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Sampling frequency affects the processing of ActiGraph raw acceleration data to activity counts

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Abstract

ActiGraph acceleration data are processed through several steps (including bandpass filtering to attenuate unwanted signal frequencies) to generate the activity counts commonly used in physical activity research. We performed three experiments to investigate the effect of sampling frequency on the generation of activity counts.

Ideal acceleration signals were produced in the MATLAB software. Thereafter, ActiGraph GT3X+ monitors were spinned in a mechanical setup. Finally, twenty subjects performed walking and running wearing GT3X+ monitors. Acceleration data from all experiments were collected with different sampling frequencies and activity counts were generated with the ActiLife software.

With the default 30 Hz (or 60 Hz, 90 Hz) sampling frequency, the generation of activity counts was performed as intended with 50 % attenuation of acceleration signals with a frequency of 2.5 Hz by the signal frequency bandpass filter. Frequencies above 5 Hz were eliminated totally. However, with other sampling frequencies, acceleration signals above 5 Hz escaped the bandpass filter to a varied degree and contributed to additional activity counts. Similar results were found for the spinning of the GT3X+ monitors, although the amount of activity counts generated was less, indicating that raw data stored in the GT3X+ monitor is processed. Between 600 and 1600 more counts per minute were generated with the sampling frequencies 40 Hz and 100 Hz compared to 30 Hz during running.

Sampling frequency affects the processing of ActiGraph acceleration data to activity counts. Researchers need to be aware of this error when selecting sampling frequencies other than the default 30 Hz.

Keywords: Accelerometer, physical activity, frequency, amplitude, oscillation, mechanical, walking, running.

Introduction

Accelerometers are commonly used to provide objective measures of physical activity (19). The ActiGraph is one of the most utilised accelerometer and its output measure activity counts is employed in a vast number of studies to assess total physical activity and to derive measures of time spent at different physical activity levels (e.g. moderate and vigorous physical activity). The activity counts reflect both the amplitude and frequency of movements and are generated through several processing steps from the raw acceleration signal (9, 20). For the original model AM 7164 most of the signal processing is performed on the monitor, while for the more recent models GT3X+ and wGT3X-BT some of the processing steps have been moved to the data analying software ActiLife as it facilitates the use of raw data (9). Although some insight into the processing characteristics have been provided from research and from the manufacturer, we still lack a lot of information to fully understand and to improve the performance of the ActiGraph.

One of the most investigated processing step is the ActiGraph signal frequency bandpass filtering. The purpose of this filtering is to attenuate unwanted acceleration signals outside the frequency range of normal human movements. Previous research has shown a plateau/inverted U phenomenon with the ActiGraph activity counts, with the highest values reached when running at 10-12 km·h^{-1} and thereafter an inverse curvilinear relationship with higher running speeds (5, 8, 10, 17, 18). This response pattern is caused by the signal frequency bandpass filter (10). The function of this filter is proprietary information, although some characteristics are presented by the manufacturer in form of the passband range (AM7164, 0.21-2.28Hz; GT1M/GT3X/GT3X+/wGT3X-BT, 0.25-2.50Hz). However, this information may mislead investigators to believe that only movements outside this frequency range are attenuated. In fact, the movement signal is attenuated according to a weighting function with the full weight (1.0) set at 0.75Hz, and with successively reduced weight with higher or lower movement frequencies (20). Hence, acceleration signals corresponding to vigorous physical activity will be eliminated with the signal frequency bandpass filter, as they occur with frequencies above 2.3 Hz (5, 7, 10, 18).

The responsiveness to the acceleration amplitude (dynamic range, g) and signal frequency (sampling frequency, Hz) has evolved with the progression of newer ActiGraph models: AM7164, 0.05-2.13g/10Hz; GT1M, 0.05-2.5g/30Hz; GT3X, ±3g/30Hz; GT3X+, ±6g/30-100Hz; wGT3X-BT, ±8g/30-100Hz. The option with different sampling frequencies (30-100 Hz) in the more recent models may require different filter processings (e.g. down-sampling). Incorrect settings of the filters or omission of some filter components may affect subsequent signal processings (13) and the generation of activity counts. Potential errors from the use of different sampling frequencies have not been investigated previously.

The performance of the ActiGraph has been evaluated under controlled conditions using mechanical oscillators with signal frequencies up to 4 Hz (4, 11, 16, 17). The vertical acceleration amplitude and step frequency of human ambulatory walking and running have been reported to range between 1-3 g and 1.4-3.4 Hz, respectively (5-7, 12, 14, 15). However, the frequency content of ambulatory movement goes far beyond 3.4 Hz; up to 100 Hz has been reported (1, 10). Therefore, the aim of the present study was to investigate the effect of sampling frequency on the ActiGraph activity counts generated from a broad range of signal frequencies.

Materials and methods

Experimental design

This study was performed during autumn 2014 and spring 2015. None of the experiments performed herein required registration to the ethics committee according to a decision by the Ethics committee of the region of Southern Denmark. Three different experiments were performed to target our research aim:

Experiment 1: Synthetical oscillations

Raw sinusoidal acceleration data with a peak amplitude of ±1 g were generated synthetically at different signal frequencies between 0-15 Hz for each of eight sample frequencies available with the ActiGraph monitor. This setup generates ideal acceleration recordings free from measurement errors and not influenced by any processing in the ActiGraph monitor.

Experiment 2: Mechanical oscillations

Vertical spinnings of two GT3X+ monitors was performed to generate sinusoidal acceleration data with a peak amplitude of ±1 g and with signal frequencies between 2-15 Hz. Multiple runs were performed with all pairwise combinations of sampling frequencies available with the ActiGraph monitor. Differences in results between experiment 1 and 2 may indicate processings of the raw data in the GT3X+ monitor.

Experiment 3: Outdoor walking and running

Acceleration data were collected from 20 subjects during walking and running with two GT3X+ monitors at the waist. One of the monitors was set to the default 30 Hz sampling frequency. The other monitor was set to either 40 Hz or 100 Hz sampling frequency, with random allocation among the 20 subjects. This third experiment was employed to confirm the results from the other two experiments under real conditions.

ActiGraph GT3X+ accelerometer and ActiLife Data Analysis Software

The ActiGraph GT3X+ (ActiGraph, Pensacola, FL, USA) is a tri-axial micro-electro-mechanical system (MEMS) based accelerometer, recording accelerations ranging in magnitude of ±6g with a sampling frequency that can be preset from the default 30 Hz up to 100 Hz. Data stored on the non-volatile flash-memory is downloaded to a computer for post-processings in the ActiLife Data Analysis Software. The standard proprietary algorithm filters the signals at a passband ranging from 0.25 to 2.5 Hz. In the present study the ActiLife 6.11.4 software version was used (released in September 2014).

Experimental procedures

In the first experiment, eight GT3X binary data files were generated in MATLAB R2011 (MathWorks, Natick, MA, USA). Each data file was generated with one of eight different sampling frequencies corresponding to the options of the GT3X+ minitor (30, 40, 50, 60, 70, 80, 90 and 100 Hz). The file contained raw sinusoidal acceleration data with a peak to peak amplitude of ±1 g with the signal frequency increasing in 0.12 Hz incremental steps of 2 minutes duration from 0 Hz to 15 Hz, providing 128 different signal frequencies. The 0-15 Hz signal frequency range was selected for all sampling frequencies used in order to comply with the Nyquist-Shannon sampling theorem (13). Accordingly, the lowest sampling frequency of the GT3X+ monitor (30 Hz) determined the highest signal frequency to be detected (15 Hz). Figure 1A displays raw sinusoidal acceleration data (g) generated at four of the 128 different signal frequencies. This is how the ideal acceleration signal looks like before being processed in the ActiLife software, without any attenuation of the signal depending on signal frequency.

In the second experiment a spinning system was set up with a vertical rotational arm and fixed mounting positions for a GT3X+ monitor at each end of the arm. The distance (radius) from the MEMS accelerometers to the rotational center was 40 mm. Two GT3X+ monitors were used in this experiment. The central shaft of the arm is secured to DC-brushless gear motor (model 9.68:1 25D, Pololu Corp., Las Vegas, NV, USA; www.pololu.com) with a 464.64 counts/revolution encoder in combination with a Pololu motor controller (model JRK 21v3). The motor controller was connected through USB to a host computer in order to set up an automated testing protocol. The automated protocol was developed using the available JRK Configuration Utility and the official C# library together with Microsoft Visual Studio Express (Microsoft Corp., Redmond, WA, USA; www.visualstudio.com). The PID regulation time was set to 10 msec to give smooth rotation with minimal jerks and movement artifacts during rotations. This spinning system allowed the change of the angular velocity in 16 incremental steps, providing a 0.85 Hz increase in the signal frequency for each step from 2.12 Hz to 14.87 Hz. Each signal frequency was generated for 1 minute. At the first run of the 16 frequencies, both monitors were set to the sampling frequency of 30 Hz. For the other runs, the sampling frequency was changed for one monitor at a time while the other remained at 30 Hz. A total of 15 runs each containing 16 signal frequencies were performed for each GT3X+ monitor (8 runs with 30 Hz sampling frequency + 7 runs with the other 7 sampling frequencies).

The vertical rotation consists of two components contributing to the total acceleration (A) according to following relationsship: $A = g \cdot \sin\omega t + r \cdot \omega^2$, where ω is the angular velocity, t is time and r is the distance (radius) to the rotational center (3, 20). The first component of the equation ($g \cdot \sin\omega t$) reflects how the gravitational acceleration (g) varies sinusoidally between

-1 g and 1 g generating a signal frequency determined by the angular velocity ($f_s = \omega \cdot (2 \cdot \pi)^{-1}$), and the second component ($r \cdot \omega^2$) is the radial (or centrifugal) acceleration. The first component allows the investigation of the separate effect of signal frequency on the generation of activity counts. The raw sinusoidal acceleration data generated from one of the GT3X+ monitors at four of the 16 different signal frequencies is presented in Figure 1B. Like the raw data generated with MATLAB (Figure 1A), the signal amplitude is the same across signal frequencies.

In the third experiment, twenty students were recruited from the physical education program at the institution. They were informed about the experiment and provided their consent before participation. The subjects performed simultaneously and at the same pace walking and running on a 400 meter running track. They wore two GT3X+ monitors adjecently attached, but without contact to each other, to an elestic belt over the right hip. The two monitors were set to different sampling frequencies (30 Hz and 40 Hz, or 30 Hz and 100 Hz). The order of the paces was randomized into following protocol:

1. Slow walk, 400 m
2. Pause, 10 sec
3. Slow run, 400 m
4. Pause, 10 sec
5. Fast run, 200 m
6. Pause, 10 sec
7. Fast walk, 200 m

Data post-processing and statistical analysis

Recordings from all three experiments were stored into the ActiLife raw binary .gt3x format. The files were thereafter processed in the ActiLife software set to generate activity counts in 10-second epochs, which would provide sufficient resolution for our analyses (setting the epoch is required by the ActiLife software to generate activity counts). However, we chose to aggragate data and present it as counts per minute (cpm), as this is the variable most researchers are used to. For MATLAB generated data, the integrity of the raw binary .gt3x files was confirmed by converting them into comma-separated values (CSV) files and comparing them to the original data. The initial and ending 5 seconds of the GT3X+ raw data from the walking and running experiment were remowed in order to not enter into the analyses the specific acceleration pattern from the initiation and stop of movement. 30 Hz sampling frequency is the default setting for the GT3X+ monitor and was used as reference in this study to compare the output from the other sampling frequencies to. The setup in experiment 2 also allowed us to track the reliability of the system, as the first run was performed with both monitors set at 30 Hz sampling frequency across the signal frequencies generated (inter-monitor reliability) and as one of the monitors remained at 30 Hz sampling frequency across eight repeated runs of signal frequency generation (intra-monitor reliability).

A Bland-Altman plot was used to display the pattern of difference between sampling frequencies in the generation of activity counts across the four activity intensities in experiment 3 (2). A paired t-test was used to assess statistical difference in activity counts between sampling frequencies for experiment 3, with 30 Hz sampling frequency as reference. Statistical analyses and generation of graphs were performed using SPSS Statistics 23.0 (IBM Corporation, Armonk, NY, USA).

Results

Experiment 1

When the binary .gt3x files created from MATLAB were processed in the ActiLife software, different patterns were observed (Figure 2). All sampling frequencies generated the same activity counts up to a signal frequency of 5 Hz. With the sampling frequencies 30, 60 and 90 Hz, no activity counts were generated from signal frequencies above 5 Hz. With these sampling frequencies, Figure 2 demonstrates the intended attenuation by the signal frequency bandpass filter up to a signal frequency of 15 Hz. However, with the sampling frequencies 40, 50, 70, 80 and 100 Hz, activity counts were generated to a varied degree from signal frequencies above 5 Hz, adding to the total activity counts.

Experiment 2

The vertical spinning of the GT3X+ monitors demonstrated high intra-monitor reliability across eight repeated runs with 30 Hz sampling frequency. This is shown in Figure 3 by the low values of the 2SD error bars for signal frequencies generated from 2.1 Hz up to 14.9 Hz. This figure also demonstrates the high inter-monitor reliability with almost identical mean values across the signal frequency range. The mean of the two monitors was therefore used to present the effect of sampling frequency in experiment 2 (Figure 4). The vertical spinning of the GT3X+ monitors comfirmed the variation in activity counts due to sampling frequency observed in experiment 1. However, less activity counts were generated with no activity counts from signal frequencies above 9 Hz. In both experiments, 40 Hz sampling frequency contributed to the largest amount of activity counts followed by 70 Hz and 100 Hz.

Experiment 3

In this experimental setup the inter-subject variation in the activity counts and in the effect of sampling frequency during walking and running was explored. Figure 5 presents the activity counts generated across the four paces for the 20 subjects as well as the mean of the group using the GT3X+ default sampling frequency of 30 Hz. The speeds at the four paces were determined to be 4, 7, 8 and 17 $km \cdot h^{-1}$. In all subjects the activity counts increased up to slow run, followed by a decrease in almost all subjects for fast run. There was a large inter-subject variation at all paces. The largest difference between two subjects was found at fast run and reached 5454 counts per minute.

Figure 6 presents Bland-Altman plots, with the mean of the activity counts (counts per minute, cpm) generated with the two sampling frequencies on the x-axis and the difference in activity counts on the y-axis. The sampling frequency 30 Hz was used as reference. There were small differences at group level in activity counts for sampling frequency 40 Hz compared to 30 Hz for slow walk (+90 cpm, P=0.35), fast walk (+180 cpm, p=0.32) and slow run (+103 cpm, p=0.63). However, the difference reached +1601 cpm (p<0.001) at fast run. A somewhat different pattern was obsereved with the sampling frequency set to 100 Hz. While there were still small differences at slow walk (+47 cpm, p=0.41) and fast walk (+121 cpm, p=0.31), large differences accorred at both slow run (+611 cpm, p=0.14) and fast run (+1238 cpm, p=0.005). Figure 6 also demonstrates large inter-subject variation in the difference between the sampling frequencies. For some subjects, a sampling frequency of 40 Hz or 100 Hz contributed to 1000-3000 more cpm compared to 30 Hz, while for others the differences were minimal.

Complex movements generate a spectrum of signal frequencies. Analysis of the signal frequency spectrum can help to explain the inter-subject variation in the difference in activity counts due to sampling frequency. Figure 7 displays the signal frequency spectrum registered by the GT3X+ set at 30 Hz sampling frequency during walking and running of one subject selected for having minimal variation in activity counts due to sampling frequency (Subject 1, 40 Hz versus 30 Hz sampling frequency). This subject was compared to a subject selected for having a large variation in activity counts due to sampling frequency for fast run (Subject 2, 40 Hz versus 30 Hz sampling frequency). Both subjects had their dominant signal frequency peak below 2 Hz during slow walk with minimal frequency content at higher signal frequencies (Figure 7A). During fast walk the dominant signal frequency peak passed 2 Hz and some frequency content became more apperent at higher signal frequencies but with low amplitudes (Figure 7B). The dominant signal frequency peak during slow run approached 3 Hz with more of the frequency content at higher frequencies but still with relative low amplitudes (Figure 7C). For each of these paces there were minimal difference between the two subjects in their signal frequency spectrum and also in the variation in activity counts due to sampling frequency.

However, a different pattern was observed for fast run (Figure 7D). At this pace Subject 1 had its dominant signal frequency peak at 4 Hz with a large amount of low-to-medium amplitude signal frequency content at higher frequencies. Subject 2 demonstrated considerable higher amplitudes of the dominant signal frequency peaks. Some of these peaks occured at the signal frequencies demonstrated in experiment 1 and 2 to contribute to the additional activity counts, i.e. at 8-10 Hz. The amplitude of these signal frequency peaks was considerable higher compared to the peaks at 2 Hz or 3 Hz.

Discussion

This study showed that with the default 30 Hz (or 60, 90 Hz) sampling frequency most of the acceleration signals generated from movements corresponding to vigorous physical activity were eliminated with the ActiGraph signal frequency bandpass filter. However, when other sampling frequencies were used, a considerable amount of unwanted signals escaped the filter and contributed to the activity counts generated. Although, the effect of the sampling frequency was less pronounced when activity counts were generated from ActiGraph recordings compared to when generated from an external source, indicating unknown processings of the raw accelerometer data in the ActiGraph monitor.

Much of the the processing of ActiGraph acceleration data is proprietary information and the results from the present study cannot tell us at what specific processing step the error of the sampling frequency arise. As the error occurred with both ideal acceleration signals and acceleration signals recorded with the GT3X+ monitor, it seems that the processing step(s) affacted would be located in the ActiLife software. It can only be speculated why the attenuation is not similar for different sampling frequencies but the ringing effect observed might be related to either resampling or filter type. The origianl AM7164 monitor generates activity counts by digitizing the analogue bandpass-filtered acceleration signal using a sampling frequency of 10 Hz followed by retification and integration into user-selectable epochs (e.g. counts per 10 seconds or counts per minute) (20). It is plausible that this signal processing is preserved in the newer models with the difference that the bandpass filtering has been moved to post-digitization and to ActiLife. As the sampling frequency is user-selectable at 30-100 Hz, down-sampling to 10 Hz is needed. Down-sampling requires low pass anti-aliasing filtering to ensure that the Nyquist-Shannon sampling theorem is obeyed (13). Data down-sampled to 10 Hz requires a low pass filter with a signal cut-off frequency of 5 Hz or below before resampling. The degree of attenuation of data above the low pass filter cut-off has to be selected with respect to how close the cut-off frequency is to the half sampling frequency. If the low-pass filtering is omitted, high frequency components could potentially generate the ringing effect we see with the frequency data. Digital signal processing offers several methods of filtering. Common filter types are the Finite Impulse Response (FIR) or the Infinite Impulse response (IIR) (13). Both filter types are implemented in the time domain using a transfer function with a selected number of filter coefficients. The number of coefficients and their values define how the filter responds when data is entered in the filter. Some filter-type implementations can have severe issues with ringing in the frequency range above the cut-off value and the amount of ringing has to be minimized by properly adjusting the filter coefficients with respect to the sampling frequency (13).

Processings in the GT3X+ monitor seems to compensate for some of the effect due to sampling frequency, as the amount and pattern of the activity counts generated with the GT3X+ monitors differed from the activity counts generated from ideal acceleration signals. This implies that the .gt3x raw data file is not in reality ”raw”. The access to unfiltered raw accelerometer data facilitates interpretation and comparability to other monitors. There are several brands of accelerometers today. If, for example, the dynamic range (e.g. ±6g) and sampling frequency (e.g. 30 Hz) are the same for collections of accelerometer data using different brands, processing of the two sources of unfiltered raw data in the ActiLife software to generate activity counts and other secondary variables (e.g. time spent in vigorous physical activity) would be tenable. A previous study compared the GT3X+ monitor to the GENEA monitor in raw acceleration data generated in a horizontal mechanical shaker at signal frequencies ranging from 0.7 Hz to 4.0 Hz. Both monitors were set to sample data at 80 Hz (11). Significantly lower values were generated from the GT3X+ monitor at all signal frequencies. The authors speculated that one possible cause would be different settings of the low pass anti-aliasing filter that minimizes distortion of the signal during analog to digital conversion, which are proprietary information.

The results from the present study and previous research (4, 5, 8, 10, 11, 17, 18) have serious implications on the reliability of the ActiGraph acceleration data to be used for measures of physical activity. If activity counts are generated from GT3X+ data collected with the default 30 Hz (or 60, 90 Hz) sampling rate, most of the acceleration signals corresponding to vigorous physical activity would be eleminated. Step frequencies for walking have been reported as 1.4-1.5 Hz for 3 $km \cdot h^{-1}$ up to 2.2 Hz at 7 $km \cdot h^{-1}$ (5, 6, 10, 18). These walking intensities would range from light to moderate physical activity. According to the present study and previous studies (4, 17, 20), a large part of the acceleration signal for these activity intensities would still be left after processing through the signal frequency bandpass filter. However, step frequencies for running have been reported from 2.3 Hz at 8 $km \cdot h^{-1}$ to 3.2 Hz at 20 $km \cdot h^{-1}$ (5, 7, 10, 18), where at least 50 % of the acceleration signal is attenuated by the signal frequency bandpass filter. The consequences are that the activity counts may be of limited use to determine the variation of vigorous physical activity in the population and its contribution to the health effects of physical activity. Further, the option to select sampling frequency has large impact on physical activity output data and introduces a random error that will decrease comparability between measures using different sampling frequencies.

Therefore, full insight into the different processing steps from the acceleration signal to the final physical activity measure would facilitate the work to eliminate some of the errors with the ActiGraph acceleration data identified in the research and to support the improvements of the ActiGraph to become a more reliable method to measure physical activity. In the meantime, to be able to compare ActiGraph data we suggest using the same sampling frequency across waves of measurements. The choice of sampling frequency depends on the purpose of data collection. If the goal is to compare new data with data collected using previous ActiGraph models and/or to employ algorithms/cutoffs for physical activity levels (e.g. moderate and vigorous physical activity) developed from previous ActiGraph models, the recommendation is to use the default 30 Hz (or 60, 90 Hz) sampling frequency. Even with this option, one needs to be aware of that ActiGraph models may differ in responses to and processings of acceleration signals (1, 10). If data is already collected with other sampling frequencies than the default 30 Hz (or 60, 90 Hz), one has the option to perform down-sampling. However, this option requires expertise in signal processing and the proper use of filters for accurate results (1, 10), as indicated by the results in the present study.

Strenghts and limitations

The study design with three different expreimental setups allowed us to demonstrate the effect of the sampling frequency with non-processed raw acceleration data compared to the raw acceleration data from the GT3X+ monitor, and the consequences for real human movements. The wider range of signal frequency explored compared to previous research was required to achieve these results. A high reliability of the spinning setup for repeated and concurrent recordings could be confirmed from the minimal intra- and inter-monitor differences. Still, the importance of the findings for the assessment of the habitual physical activity needs to be determined.

Conclusions

Sampling frequency affects the processing of ActiGraph GT3X+ raw acceleration data to activity counts, but this effect is compensated to some degree by processings performed in the GT3X+ monitor. Researchers need to be aware of the error when selecting sampling frequencies other than the default 30 Hz. With the 30 Hz (or 60 Hz, 90 Hz) setting, the generation of activity counts performs as intended with most of the acceleration signals corresponding to vigorous physical activity eleminated by the signal frequency bandpass filter. However, with other sampling frequencies there is an escape of these acceleration signals from the bandpass filter to a varied degree, contributing to additional activity counts.

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Disclosures

The authors disclose no conflicts of interest.

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Figure captions

Figure 1

Raw sinusoidal acceleration data generated in increasing incremental signal frequency steps from MATLAB (1A) and from the spinning of GT3X+ monitors (1B). Data from four different signal frequencies are presented as examples to demonstrate how the peak signal amplitude (±1 g) is the same across signal frequencies before being processed in the ActiLife software. Note that the frequencies are not displayed to be true representations of the real signal frequencies.

Figure 2

Activity counts produced by the ActiLife software from oscillations generated in the MATLAB software with a signal frequency range of 0-15 Hz, a peak acceleration amplitude of ±1 g and sampled at different frequencies 30-100 Hz. Note that all sampling frequencies produced identical activity counts up to 5 Hz signal frequency.

Figure 3

Intra- and inter-monitor reliability of activity counts produced by the ActiLife software from mechanical oscillation of two GT3X+ monitors with a signal frequency range of 2-15 Hz, a peak acceleration amplitude of ±1g and sampled at ActiGraph default frequency of 30 Hz. Each line represents mean (2SD) counts per minute of eight repeated recordings by each monitor at each frequency generated. Note that the oscillations produced identical activity counts from the two GT3X+ monitors.

Figure 4

Activity counts produced by the ActiLife software from mechanical oscillations of GT3X+ monitors with a peak acceleration amplitude of ±1 g and a signal frequency range of 2-15 Hz using different sampling frequencies 30-100 Hz. Activity counts are the mean of recordings by the two GT3X+ monitors.

Figure 5

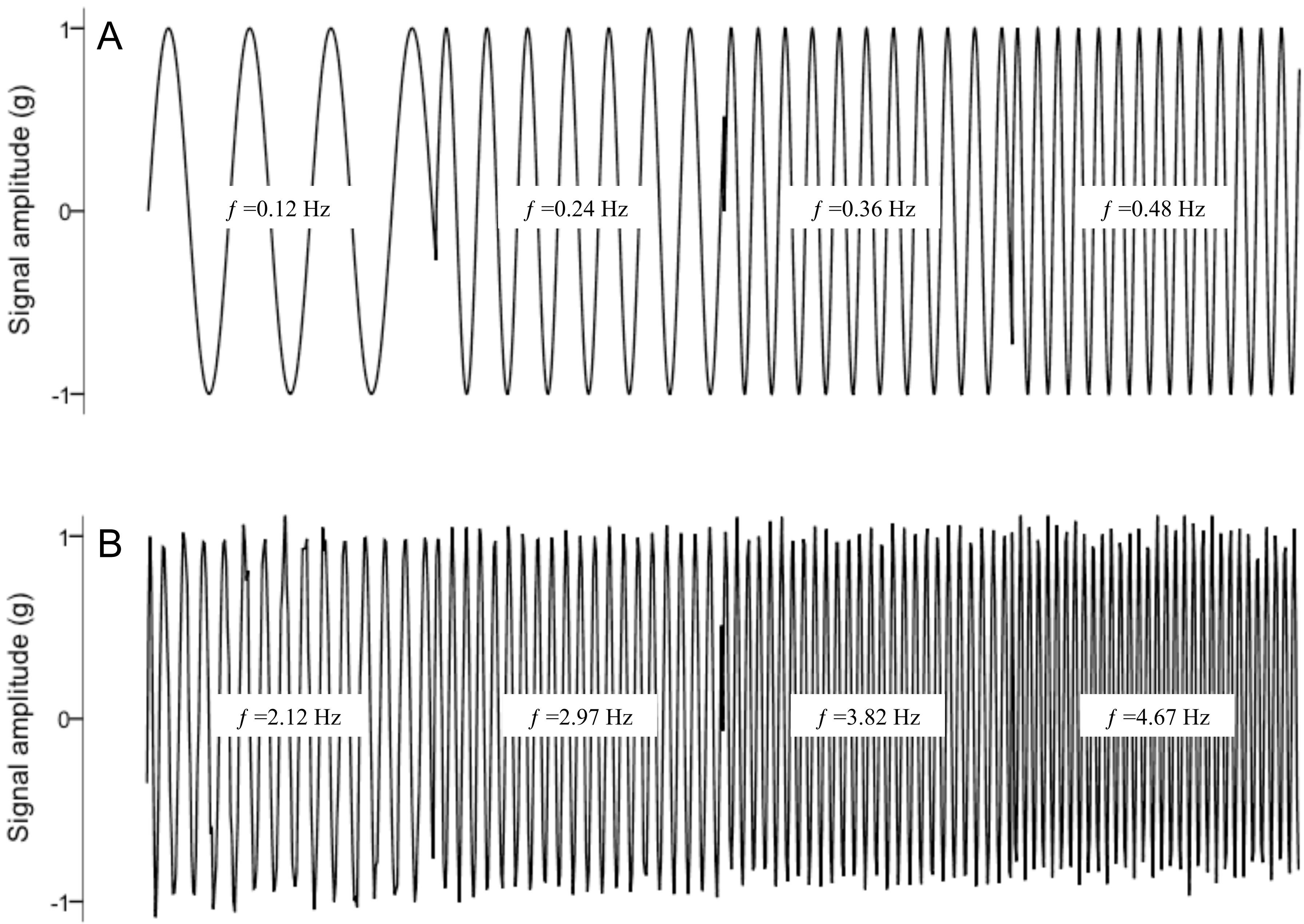
Activity counts produced by the ActiLife software from GT3X+ recordings with the ActiGraph default sampling frequency of 30 Hz during walking and running in 20 subjects. Bold line is the group mean. The speeds of the walking and running correspond to 4, 7, 8 and 17 km·h^{-1}.

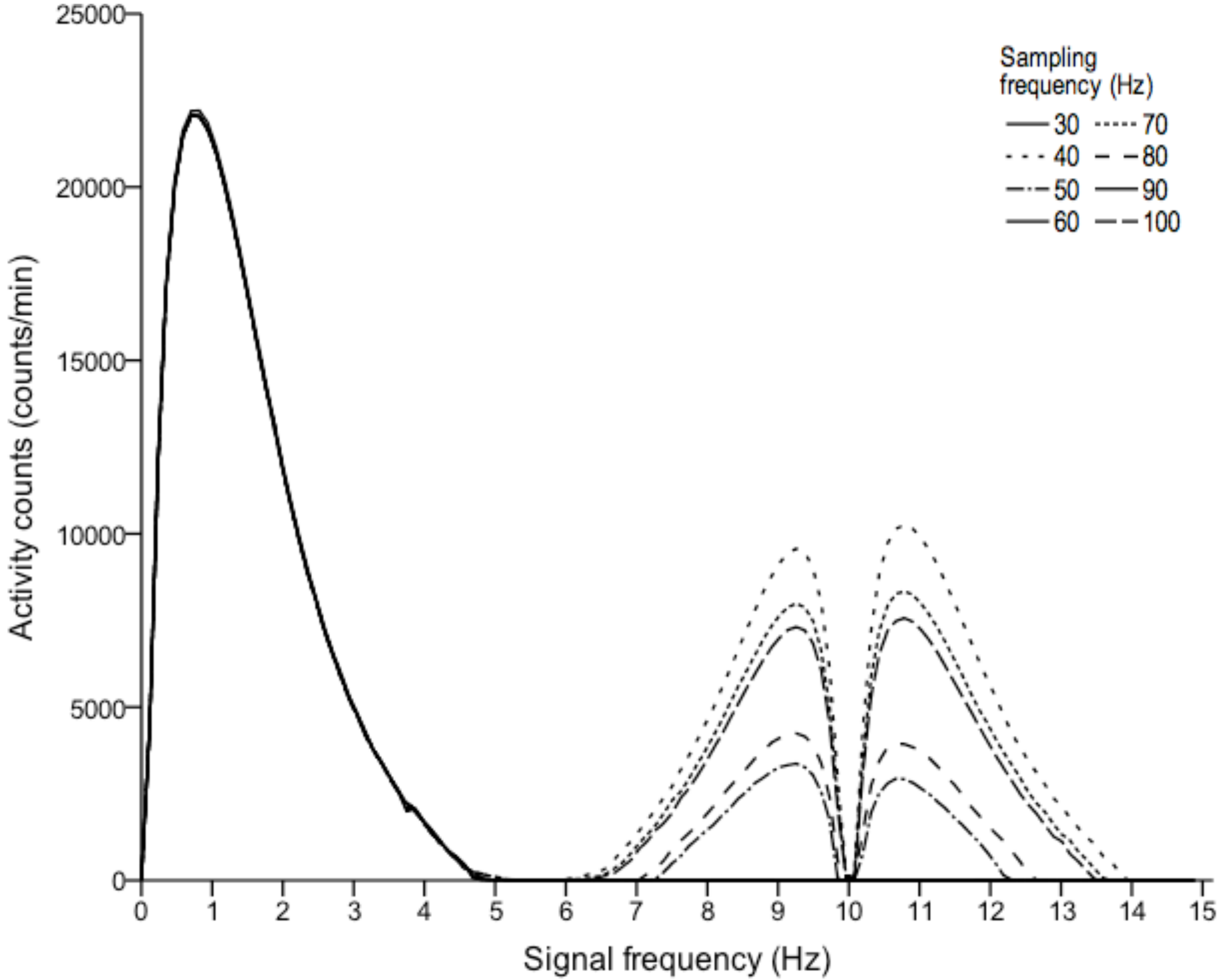
Figure 6

Difference in activity counts due to sampling frequency during walking and running. **A:** 40 Hz versus 30 Hz (10 subjects). **B:** 100 Hz versus 30 Hz (10 subjects). ▯ Slow walk, ◇ Fast walk, ◁ Slow run, ● Fast run. X-axis represents the mean activity counts of the two sampling frequencies and y-axis is the difference in activity counts between the sampling frequencies. Horizontal lines are group mean differences (dashed lines of increasing size are Slow walk, Fast walk and Slow run, and solid line is Fast run). Note that the lowest mean value for Slow walk in Figure 6A consists of two overlapping subjects.

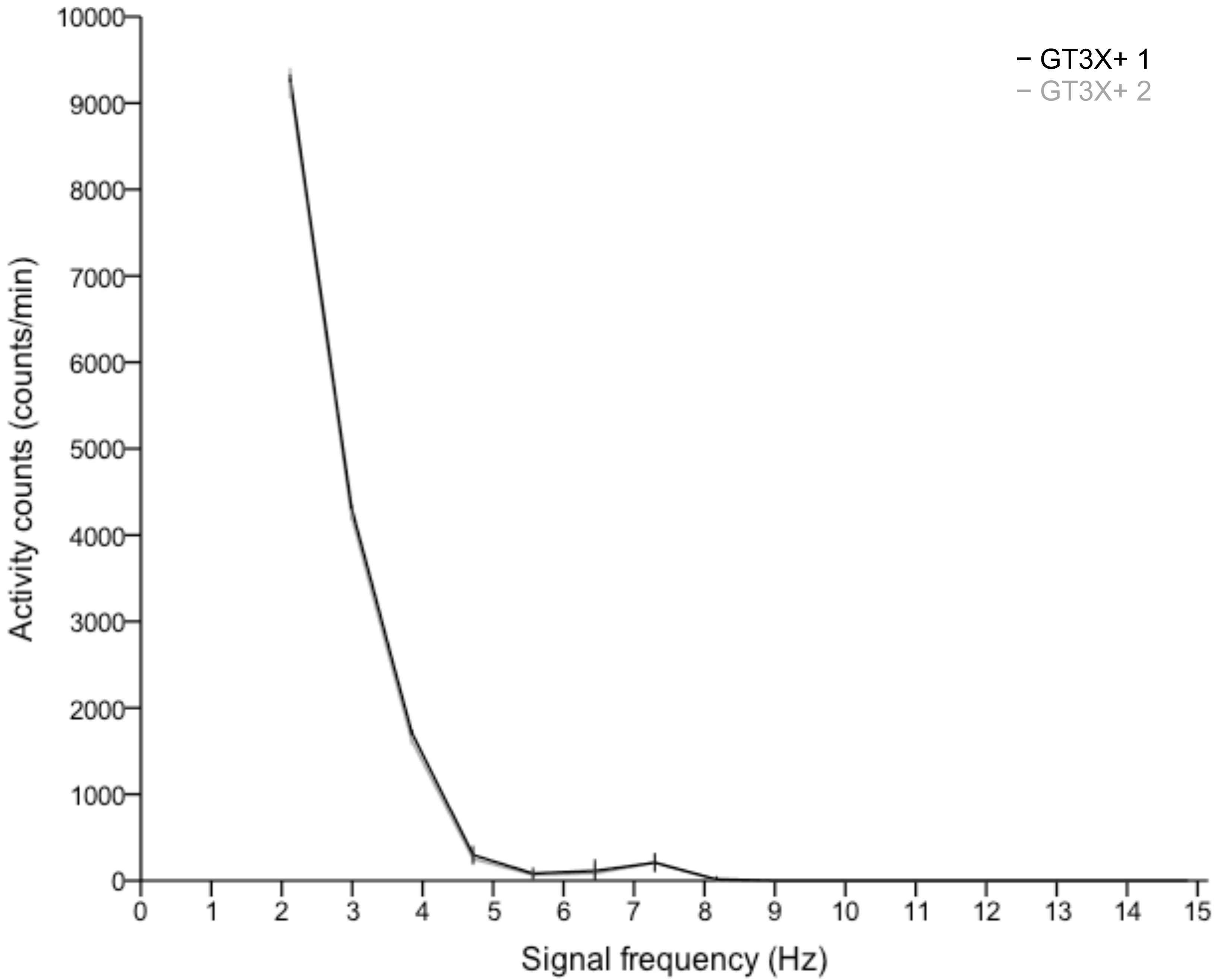
Figure 7

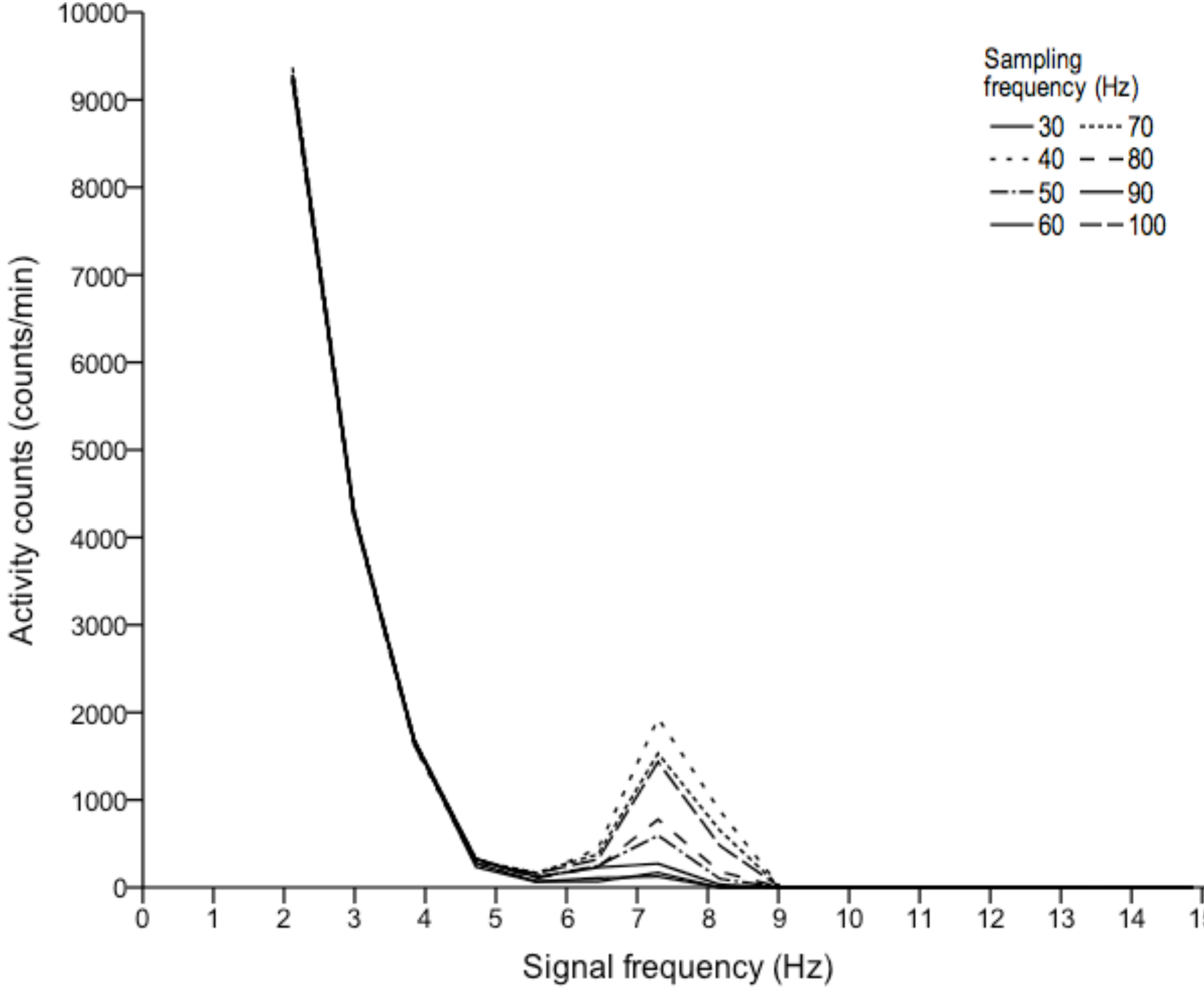
Signal frequency spectrums 0-15 Hz of two subjects. During slow walk **(A)**, fast walk **(B)**, and slow run **(C)** there were only small differences in the frequency spectrums between the subjects. During fast run **(D)**, larger signal frequency amplitudes above 5 Hz were recorded in subject 2 compared to subject 1. In subject 2 there was a large difference in activity counts due te sampling frequency during fast run, but in subject 1 only minimal differences occurred. Note the different scales on the y-axis of Figures 7A-C compared to Figure 7D.

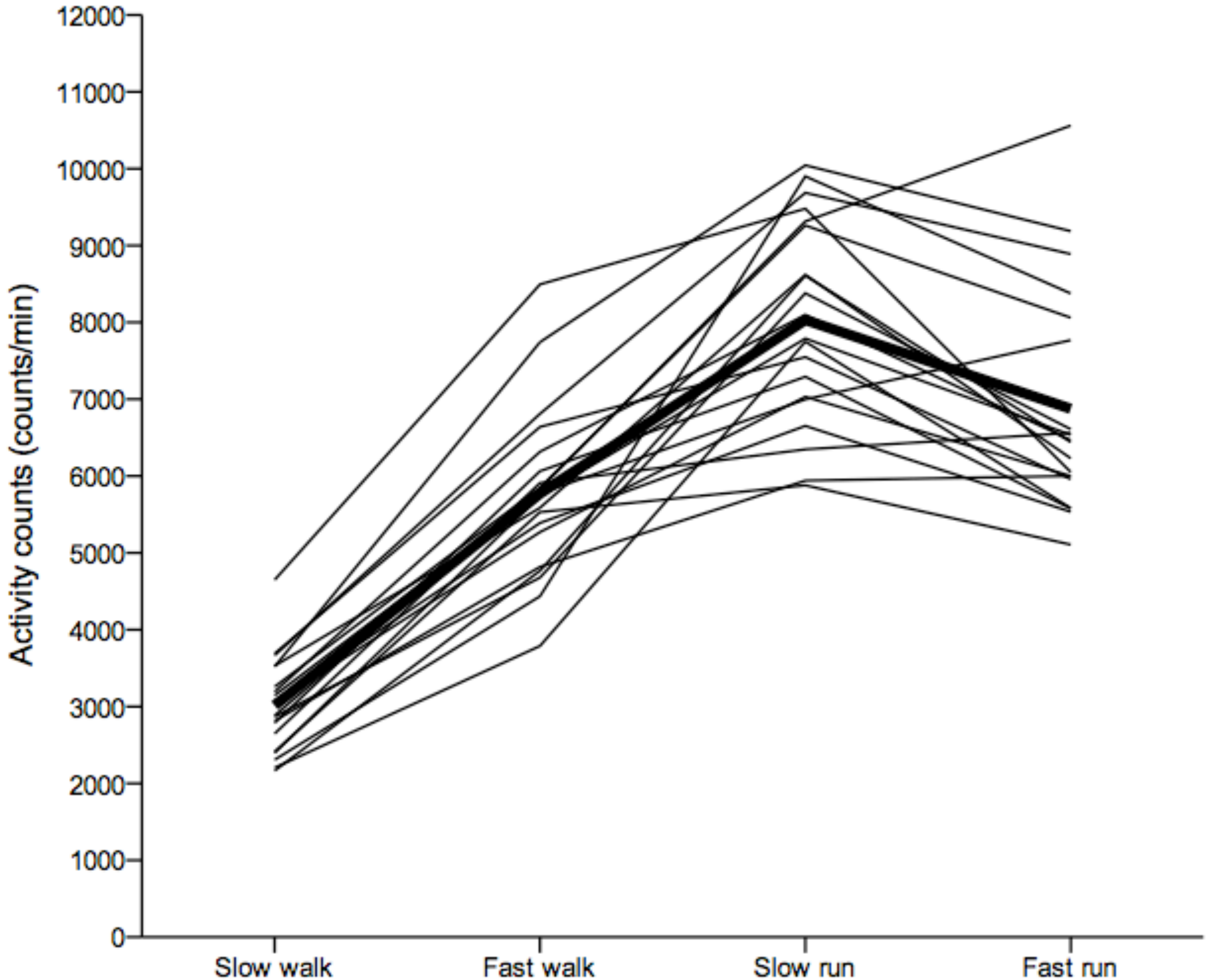

A
Signal amplitude (g)
1
0
-1
f =0.12 Hz
f =0.24 Hz
f =0.36 Hz
f =0.48 Hz
B
Signal amplitude (g)
1
0
-1
f =2.12 Hz
f =2.97 Hz
f =3.82 Hz
f =4.67 Hz



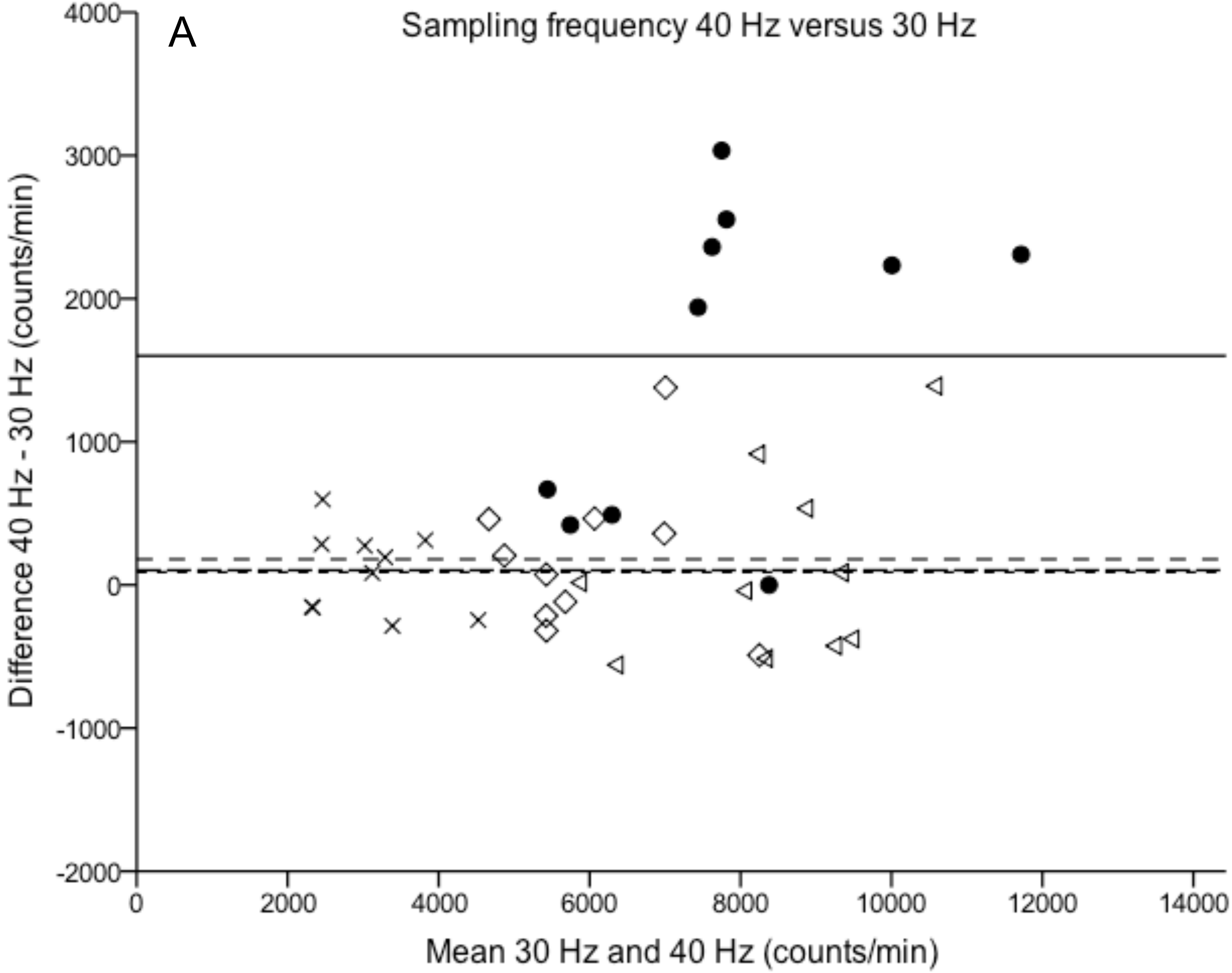
Activity counts (counts/min)
25000
20000
15000
10000
5000
0
Signal frequency (Hz)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Sampling frequency (Hz)
30
40
50
60
70
80
90
100


GT3X+ 1
GT3X+ 2
Activity counts (counts/min)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Signal frequency (Hz)

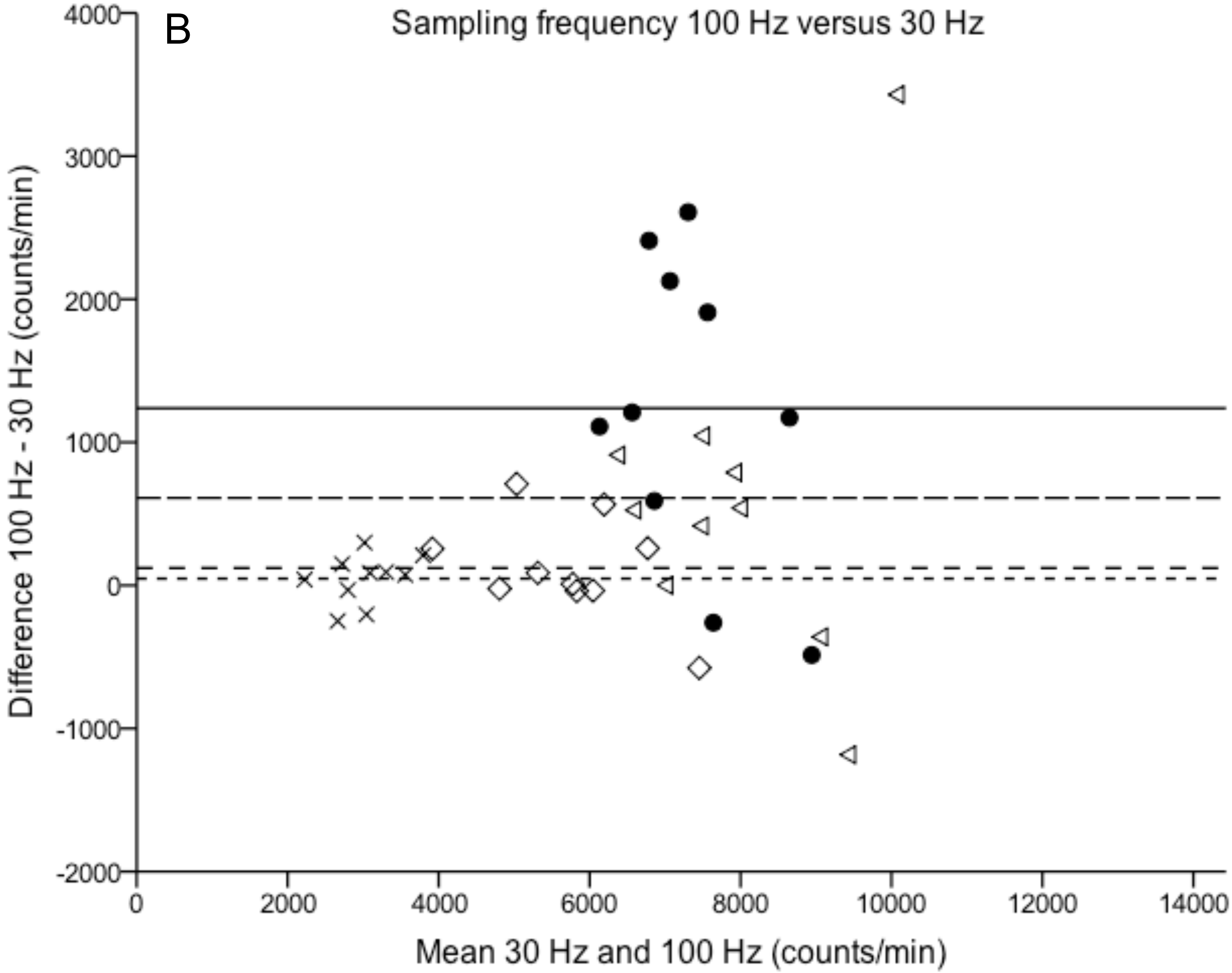

Sampling frequency (Hz)
30
40
50
60
70
80
90
100
Activity counts (counts/min)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Signal frequency (Hz)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

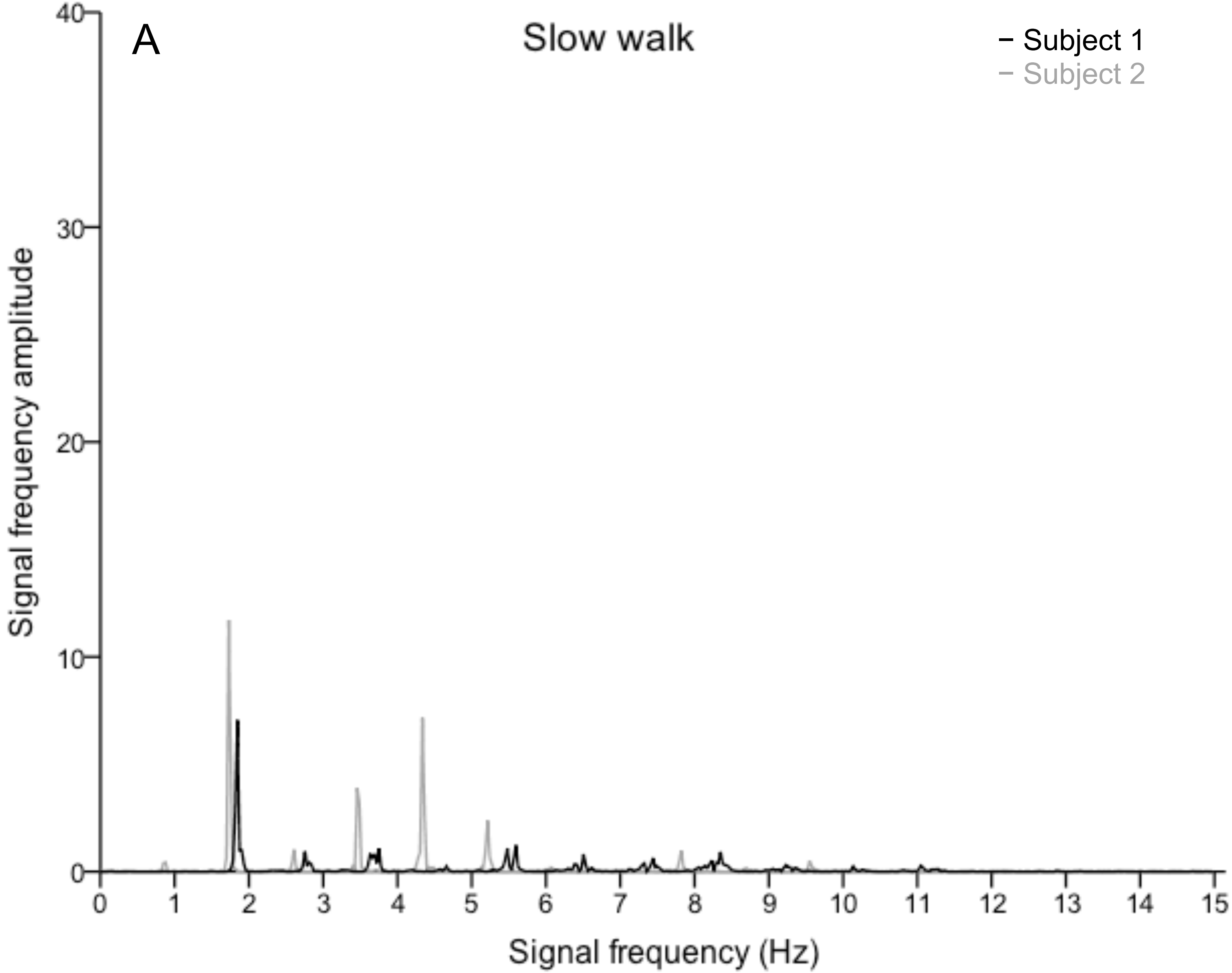


Activity counts (counts/min)
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Slow walk
Fast walk
Slow run
Fast run

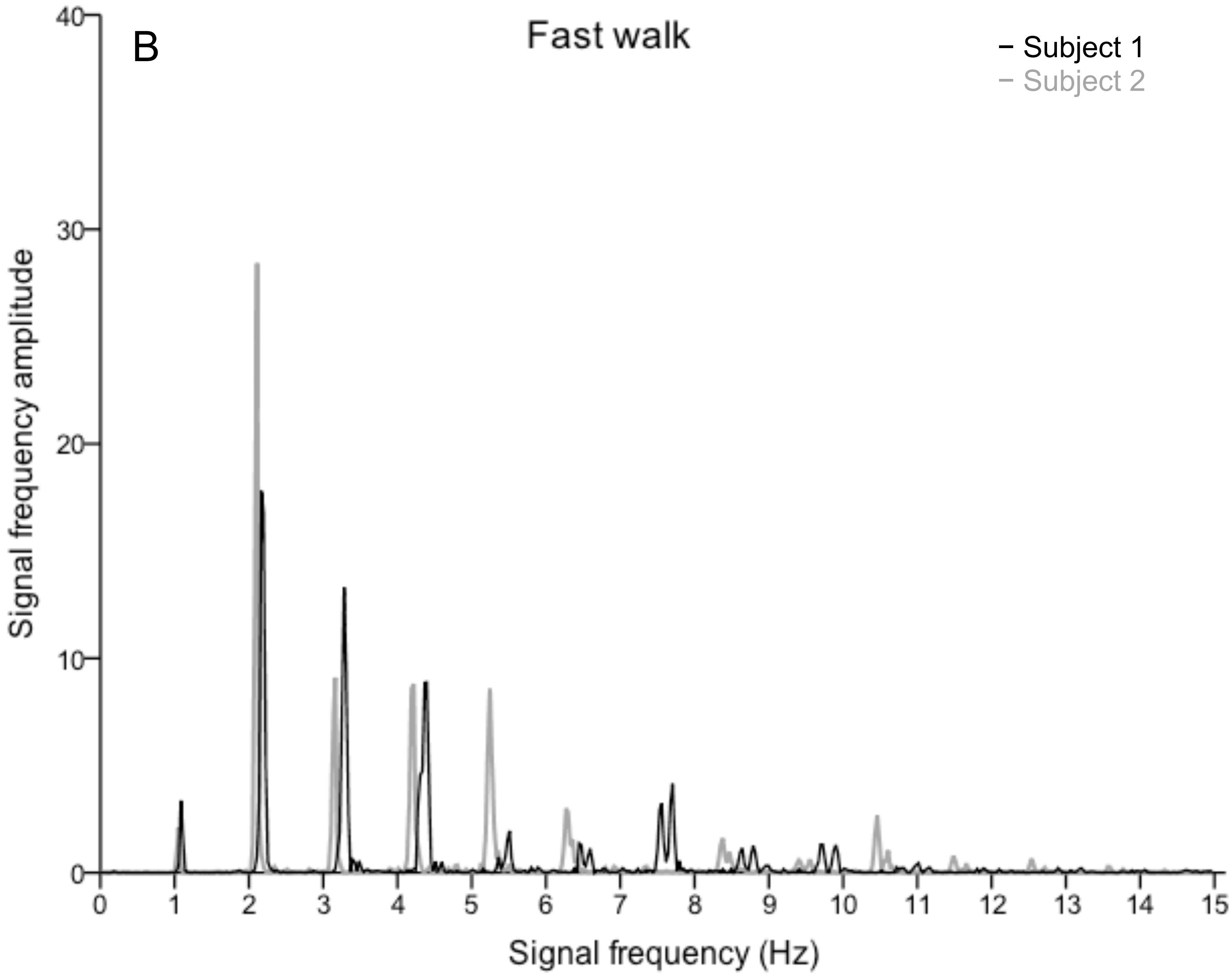


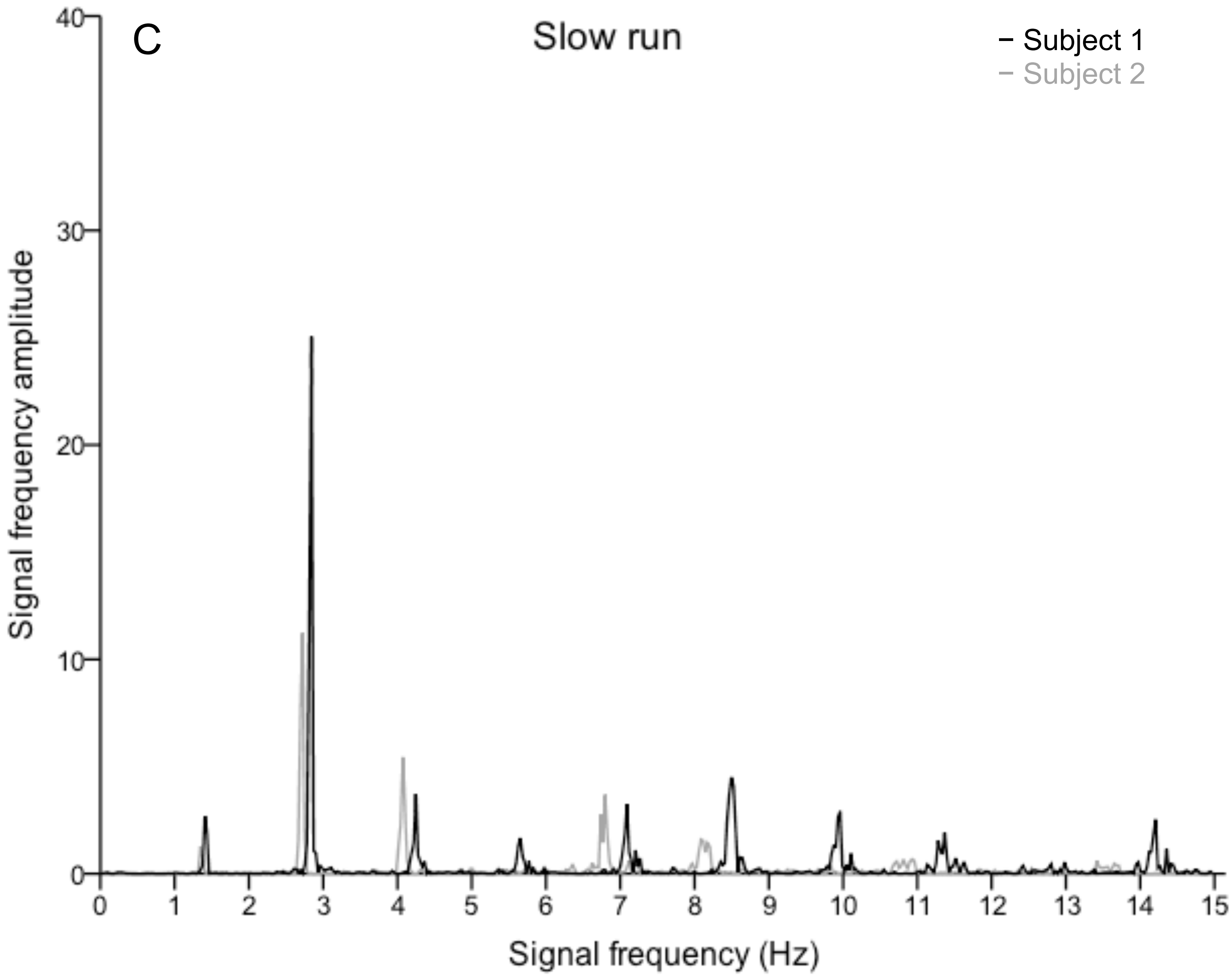
A
Sampling frequency 40 Hz versus 30 Hz
Difference 40 Hz - 30 Hz (counts/min)
Mean 30 Hz and 40 Hz (counts/min)
4000
3000
2000
1000
0
-1000
-2000
0
2000
4000
6000
8000
10000
12000
14000

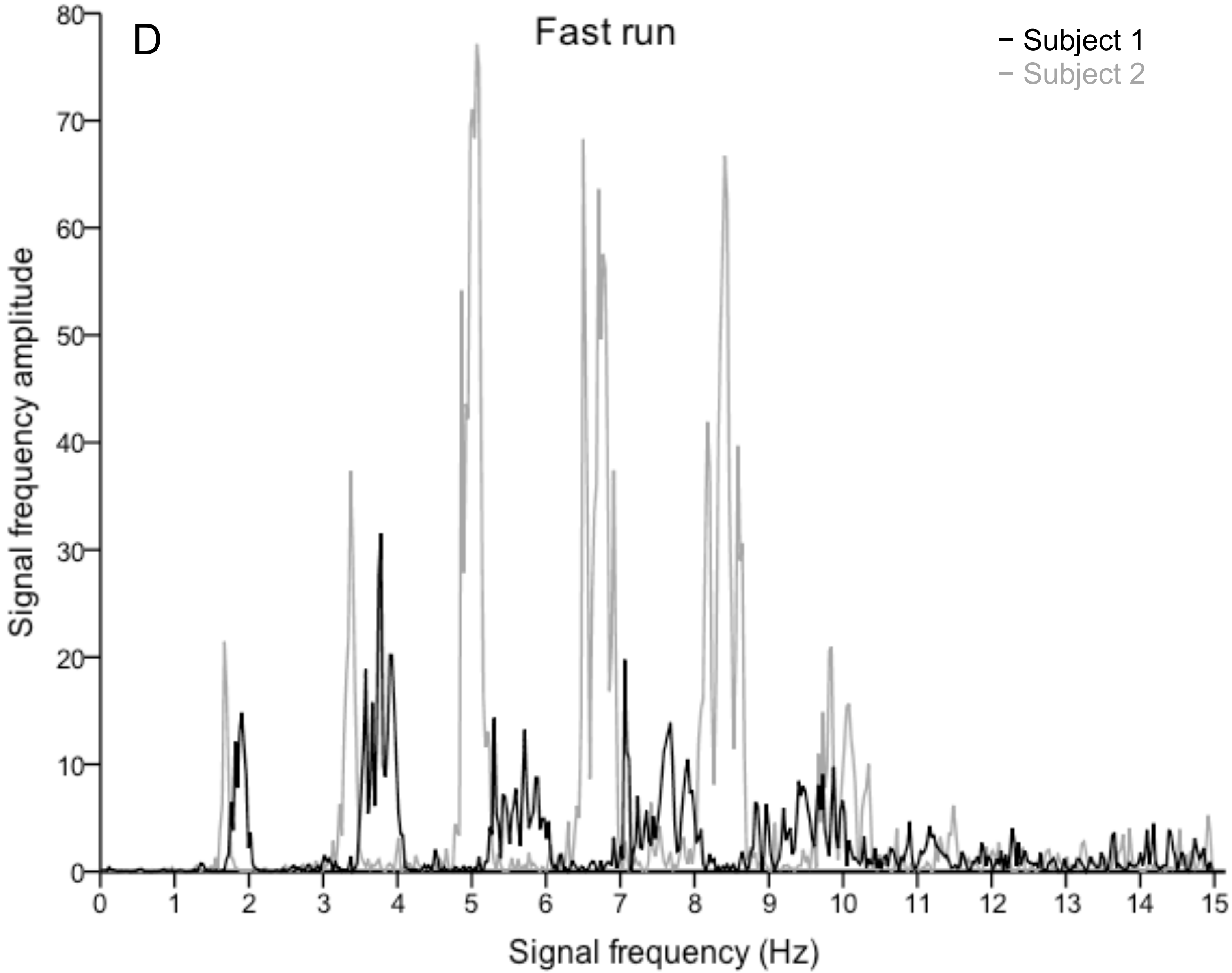

B
Sampling frequency 100 Hz versus 30 Hz
4000
3000
2000
1000
0
-1000
-2000
Difference 100 Hz - 30 Hz (counts/min)
0
2000
4000
6000
8000
10000
12000
14000
Mean 30 Hz and 100 Hz (counts/min)



A
Slow walk
Subject 1
Subject 2
Signal frequency amplitude
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Signal frequency (Hz)


B
Fast walk
Subject 1
Subject 2
Signal frequency amplitude
Signal frequency (Hz)
0
10
20
30
40
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15


C
Slow run
Subject 1
Subject 2
Signal frequency amplitude
Signal frequency (Hz)
0
10
20
30
40
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15


D
Fast run
Subject 1
Subject 2
Signal frequency amplitude
Signal frequency (Hz)
0
10
20
30
40
50
60
70
80
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15