Validity of Fibion Physical Activity Monitor in Measuring Posture and Energy Expenditure During Simulated Daily Activities

Fibion Inc. White Paper

Background. Several accelerometer-based physical activity monitors have been developed to measure habitual activity intensities, but few are capable of categorizing activities. The purpose of this study was to test the validity of Fibion Device in categorizing typical daily activities and in estimating their energy expenditure.

Methods. Activity categorization: 12 adults performed 2 sitting, 1 standing, 7 walking, 6 cycling and 6 running activities while wearing Fibion Device and being recorded on a video for reference data. Seconds at the correct category were compared against video. Studies 2 and 3: 6 (Study 2) and 19 (Study 3) adults performed 3 walking (2, 4 and 6 km/h), 3 running (8, 11 and 14 km/h on a treadmill) and three cycling activities (50W at 40 rpm, 125W at 60 rpm and 200W at 80 rpm on a stationary bike). Physical activity energy expenditure was measured by indirect calorimetry (CORTEX Biophysik MetaLyzer® 3B, Germany, n=6), Actigraph GTX3+, heart rate and compared against Fibion Device (n=19).

Results. Fibion classified 92.8% of samples correctly when worn in the pocket and 97.0% correctly when worn in the thigh strap. When worn in the pocket, standing, walking (at 3-5 km/h) and running (12 and 15km/h) were categorized at 100% agreement, while the lowest agreement values were found for slow running (6km/h, 69,9% running, 30,1% walking) and fast cycling outside (75% cycling, 25% walking). As compared to indirect calorimetry, Fibion energy expenditure estimate was 0,8% lower across all activities, 4,7% lower during walking, 19,7% lower during running, and 17% higher during cycling. As compared to heart rate, Fibion underestimated energy expenditure by -1,6%, as compared -36,7% by Actigraph GTX3+.

Conclusion. Fibion is a valid tool in categorizing sitting, standing, walking, cycling and high-intensity movement and their energy expenditures. Fibion categorized more than 90% of activities correctly irrespective of pocket or thigh wear, and was superior in estimating energy expenditure as compared to Actigraph GTX3+ device.

INTRODUCTION

Physical activity is a well-acknowledged means to decrease the non-communicable disease burden, including obesity, type 2 diabetes, cardiovascular diseases, some cancers and premature mortality[1]. However, the majority of population does not meet the recommended physical activity level for health benefits, defined as 30 minutes of moderate-to-vigorous activity in five days of the week[2]. In addition to physical inactivity, sedentary lifestyle defined as seated or reclined posture expending little energy[3], is highly abundant in todays society. In practice, people are sitting 9-11 hours per day[4] and even those meeting physical activity recommendations appear to not sit any less[5]. Sedentary lifestyle adds to the risk of inactivity. For example, in adults sitting more than 7 hours a day, each additional hour of sitting per day is associated with 5% increased risk of premature mortality independent of moderate-to-vigorous activity[4]. To support interventions targeting increased physical activity or reduced sedentary time, it is useful to know how physical active persons are in daily living. In this way interventions can be tailored to the level of daily physical activity or sedentary time and the needs of an individual. Additionally, the self-monitoring of physical activity can be used to increase self-efficacy[6] and physical activity[7] and the effectiveness of interventions can be objectively measured.

Over the past years several devices have been developed to measure everyday physical activities[8] and are validated against energy expenditure to provide a proxy for physical activity energy expenditure during normal daily activities[9]. However, these devices are often limited to the measures of physical activity intensity without information on actual postures or movements[10], although the definition of sedentary time includes the sitting or reclining as a posture[3]. Thus, already standing is defined as physical activity, although it increases energy expenditure only little[11]. Consequently, some of the widely used devices in scientific research have low validity in measuring changes in sedentary time, resulting in inaccurate evaluation of interventions and associations to health outcomes[12].

The Fibion Device is a relatively new activity monitor being based on a 3D accelerometer like most other activity monitors. However, the Fibion Device in significantly different from the competitors in that it is very small and lightweight and it is prescribed to be worn in the front pocket of trousers. Because of its position, the Fibion Device is capable of detecting a set of body postures and movements, including sitting and standing, and it uses this information to improve the estimate of energy expenditure. However, so far the validity of the device to detect body postures and movements and energy expenditure has not been studied. The purpose of this white paper is to test the validity of the Fibion Device in detecting a set of postures and movements against video recording, and energy expenditure of common everyday activities against indirect calorimetry, heart rate and Actigraph accelerometer, which is the most widely applied physical activity monitor in scientific studies.

METHODS

This study consisted of three measurements, of which each aimed to answer one research question. ***Study 1*** aimed at testing the validity of Fibion Device in detecting a set of postures and activities. ***Study 2*** aimed at comparing the Fibion energy expenditure estimate against indirect calorimetry. ***Study 3*** was conducted to compare the Fibion energy expenditure estimate against heart rate monitor and Actigraph GT3X+ monitor.

The participants for each study were young healthy adults being able to perform the tested activities, including running at high speed. The number of participants considered sufficient to answer each research question was 12, 6 and 19 for studies 1, 2 and 3, respectively.

Study 1 protocol and analysis: validity of Fibion in detecting postures and activities

The participants performed a series of consecutive activities according to a standard protocol. They wore their own clothes and shoes while wearing two Fibion devices: one at the prescribed location (in the pocket), and one attached with a strap to the front of the thigh. During the testing procedure activities were timed with a stopwatch. In addition the activities of the participants were video-taped. All devices were synchronized before each measurement.

The activity protocol consisted of activities being representative for everyday life (Tables 1 and 2). The duration of each activity in the protocol ranged from 30 seconds to 2 minutes. The total measurement time was 1 hour maximally and the participants were offered an opportunity to rest between the activities.

All activities were timed with a stopwatch and filled in a logbook. A handheld digital video camera was used for video recordings, which was used as reference method to categorize activities. Two experienced researchers analyzed the time interval of each performed activity based on the video. Additionally, the researchers ensured that the performed activities were consistent without breaks or interruptions.

For most activities the “correct” classification was clear. For example, walking on a treadmill on different speeds, walking outside the lab, or climbing stairs must all be detected as walking. For some activities this relationship was less clear. Jumping rope is a high-intensity activity, and the detection as "running" was considered as correct. Doing dishes is an activity consisting of standing and walking and therefore the detection of both standing and walking are considered as correct. However, the ratio between these activity categories was assumed to differ such that standing should be more prevalent during doing dishes.

The validity of the Fibion Device as compared to the reference method was determined as follows:

“How many of the actually performed activities were detected correctly by Fibion Device (% of Fibion Device activity output of the actually performed activity based on video)?” (Sensitivity)

In addition, the data from the Fibion Device worn in the front pocket was compared into the Fibion Device worn in the thigh strap.

TABLE 1. The % of correct samples categorized by Fibion Device worn in front pocket against video recording, across the measured activities.

Protocol activity	Video	Sitting	Standing	Walking	Cycling	Running	% correct
Sitting							**92,5**
Easy chair	100,0	90,0	10,0	0,0	0,0	0,0	90,0
Office work	100,0	95,1	4,8	0,1	0,0	0,0	95,1
Standing							**100,0**
Doing dishes	100,0	0,0	91,6	8,4	0,0	0,0	100,0
Walking							**97,4**
Walking 2 km/h	100,0	0,9	4,1	95,0	0,0	0,0	95,0
Walking 3 km/h	100,0	0,0	0,0	100,0	0,0	0,0	100,0
Walking 4 km/h	100,0	0,0	0,0	100,0	0,0	0,0	100,0
Walking 5 km/h	100,0	0,0	0,0	100,0	0,0	0,0	100,0
Walking 6 km/h	100,0	0,0	0,0	90,7	0,0	9,3	90,7
Stairs up	100,0	0,1	3,6	96,3	0,0	0,0	96,3
Stairs down	100,0	0,2	0,0	99,8	0,0	0,0	99,8
Cycling							**82,7**
Cycling hometrainer R1	100,0	4,9	0,4	18,9	75,8	0,0	75,8
Cycling hometrainer R2	100,0	0,0	0,0	20,1	79,9	0,0	79,9
Cycling hometrainer R3	100,0	0,0	0,0	20,0	77,4	2,6	77,4
Cycling outside slow	100,0	3,5	0,0	0,0	96,5	0,0	96,5
Cycling outside normal	100,0	0,0	0,0	8,4	91,6	0,0	91,6
Cycling outside fast	100,0	0,0	0,0	25,0	75,0	0,0	75,0
High-intensity activity							**91,4**
Running 6 km/h	100,0	0,0	0,0	30,1	0,0	69,9	69,9
Running 9 km/h	100,0	0,0	0,0	2,5	0,0	97,5	97,5
Running 12 km/h	100,0	0,0	0,0	0,0	0,0	100,0	100,0
Running 15 km/h	100,0	0,0	0,0	0,0	0,0	100,0	100,0
Sprint	100,0	0,0	2,8	5,8	0,0	91,4	91,4
Jumping rope	100,0	0,0	4,1	6,6	0,0	89,3	89,3
Total agreement							**92,8**

TABLE 2. The % of correct samples categorized by Fibion Device worn in thigh strap against video recording, across the measured activities.

Protocol activity	Video	Sitting	Standing	Walking	Cycling	Running	% correct
Sitting							100,0
Easy chair	100,0	100,0	0,0	0,0	0,0	0,0	100,0
Office work	100,0	100,0	0,0	0,0	0,0	0,0	100,0
Standing							97,9
Doing dishes	100,0	2,1	84,2	13,7	0,0	0,0	97,9
Walking							97,0
Walking 2 km/h	100,0	0,0	4,9	95,1	0,0	0,0	95,1
Walking 3 km/h	100,0	0,0	0,0	100,0	0,0	0,0	100,0
Walking 4 km/h	100,0	0,0	0,0	100,0	0,0	0,0	100,0
Walking 5 km/h	100,0	0,0	0,0	100,0	0,0	0,0	100,0
Walking 6 km/h	100,0	0,0	0,0	87,1	0,1	12,9	87,1
Stairs up	100,0	0,0	3,4	96,5	0,0	0,1	96,5
Stairs down	100,0	0,0	0,0	100,0	0,0	0,0	100,0
Cycling							95,9
Cycling hometrainer R1	100,0	4,3	0,0	0,0	95,6	0,1	95,6
Cycling hometrainer R2	100,0	0,0	0,0	0,0	94,2	5,8	94,2
Cycling hometrainer R3	100,0	0,0	0,0	0,0	93,5	6,5	93,5
Cycling outside slow	100,0	4,1	0,7	0,9	94,3	0,0	94,3
Cycling outside normal	100,0	0,0	0,0	0,0	100,0	0,0	100,0
Cycling outside fast	100,0	0,0	0,0	2,5	97,5	0,0	97,5
High-intensity activity							94,5
Running 6 km/h	100,0	0,0	0,0	12,9	0,0	87,1	87,1
Running 9 km/h	100,0	0,0	0,0	0,5	0,0	99,5	99,5
Running 12 km/h	100,0	0,0	0,0	0,0	0,0	100,0	100,0
Running 15 km/h	100,0	0,0	0,0	0,0	0,0	100,0	100,0
Sprint	100,0	0,0	2,5	3,8	0,0	93,8	93,8
Jumping rope	100,0	0,0	2,9	10,6	0,0	86,5	86,5
Total agreement							97,0

Study 2 protocol and analysis: comparison of Fibion energy expenditure estimate against indirect calorimetry

The purpose of the first study was to test the accuracy of Fibion energy expenditure estimate against indirect calorimetry, which is the most accurate method to measure physical activity energy expenditure. 6 adults performed three walking activities (2, 4 and 6 km/h) and three running activities (8, 11 and 14 km/h) on a treadmill and three cycling activities (50W at 40 rpm, 125W at 60 rpm and 200W at 80 rpm) on a stationary bike. Physical activity energy expenditure was measured by indirect calorimetry (CORTEX Biophysik MetaLyzer® 3B, Germany) and the Fibion Device, and these energy expenditures were compared to find out how accurately Fibion measures energy expenditure against indirect calorimetry.

Study 3 protocol and analysis: comparison of Fibion energy expenditure estimate against heart rate and Actigraph GTX3+

The purpose of the second study was to compare the energy expenditure output of Fibion into that of heart rate sensor and Actigraph GTX3+ accelerometer, which are the most widely used devices to estimate energy expenditure in large-scale scientific research studies. 19 adults performed the same protocol as in the study 1 while wearing the three devices: Fibion on thigh, Actigraph GTX3+ on waist and heart rate sensor on chest. The energy expenditure output of the sensors was compared descriptively, as well as with correlation.

Fibion Device

The Fibion Device is a small device to track physical activity and sedentary behavior during daily life. The Fibion Device contains a three-axis accelerometer, a battery, a real-time clock and a medium for data storage. The Fibion Device is equipped with firmware algorithms, which convert the raw accelerometer signal into activity classes and their energy expenditures without storing the raw data. The categorizing frequency is 1 second and the storage interval of the device is 1 minute, meaning that each storage interval contains 60 seconds categorized activity classes with their energy expenditure. The activity categories are lying, sitting, standing, walking, cycling, and running. These categories are mainly determined by 1) the angular position of the unit - the system is based on a position that is to some extent parallel to the front side of the thigh - and 2) by the variability of the signal, which depends on the intensity of movement. The detection of lying is based on the absence of movement/signal variability for a longer time interval (>5 minutes). For each storage interval (1 min) the total energy expenditure (expressed in METS) of each activity category is determined and stored. For the purpose of this validation study, the 1 minute storage interval was lowered to 2.5 sec to be able to select the duration of validated activity bouts accurately. Concurrently, the sample interval was lowered to 0.6 seconds (4 samples per storage interval).

Results

Study 1 results: validity of Fibion in detecting postures and activities

From the all activity classes determined from the video, Fibion classified 92.8% of samples correctly when worn in the pocket (Table 1) and 97.0% correctly when worn in the thigh strap (Table 2). For example, Table 1 shows that device worn in the pocket classifies standing, walking (at 3-5 km/h) and running (12 and 15km/h) at 100% agreement, while the lowest agreement values were found for slow running (6km/h, 69,9% running, 30,1% walking) and fast cycling outside (75% cycling, 25% walking). Table 2 shows that the device worn in thigh was able to classify sitting, walking (3-5km/h), stair descending, cycling outside at normal pace and running (12 and 15 km/h) at 100% agreement. The lowest agreement values were found for fast walking (6km/h, 87,1% walking, 0,1% cycling, 12,9% running) and slow running (87,1% running, 12,9% walking). The average agreement values for each activity class were 92,5% and 100% for sitting, 100% and 97,9% for standing, 97,4% and 97,0% for walking, 82,7% and 95,9% for cycling, and 91,4% and 94,5% for high intensity activity, for pocket device and thigh device, respectively.

Study 2 results: comparison of Fibion energy expenditure estimate against indirect calorimetry

Figure 1 shows the averaged values for each activity between Fibion and indirect calorimetry revealing that the estimated energy expenditure by the Fibion device is largely in accordance with indirect calorimetry. As compared to indirect calorimetry, The Fibion Device energy expenditure estimate was 4,7% lower during walking (-15,5%; +7,3; +2,0% and -12,7% for walking at 2, 4, 6 and 8km/h, respectively), 19,7% lower during running (-13,9% and -25,6% for running at 11 and 14km/h, respectively), and 17% higher during cycling (+76,8%; -0,3% and -25,5% for 50W/40rpm, 125W/60rpm and 200W/80rpm, respectively). On average, Fibion energy expenditure estimate is 0,8% lower as compared to that of indirect calorimetry in the measured activities.

Study 3 results: comparison of Fibion energy expenditure estimate against heart rate and Actigraph GTX3+

Figure 2 shows the averaged energy expenditures at different activities as estimated by heart rate, Fibion device and Actigraph GTX3+. Across all activities, Fibion underestimated energy expenditure only by -1,6%, as compared -36,7% by Actigraph GTX3+.

During walking Fibion overestimated energy expenditure by 22,9% and Actigraph by 2,8% as compared to heart rate. However, the range was wide for different walking speeds. Fibion estimate ranged from -13,9% (walking at 8km/h) to +61,4% (walking at 4km/h) and Actigraph estimate from -73,1% (walking at 2km/h) to +15,0% (walking at 8km/h). During running both devices underestimated energy expenditure; Fibion by -20,0% and Actigraph by -27,5%. During cycling the underestimate was slightly more for Fibion (-21,9%), and clearly more for Actigraph (-89,2%).

At walking and running, the correlation (r) between Fibion and heart rate energy expenditure estimate was 0,91 (P<.001) and between Actigraph GTX3+ and heart rate 0,89 (P<.001).

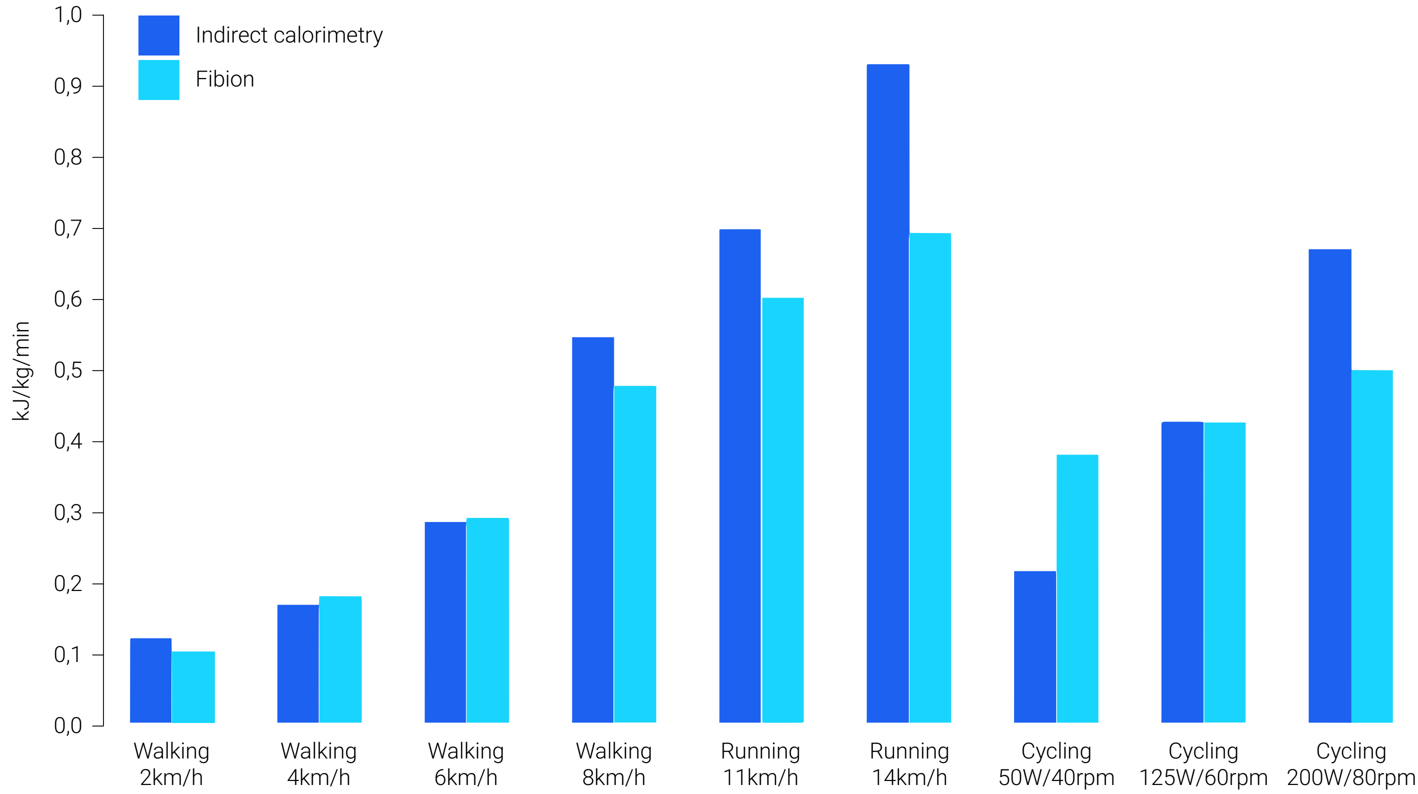

FIGURE 1. Energy expenditure as measured by indirect calorimetry and estimated by FibionDevice across measured activities.

Discussion

The purpose of this study was to test the validity of Fibion physical activity monitor in categorizing a range of simulated daily activities and in estimating their energy expenditure against high quality criterion measures video recording and indirect calorimetry. In addition, the energy expenditure estimate of Fibion was compared against heart rate monitor and Actigraph GTX3+, which are commonly used in scientific research. The main findings of this study were that Fibion classified 92.8% and 97.0% of samples correctly when worn in the pocket and thigh strap, respectively, and underestimated energy expenditure by 0,8% as compared to indirect calorimetry, and by 1,6% as compared to heart rate. Thus, Fibion was more accurate than the widely utilized Actigraph GTX3+ -device (-36,7% as compared to heart rate). Based on these results Fibion appears to be a valid device in categorizing activities and in measuring their energy expenditure.

Over the past years accelerometers have become recommended tool to quantify daily activities over prolonged periods[13]. Typically, devices are validated against energy expenditure measurements at laboratory conditions, and specific cut-points values are

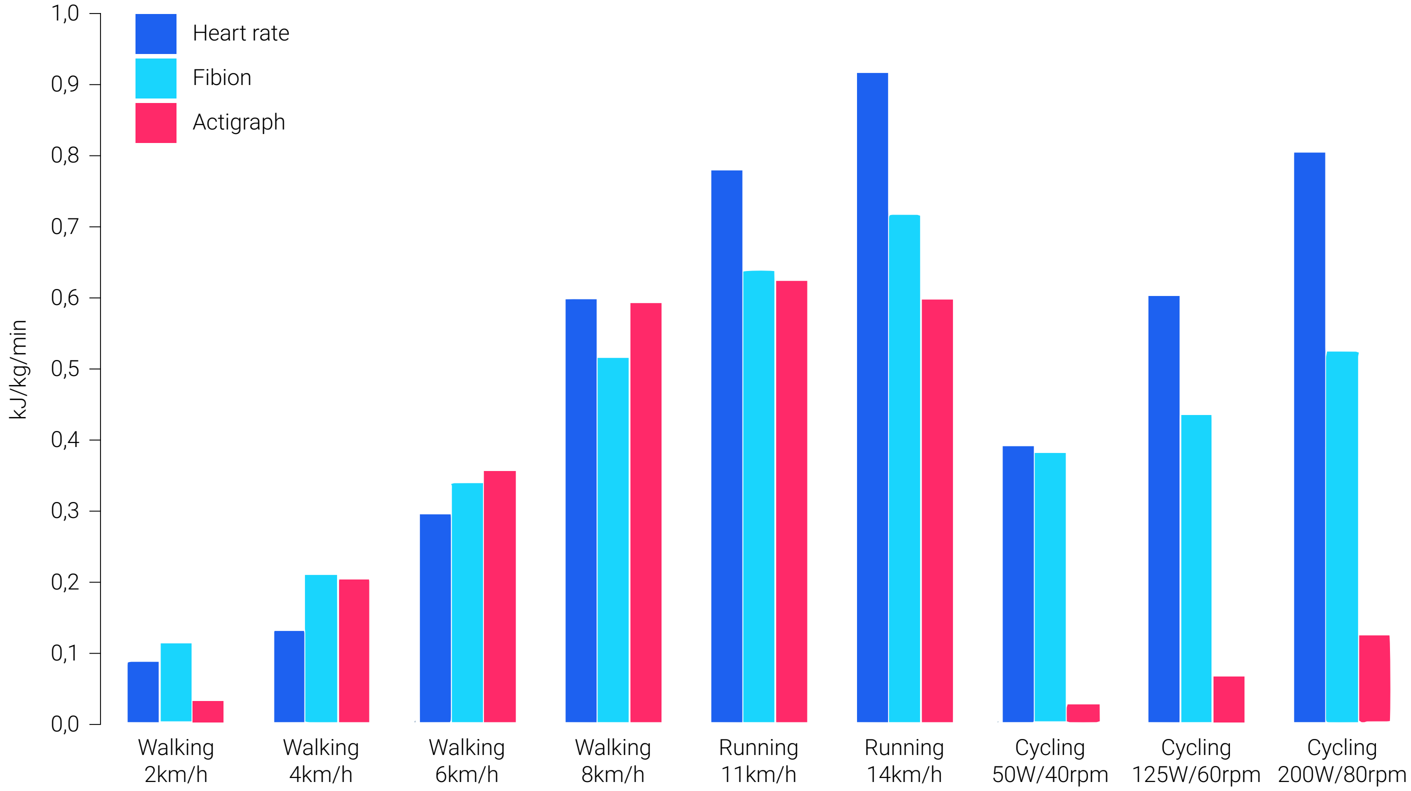

FIGURE 2. Energy expenditure as estimated by heart rate, Actigraph GTX3+ and Fibion Device across measured activities.

used to categorize different activity intensities[14]. However, a more recent extension in their measurement requirements is to be able to quantify sitting periods accurately[10]. The down side of the most widely utilized devices is that they are incapable of categorizing the types of activities, in addition to the sole energy expenditure estimate or time spent at a given intensity level. Specifically, the majority of devices are incapable of measuring sitting per se, but rather measure lack of movement from the waist or wrist[15]. Thus, quiet standing is typically categorized as sedentary time, although standing increases muscle activity[16] and energy expenditure[17] as compared to sitting. Consequently, waist-worn devices are not able to measure real breaks in sitting time[18] nor are sensitive to changes in sedentary behavior interventions[12,19]. Another typical misclassification occurs during cycling, because waist- or wrist-worn devices lack sensitivity to the cycling activity because of their placement. These drawbacks can be overcome by placing the sensor on thigh, because the posture and movement of thigh is clearly identifiable during sitting, standing and walking, and a range of other typical activities. Fibion device benefits from its preferred placement on thigh, which was seen as a high validity in categorizing typical daily activities and their energy expenditures. For example, during cycling Actigraph underestimated energy expenditure almost 70% more as compared to Fibion.

The primary design criteria for the Fibion Device is comfort of use for the end user, which is why the intended wear position is the front pocket of trousers. However, the downside might be within and between person variability in measured outcomes. The current validation study provided evidence of the robustness of this method, because the validity of the pocket sensor vs thigh sensor were highly parallel to each other. However, in some occasions the output of Fibion device is incorrect, which might be due to several internal or external reasons. For example, sometimes cycling was determined as walking, especially when worn in the pocket. This might be due to loose pockets enabling significant movement of the device, or a cycling style where legs are vertical, and thus the movement mimics walking. On the other hand, sometimes the activities where the thigh movement mimics some other activity, are categorized so. An example is stair ascending categorized as cycling, if a participant raises the legs in a cyclical movement. However, these data are reported as single cases and we couldn't see any evidence of this in the data. Another problem arousing from pocket wear is a wrong sensor placement in the side of the thigh. In these occasions the device can be in a similar position during sitting and standing, or the movement of the sensor does not mimic the validated data due to wrong placement. However, this source of error is easily minimized by securing the sensor in the front side of thigh, in the pocket or leg strap. Another typical source of error is external noise, e.g. during car driving. If a significant amount of external vibration is applied, sitting might be misclassified as activity. However, Fibion device is equipped with a high-pass filter to diminish the effect of external vibrations, which is why these occasions are extremely rare.

The limitations of accelerometers in general should be kept in mind when interpreting the results. Accelerometers worn in lower extremities are incapable of measuring upper body movements, the acceleration signal does not bare information about the intensity of movement relative to an individual's physiological capacity, and any isometric muscle activities where external movement does not occur, cannot be detected[9]. In addition the validity of Fibion can be interpreted only in the context of the studied activities. However, in habitual use these limitations are more minor than major, and do not limit the utilization of Fibion in scientific, clinical or other use.

In conclusion, Fibion is a valid tool in categorizing sitting, standing, walking, cycling and high-intensity movement and their energy expenditures. Fibion categorized more than 90% of activities correctly irrespective of pocket or thigh wear, and was superior in estimating energy expenditure as compared to Actigraph

GTX3+ device in the studied typical daily activities.

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