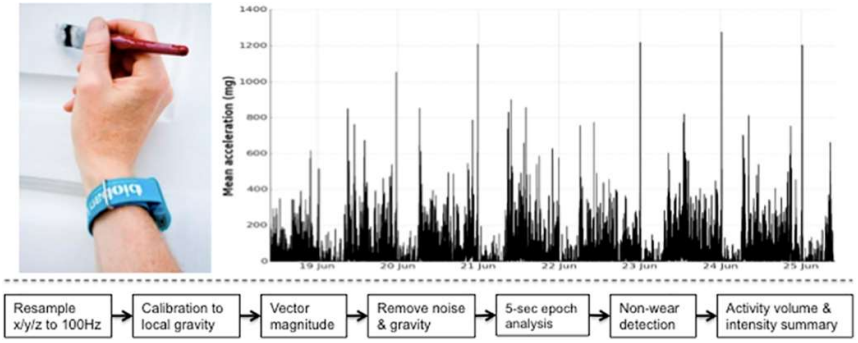

Figure 1. Overall approach for the processing of the accelerometer data

2. Accelerometer device

2.1: For objective assessment of physical activity, UK Biobank has used the Axivity AX3

[1] https://github.com/computationalEpidemiology/biobankAccelerometerAnalysis

wrist-worn triaxial accelerometer, a commercial version of the Open Movement AX3 open source sensor designed by Open Lab, Newcastle University[2]. The Axivity device facilitates transparent data processing analysis due to its open-source firmware platform and unforced sampling of raw measurement data. It is easily deployed (and returned) by post. The device demonstrates equivalent output on multi-axis shaking tests (Ladha et al. 2013) to the GENEActiv accelerometer used in other large-scale population cohorts (Sabia et al. 2013, da Silva et al., 2014, van Hees et al. 2014).

2.2: The Axivity device was set up to capture tri-axial acceleration data over a seven-day period at 100Hz with a dynamic range of +-8*g*.

3. Data collection

3.1: Main accelerometry study

3.1.1: Participants were emailed to invite them to wear an accelerometer in order to capture data on physical activity for a seven-day period. Invitation dates are available under Data-Field 110006, Instance 0.

3.1.2: Participants were informed in the invitation email and device mail-out letter that the accelerometer should be worn continuously and to carry on with their normal activities.

3.1.3: Once the participants had received the device in the mail, they were asked to start wearing the accelerometer immediately on the wrist of the hand that they usually write with.

3.1.4: Participants were informed that the device is configured to turn itself on and off automatically at pre-determined times.

3.1.5: At the end of the seven-day period, participants were asked to mail the device back to the co-ordinating centre in the pre-paid envelope provided.

3.1.6: On receipt at the co-ordinating centre, the data were downloaded and the

[2] https://github.com/digitalinteraction/openmovement

devices cleaned and recharged ready to be dispatched to the next participant.

3.1.7: Accelerometer data from 103,720 participants were collected from May 2013 until Dec 2015. Overall, 240,000 invitations were sent, with a response rate of 44% - see Data-Field 110005. Devices were dispatched for 106,053 participants and, of these, data were received from over 130,000 - with data on activity on three days or more from 93% of devices. The median return rate was 17 days, and the loss rate of devices was very low (1.2%).

3.2: Accelerometry seasonal repeat study

3.2.1: Over 5000 invitations to an accelerometry seasonal repeat study were sent between November 2017 and April 2018, to a stratified random sample of participants who had completed the main accelerometry study and returned the original activity monitor within 14 days of the date of issue. Stratification was by sex and four age bands at time of selection: <55, 55-65, 65-75 and >75 years. Invitation dates are available under Data-Field 110006, Instance 1.

3.2.2: Participants were asked to take part in four cycles ('seasons') of data collection over a 12-month period, each approximately three months apart. Cycles ran identically to the single data collection of the main study and using the same activity monitors (see sections 2.1 to 3.1.6). Participants were informed that at each cycle an email notification would be sent two weeks in advance of a kit being dispatched.

3.2.3: Participants were told that they could contact the participant call centre at any time if they needed to 'skip' a season if the timing was inconvenient, or, if they elected to withdraw from the study.

3.2.4: Over 3000 participants accepted the invitation - a response rate of 63%.

3.2.5: Kits were dispatched per season during the following periods:

Season 1	Nov 2017 - May 2018
Season 2	Feb 2018 - Aug 2018
Season 3	May 2018 - Nov 2018
Season 4	Aug 2018 - Jan 2019

3.2.7: Responses to the initial invitation, and kit activity of participants who accepted invite, are captured in Data-Field 30018 using encoding 2501, which includes the following values:

value	meaning	description
1	no response to the initial invitation	-
2	kit returned, incomplete	incomplete or no data
3	kit returned, complete	data available under Data-Field 90001
4	kit not returned	-
5	kit not dispatched	due to skipping a season, or withdrawal

Researchers should take note of the following:

- In season 1 there are a disproportionate number of kits with a 'kit returned, incomplete' value, i.e. 17% of all kits dispatched compared with <1% in seasons 2, 3 and 4. This disparity is due to suboptimal battery performance among kits that were re-used from the main study in season 1, which was rectified in later seasons.

- Participants may not have had a kit dispatched to them if they requested to skip one or more seasons, or, they withdrew from the study. However, if a season was skipped participants could still receive and return kits in subsequent cycles.

3.2.8: Accelerometer kits were dispatched to >3000 participants at each of the four repeat seasons. The median response time to return a kit was 15 days for seasons 1 to 3 and 14 days for season 4.

4. Data Processing and summary fields

4.1: Data Preparation

4.1.1: Calibration: To ensure different devices provided a similar output under similar conditions we calibrated the acceleration signals to local gravity using the procedure described by Van Hees and colleagues (2014). Briefly, we identified stationary periods in ten second windows where all three axes had a standard deviation of less than 13.0 mg. These stationary periods were then used to

optimise the gain and offset for each axis (6 parameters) to fit a unit gravity sphere using ordinary least squares linear regression. If insufficient data were available to conduct calibration for a given participant (where any of the three sensor axes did not have values outside a +- 300 mg range), we used the calibration coefficients from the previous (or if unavailable, the next) accelerometer record from the same device worn on a different participant.

4.1.3: Highlight interrupts, and invalid values: Clipped values, which occur when the sensor's dynamic range of +-8g is exceeded, were flagged before and after calibration. Recording errors and 'interrupts', which could have occurred for example if participants tried to plug their accelerometer device into a computer, were also logged.

4.1.2: Resampling: While the accelerometer is setup to record data at 100Hz, the actual sample rate can fluctuate between 94-104Hz. Thus, valid data was then resampled to 100 Hz using linear interpolation, except for interrupts lasting longer than 1 second which were set to missing.

4.2: Vector Magnitude Processing

4.2.1: Combine x/y/z axes: We calculated the sample level Euclidean norm of the acceleration in x/y/z axes (Sabia et al., 2014).

4.2.2: Gravity and noise removal: Machine noise was removed using a fourth order Butterworth low pass filter with a cut-off frequency of 20Hz. This filter is applied to the vector magnitude scores, rather than the individual axes, due to more precisely capturing arm rotations. In order to separate out the activity-related component of the acceleration signal, we removed one gravitational unit from the vector magnitude, with remaining negative values truncated to zero (Sabia et al., 2014; Van Hees et. al. 2011; da Silva et al., 2014).

4.3.3: Epoch generation: To describe the overall level and distribution of physical activity intensity, we combined the sample level data into five second epochs for summary data analysis, maintaining the average vector magnitude value over the epoch. To represent the distribution of time spent by an

individual in different levels of physical activity intensity, we generated an empirical cumulative distribution function from all available five second epochs (Hammerla et al., 2013).

4.3: Physical activity analysis

4.3.1: Detect non-wear: We removed non-wear time, defined as consecutive stationary episodes lasting for at least 60 minutes. The same standard deviation threshold criteria were applied as described in the calibration procedure to identify stationary episodes from the selected epochs.

4.3.2: Wear-time weighting: We imputed non-wear data segments using the average of similar time-of-day vector magnitude and intensity distribution data points with one minute granularity on different days of the measurements. This imputation accounts for potential wear time diurnal bias where, for example, if the device was systematically not worn during sleep in an individual, the crude average vector magnitude during wear time would be a biased overestimate of the true average (Van Hees et al., 2011).

4.4: Summary Physical Activity Variable: A physical activity outcome variable was generated by averaging all worn and imputed values. The expert working group decided that it may be prudent to remove individuals who had less than three days (72 hours) of data or who did not have data in each one-hour period of the 24-hour cycle. They defined these minimum wear-time guidelines by performing missing data simulations on 29,765 participants. Using intraclass correlation coefficients, at least 72 hours (3 days) of wear were needed to be within 10% of the true stable seven-day measure.

4.5: Time series file: A .csv time series file is generated for each participant. This will provide researchers with a simple way to interrogate the five second by five second interpreted physical activity variable, without the need for expertise in processing large complex raw data files.

5. Data available in Showcase

5.1: Data-fields currently available under Category 1008, include:

	Main study	Seasonal repeats
Raw acceleration data	✓	✓
Average acceleration by day and by hour	✓	*
Acceleration intensity distribution	✓	*
Wear time/non-wear time and duration by day and by hour	✓	*
Accelerometer calibration and quality metrics	✓	*
Invitation dates and responses to invitation	✓	✓

*Due for future release

6. References

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7. Physical Activity Expert Working Group

Listed in alphabetical order:

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