Measuring Heart Rate in Manual Wheelchair Users during Exercise and Free-living Activity with the latest Fitbit Surge Monitor

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ABSTRACT

Researchers have been validating the off-the-shelf activity monitors and customizing devices to help manual wheelchair users (MWUs) objectively monitor their daily physical activity (PA), a critical factor in optimizing health and function. Some of these devices track heart rate (HR) and use it to predict energy expenditure (EE). The validity of these monitors in predicting EE depends on the accuracy of their HR measurement. In this study, we examined the validity of one of the most popular fitness-tracking devices, Fitbit Surge. Fifteen MWUs (spinal cord injury (n=9), spina bifida (n=2), cerebral palsy (n=1), multiple sclerosis (n=1), polymyositis (n=1), and traumatic brain injury (n=1), Age: 36.5 ± 9.9 years) wore the device during exercise and free-living activity. The Fitbit Surge HR measurement was compared against a reference HR measured by a validated device, ActiHeart [1, 2]. Results showed the HR measured by Fitbit Surge and ActiHeart were strongly correlated (r= 0.64, p<0.001). The ICC (2, 1) was 0.78, indicating a moderate agreement. The mean bias between the HR measured by ActiHeart and Fitbit Surge was 1.9 bpm (95% limit of agreement: -35.8 – 39.6 bpm). However, the difference was substantially greater in higher intensity tasks (HR > 100 bpm) than in lower intensity tasks (HR < 100 bpm). The variance in HR of each subject recorded by ActiHeart and Fitbit Surge over the course of 2.5 hours were only comparable in sedentary tasks such as resting, watching TV and reading. More work needs to be done to better understand how to improve its sensitivity/specificity for capturing moderate to vigorous PA in MWUs across the day.

BACKGROUND

Heart rate (HR) is an important indicator of health and fitness. Evidence has shown that regular physical activity (PA), especially aerobic exercise, is associated with lower resting HR [3, 4]. Other studies have also suggested that HR response during exercise and HR recovery after exercise could be used to predict risk of coronary heart disease and total mortality [5-7]. Besides, HR measurement can be used to predict energy expenditure (EE) in moderate to strenuous activities as the HR increases linearly with oxygen consumption [8].

In the past decades, increasing attention has been paid to the development and use of portable activity monitors to help manual wheelchair users (MWUs) adopt and maintain a healthier and more active lifestyle. Many of the popular off-the-shelf monitors such as ActiHeart and Fitbit Surge track HR and use it to predict EE. For example, Nightingale et al. (2015) found that ActiHeart showed a fair accuracy (absolute percent error: 16.8 ± 15.8%) in estimating EE in MWUs during PA [9]. When investigating the abilities of monitors that use HR to estimate EE, their validity in measuring HR should first be examined.

Brage et al. (2005) and Barreira et al. (2009) had investigated the validity of ActiHeart in exercise and free-living activity in ambulatory population. Brage et al. (2005) showed that HR measured by ActiHeart were 0.1 bpm (95% limit of agreement: -4.2 – 4.3 bpm) and -0.4 bpm (95% limit of agreement: -3.4 – 2.6 bpm) different when compared to electrocardiogram (ECG) and Polar S610, respectively [1]. The intraclass correlation coefficient (ICC) was 0.99 (p<0.001) between ActiHeart and ECG, indicating a strong agreement [1]. Similarly, Barrier et al. (2009) reported a high correlation between HR measured by ActiHeart and ECG, with correlations ranged from 0.88 to 0.99 for low-, moderate-, high-intensity exercises, and free-living activities [2]. ActiHeart was concluded to be a valid tool for HR measurement.

As one of the most popular fitness tracking devices nowadays, the validity of Fitbit Surge in measuring HR has not yet been determined. In this study, we investigated the performance of Fitbit Surge in tracking HR during exercise and free-living activity in MWUs by comparing it to the HR measurements collected using ActiHeart. We hypothesized that the HR measurements collected by the two devices would have small mean differences and high agreement.

METHOD

The study was approved by the Institutional Review Board at the University of Alabama at Birmingham. Fifteen subjects between the ages of 18 and 75 years were recruited in this study. Subjects were eligible to participate in the study if they 1) used manual wheelchairs as a primary means of mobility; 2) were at least one year post-injury; 3) were medically stable; 4) were able to tolerate sitting for 3 hours; and 5) had no active pelvic or thigh wounds. Subjects were excluded if pregnant or had cardiovascular diseases at the time of testing.

Instrumentation

Two portable HR monitoring devices – ActiHeart and Fitbit Surge – were used in this study. ActiHeart (CamNtech Ltd UK) is a small, lightweight device that contains an omnidirectional accelerometer and an ECG signal processor [10]. It is worn on the chest with a strap (Figure 1). The strap has two standard ECG pads on one side and two clips on the other side to allow the two electrodes on ActiHeart to connect. The ECG signal is sampled at 128 Hz, and specific algorithms are used to interpolate interbeat interval for calculating HR [10]. Fitbit Surge (Fitbit Inc, San Francesco, CA) is a device similar to a watch that contains a gyroscope and an omnidirectional accelerometer, an ambient light sensor, a vibration motor, an altimeter, and an optical heart rate monitor (Figure 2). When the device is worn on the wrist, the PurePulse[TM] LED light is reflected onto the skin to detect blood volume changes in the capillaries, and specific algorithms are used to estimate the HR simultaneously and continuously [11].

Figure 1. ActiHeart was clipped on a strap with two standard ECG pads and was worn over the chest.

Figure 2. Fitbit Surge was worn at the wrist like a watch.

Procedure

The study was explained to the subjects, and written consent forms were obtained from them prior to participating in the study. Subjects were first asked to complete a basic demographic questionnaire and had their body weight and height measured.

There were two testing trials – lab and home. The lab trial took place at the Lakeshore Foundation, while the home trial took place at the Cottages of Lakeshore. All subjects began with resting for 30 min and 15 min for the lab and home trials, respectively.

During the lab trial, subjects were asked to perform at least six activities from the following list: wheelchair propulsion on a flat surface at self-selected slow, normal or fast speed; arm ergometry exercise at self-selected low, normal, or high speed/resistance; propulsion up/down a ramp, on a carpeted surface, on a sidewalk, or on a track at self-selected normal speed; wheelchair basketball; weight lifting; Theraband exercise. Subjects performed each activity of their choices for at least 10 minutes, and they were allowed to rest for at least 5 minutes between activities.

During the home trial, subjects were asked to perform 1.5 hours of free-living activities from the following list: reading; watching TV; cleaning house; folding clothes/bedsheets; washing dishes; stretching exercise; chair-aerobic exercise; resistance exercise. Instructional videos were provided for those who chose stretching, aerobic and/or resistance exercises. To mimic the real world situation, subjects were given enough time to finish each task they chose, and tasks were performed continuously without breaks.

Data Analysis

Data from ActiHeart was extracted using the ActiHeart software (version 4), with the HR data downloaded in 15s epoch. The Fitbit Surge data was achieved through Fitabase (Small Steps Labs LLC) with the HR data downloaded at 1s epoch. Both HR data were then condensed to 1-minute interval. The linear regression analysis and Pearson correlation coefficient were performed to examine the relationship between the HR measured by ActiHeart and Fitbit Surge. The ICC was calculated and the Bland-Altman plot was constructed to examine the agreement between the HR measured by the two devices. In addition, the variance in HR of each subject was computed by subtracting the HR between two time points. The data were split into two categories: sedentary and non-sedentary. In sedentary category, the variance in HR over time during resting, watching TV, and reading were included. The variance in HR during other activities were grouped into non-sedentary category. The mean and standard deviation of the variance in HR over time were calculated for each category.

RESULTS

Fifteen subjects completed the study. The demographic information of subjects was summarized in Table 1. The HR measurements from the two devices at both the lab and home trials were plotted to illustrate their relationship (Figure 3). A linear trend was observed, and a simple regression analysis was performed. It was found that 41% of variances in HR measured by Fitbit could be explained by the ActiHeat HR measurement. A strong correlation was found between HR measured by ActiHeart and Fitbit Surge ($r= 0.64$; $p<0.001$). The ICC (2, 1) was 0.78 [95% confidence interval: 0.75 – 0.79], indicating a moderate agreement. The Bland Altman plot was also constructed to illustrate such agreement (Figure 4). The mean difference
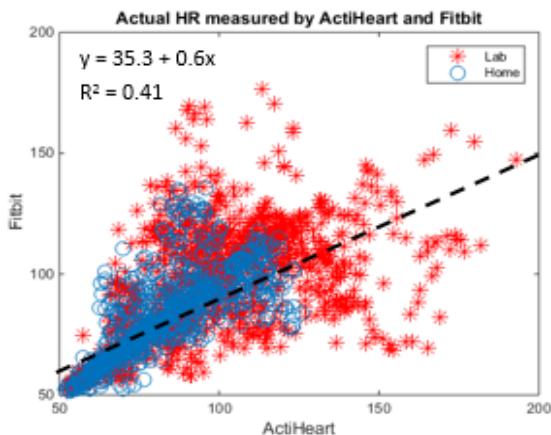
between the HR measured by ActiHeart and Fitbit was 1.90 bpm [95% limits of agreement: -35.8 – 39.6 bpm].

Since the nature of the physical activities performed in the lab trial was mainly exercise tasks while that in the home trial was free-living activities, we further examined the relationship between HR measured by both devices in the two trials separately. A stronger association was found between HR measured by ActiHeart and Fitbit Surge in the home trial (ICC (2, 1): 0.83 [95% confidence interval: 0.81 – 0.85]; r= 0.71) than in the lab trial (ICC (2, 1): 0.73 [95% confidence interval: 0.70 – 0.76]; r= 0.58).This result was also illustrated in Figure 3 and 4. The HR measured by the two devices showed greater differences during higher intensity tasks (HR above 100 bpm) than lower intensity tasks (HR below 100 bpm).

In addition, the variance in HR over the course of 2.5 hours measured by the two devices was calculated. The variance in HR of each subject performing the PA in sedentary and non-sedentary categories were plotted in Figure 5 and 6. The mean differences of variance in HR over time between the two devices were 2.4±7.8 bpm and 1.7±24.4 bpm in sedentary and non-sedentary categories, respectively.

**Table 1**. Demographic of subjects participated in the study

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Total Subjects	15
Gender	
Male	10
Female	5
Age (years)	36.5 ± 9.9
Height (inches)	66.2 ± 6.0
Weight (lbs)	155.0 ± 47.3
Years of using wheelchair	15.2 ± 10.4
Disability type	
Spinal Cord Injury	9
Spina Bifida	2
Cerebral Palsy	1
Multiple Sclerosis	1
Polymyositis	1
Traumatic Brain Injury	1

Figure 3. The heart rate (bpm) measured by ActiHeart and Fitbit Surge showed a strong linear relationship.
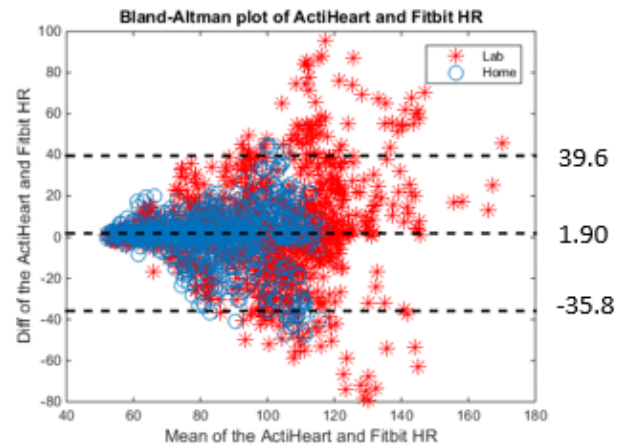
Figure 4. The Bland-Altman plot of the heart rate (bpm) measured by ActiHeart and Fitbit showed a moderate agreement.
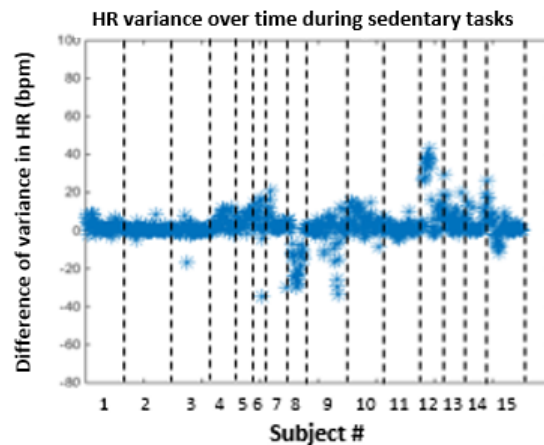
Figure 5. The difference between the variance in HR measured by ActiHeart and Fitbit during sedentary tasks in MWUs.
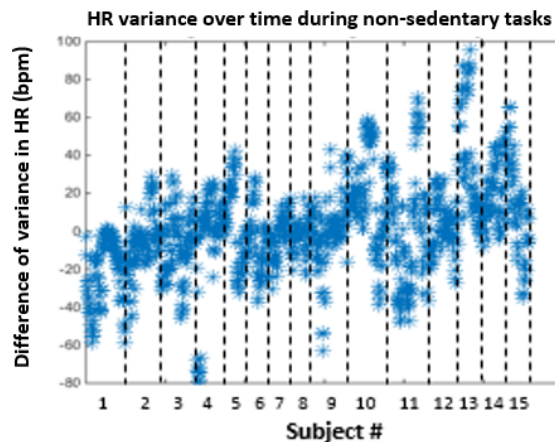
Figure 6. The difference between the variance in HR measured by ActiHeart and Fitbit during non-sedentary tasks in MWUs.

A small difference in the variance in HR over time measured by ActiHeart and Fitbit Surge was observed in the sedentary category, suggesting good compatibility between the two devices (Figure 5). However, the HR changes in non-sedentary category recorded by the two devices showed large variations (Figure 6), implying the incompatibility between the two devices in measuring HR during propulsion and arm-related activities.

DISCUSSION

Although the HR measured by ActiHeart and Fitbit showed strong association (r=0.64, p<0.001), Fitbit Surge was not valid in measuring the HR during PA as the HR difference varied a lot when compared to ActiHeart, especially during higher intensity PA (HR > 100 bpm), as shown in Figure 4. We then examined if Fitbit Surge was able to track the variance in HR over time accurately. The results showed that the variance in HR recorded by the Fitbit Surge and ActiHeart were compatible during sedentary tasks (Figure 5). However, a relatively large difference (>20 bpm or <-20 bpm) was observed in two individuals when compared to the rest of the subjects. A possible explanation is the small body size of the two subjects. The Fitbit Surge was loosely fit on the wrists of small subjects, causing potential shifts during PA and thus resulted in poor blood volume change detection. Similarly, the intensive use of arms during other activities such as propulsions and arm ergometry exercises affected the ability of Fitbit Surge to accurately track blood volume change, which could result in the large differences in the variance in HR shown in Figure 6.

Obtaining accurate and reliable HR is important, especially for people with disabilities. Clinicians, coaches and fitness trainers can utilize HR measurement to help clients achieve their fitness goals through more effective exercise training. Valid HR measurement before, during, and after activity not only can help MWUs self-monitor their physical fitness, but also clinicians and/or trainers to assess whether a fitness program and/or intervention is suitable for their clients. Accurate HR measurement can help fine-tune the program content to maximize its impacts on the health and wellness of MWUs.

CONCLUSION

Overall, the HR measured by Fitbit Surge and ActiHeart showed a strong correlation and the mean bias was 1.9 bpm. However the mean differences of the HR measured by Fitbit Surge and ActiHeart were large in higher intensity tasks (HR > 100 bpm). The variance in HR over time recorded by the two devices only demonstrated good agreement in sedentary tasks. More work needs to be done to understand how to improve monitors like Fitbit Surge for capturing moderate to vigorous PA in MWUs across the day.

REFERENCES

1. Brage S, Brage N, Franks PW, Ekelund U, Wareham NJ. Reliability and Validity of the Combined Heart Rate and Movement Sensor ActiHeart. European Journal of Clinical Nutrition. 2005;59:561 - 70. doi: 10.1038/sj.ejcn.1602118.
2. Barreira T, Kang M, Caputo JL, Farley RS, Renfrow MS Validation of the ActiHeart Monitor for the Measurement of Physical Activity. International Journal of Exercise Science. 2009;2:60 - 71.
3. Press V, Freestone I, George CF. Physical activity: the evidence of benefit in the prevention of coronary heart disease. QJM. 2003;96(4):245-51. doi: 10.1093/qjmed/hcg041.
4. Rodeheffer R, Gerstenblith G, Becker LC, Fleg JL, Weisfeldt ML, Lakatta EG. Exercise cardiac output is maintained with advancing age in healthy human subjects: cardiac dilatation and increased stroke volume compensate for a diminished heart rate. Circulation. 1984;69:203 - 13. doi: 10.1161/01.CIR.69.2.203.
5. Cole C, Foody JM, Blackstone EH, Lauer MD. Heart rate recovery after submaximal exercise testing as a predictor of mortality in a cardiovascularly healthy cohort. Annals of Internal Medicine. 2000;132(7):552 - 5. doi: 10.7326/0003-4819-132-7-200004040-00007.
6. Seccareccia F, Pannozzo F, Dima F, Minoprio A, Menditto A, Noce CL, Giampaoli S. Heart rate as a predictor of mortality: The MATISS Project. American Journal of Public Health. 2001;91(8):1258 - 63. doi: 10.2105/AJPH.91.8.1258.
7. Lauer M, Okin PM, Larson MG, Evans JC, Levy D. Impaired heart rate response to graded exercise. Circulation. 1996;93:1520 - 6. doi: 10.1161/01.CIR.93.8.1520.
8. Freedson P, Miller K Objective monitoring of physical activity using motion sensors and heart rate. Research Quarterly for Exercise and Sports. 2000;71(2 Suppl):S21 - 9. PubMed Central PMCID: PMC10925821.
9. Nightingale T, Walhim JP, Thompson D, Bilzon JL. Predicting phyiscal activity energy expenditure in wheelchair users with a multisensor device. BMJ Open Sport & Exercise Medicine. 2015;1(1). doi: 10.1136/bmjsem-2015-000008.
10. CamNtech. ActiHeart Overview 2011 [updated December 20111/26/2016]. Available from: http://www.camntech.com/images/products/actiheart/Actiheart_4_Overview.pdf.

11. Fitbit I. Heart rate FAQs 2016 [updated 12/21/20151/25/2016].
Available from:
https://help.fitbit.com/articles/en_US/Help_article/Heart-rate-
FAQs/.