Evaluation of Stair Climbing as an Approach for Estimating Heart Rate Recovery in Daily Activities

Daivaras Sokas[1], Andrius Rapalis[1,2], Andrius Petrėnas[1,2], Saulius Daukantas[1] and Vaidotas Marozas[1,2]

[1]*Biomedical Engineering Institute, Kaunas University of Technology, Kaunas, Lithuania*

[2]*Department of Electronics Engineering, Kaunas University of Technology, Kaunas, Lithuania*

Keywords: Stair Climbing, Heart Rate Recovery, Daily Activities, Fitbit, YMCA.

Abstract: Post-Exercise heart rate recovery (HRR) is a convenient approach to assess cardiovascular autonomic function. Ordinary stair climbing can be viewed as an alternative HRR test performed in daily activities, and also well-suited for implementation in wrist-worn devices. This study compares HHR parameters estimated after stair climbing to those obtained by performing the conventional YMCA bench step test using a custom-made wrist-worn device and a consumer smart wristband Fitbit Charge 2. The results show that most HHR parameters are underestimated after stair climbing but still comparable to those obtained from the bench step test. The lowest relative error, 8–11% on average, was found for the decay of heart rate in 30, 60, and 120 s after the recovery onset.

1 INTRODUCTION

Post-exercise heart rate recovery (HRR) is a simple non-invasive approach to assess cardiovascular autonomic function (Jouven et al., 2005; Peçanha et al., 2017). Slower HRR is associated with decreased physical fitness, cardiovascular diseases, and is a predictor of death (Jouven et al., 2005; Peçanha et al., 2017). HRR can be improved by cardiac rehabilitation (Streuber et al., 2006; Hai et al., 2010) and even weight loss (Thomson et al., 2010). Therefore, HRR trend monitoring could be useful for assessing the effectiveness of exercise training at home environment.

HRR is assessed using standardised tests that require specialised equipment and supervision. Hence, it is inconvenient for use outside the clinical setting. Improvement in wearable device technology gives opportunity to evaluate HRR by using a photoplethysmogram (PPG) signal (Sokas et al., 2019). Since stair climbing is a common daily activity that require physical effort, and is usually followed by slow walking or rest, this activity can be considered as an alternative HRR test performed in free-living conditions.

Our previous work reported the feasibility of estimating HRR parameters after stair climbing using the wrist-worn device with the embedded PPG and barometric pressure sensors (Sokas et al., 2019). However, it is unclear how the new approach compares to the conventional bench step test. Accordingly, the aim of this study is to compare the agreement of HRR parameters estimated after stair climbing to those obtained by performing the bench step test.

2 MATERIALS AND METHODS

2.1 Study Population and Data Acquisition

Fifty-four healthy volunteers (18 women), 25.5 ± 8.1 (mean $\pm$ SD) years old (range 18 to 50 years), with a height of 177.4 ± 8.5 cm, weight of 73.7 ± 14.4 kg, and body mass index of 23.3 ± 3.9 kg/m^2 were enrolled in the study.

The study was performed according to the protocol given in Figure 1. Participants were asked to climb four floors (96 stairs in total) three times at different climbing rate: 48, 72, and 96 steps per minute. After each activity, the participants had to rest in a standing position for five minutes, slowly descend to the ground floor and rest for three minutes before the next activity. The YMCA bench step test was performed using the protocol described in (Golding, 2000) during which a participant has to step on a 30.5 cm high bench for 3 min at a stepping rate

Sokas, D., Rapalis, A., Petrėnas, A., Daukantas, S. and Marozas, V.
Evaluation of Stair Climbing as an Approach for Estimating Heart Rate Recovery in Daily Activities.
DOI: 10.5220/0010184500210025
In *Proceedings of the 14th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC 2021) - Volume 4: BIOSIGNALS*, pages 21-25
ISBN: 978-989-758-490-9

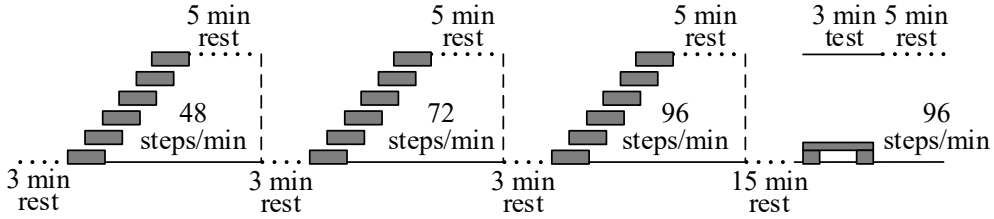

Figure 1: The protocol of consecutive stair climbing at different rates and the bench step test. All activities are separated by rest periods.

of 96 steps per minute (288 steps in total) and to sit down for 5 min after the exercise is finished. An electronic metronome ensured steady stepping rate for both tests.

Data were acquired using the custom-made wrist-worn device (Biomedical Engineering Institute, Kaunas University of Technology, Kaunas, Lithuania) on the left wrist and the consumer smart wristband Fitbit Charge 2 (Fitbit Inc., San Francisco, CA, USA) on the right wrist. A wrist-worn device synchronously acquires electrocardiogram (ECG) at a sampling rate of 500 Hz, photoplethysmogram (PPG) at a sampling rate of 100 Hz, and barometric pressure at a sampling rate of 50 Hz with an altitude resolution of 10 cm. The consumer smart wristband provides a pulse rate at intervals of 5 s or longer, depending on the quality of the PPG signal.

The study was conducted by following the ethical principles of the Declaration of Helsinki. Identifiable information was removed to ensure participant anonymity.

2.2 Estimation of Heart Rate Recovery

Heart rate normally recovers exponentially thus it can be approximated by a mono-exponential model. The exponential model is fitted in a 5 min time interval after the physical activity and the time-constant τ of exponential decay is estimated. Detection of the recovery onset, i.e., the end of stair climbing, in heart rate series was performed relying on the procedure described in (Sokas et al., 2019). The quality of exponential fitting is assessed via the coefficient of determination which should exceed a fixed threshold of 0.5 to consider the fitting acceptable.

The rapid heart rate decay immediately after the recovery onset is characterized by the short-term time constant *T30* (Peçanha et al., 2017). *T30* is found by fitting a line to the logarithm of heart rate and is the negative inverse of the slope of the resulting line, expressed as -1/slope. The decay of heart rate in 30 s, 60 s and 120 s after the recovery onset is denoted *HR30*, *HR60*, and *HR120*, respectively. The difference between the maximal heart rate at recovery onset and the baseline heart rate (i.e., minimal heart rate at the end of the recovery period) is denoted ΔHR.

3 RESULTS

Figure 2 shows the Bland-Altman plots of HRR parameters estimated from the reference ECG after stair climbing at rate of 96 steps/min and the YMCA bench step test. Given that ordinary stair climbing is less intense activity than the bench step test, it is unsurprising that most parameters are underestimated, with the exception of *HR120* and *T30*. No bias in estimating *HR120* can be explained by return of heart rate to baseline, whereas *T30* might be less affected by activity intensity since it depends on the heart rate slope rather than on absolute values.

Figure 3 shows that lowest absolute and relative errors are obtained for *HR30*, *HR60*, and *HR120*, whereas are larger for the remaining parameters. Interestingly, absolute and relative errors estimated using wrist-worn devices are similar to those obtained from the reference ECG, suggesting PPG as a useful signal for HRR estimation.

The impact of stair climbing altitude and different climbing rate on change in heart rate is illustrated in Fig. 4. Heart rate tends to increase and then reaches a plateau at 5 meters of altitude for low climbing intensity (48 steps/min). For climbing rates of 72 and 96 steps/min, heart rate rises rapidly up to 10 metres of altitude and then continues to increase only marginally.

4 DISCUSSION

With this study we seek to take a further step towards providing a more comprehensive information about health status next to available heart rate and physical activity parameters offered by most consumer wrist-worn devices.

The stair climbing test has not yet been standardised, probably due to different protocols applied in

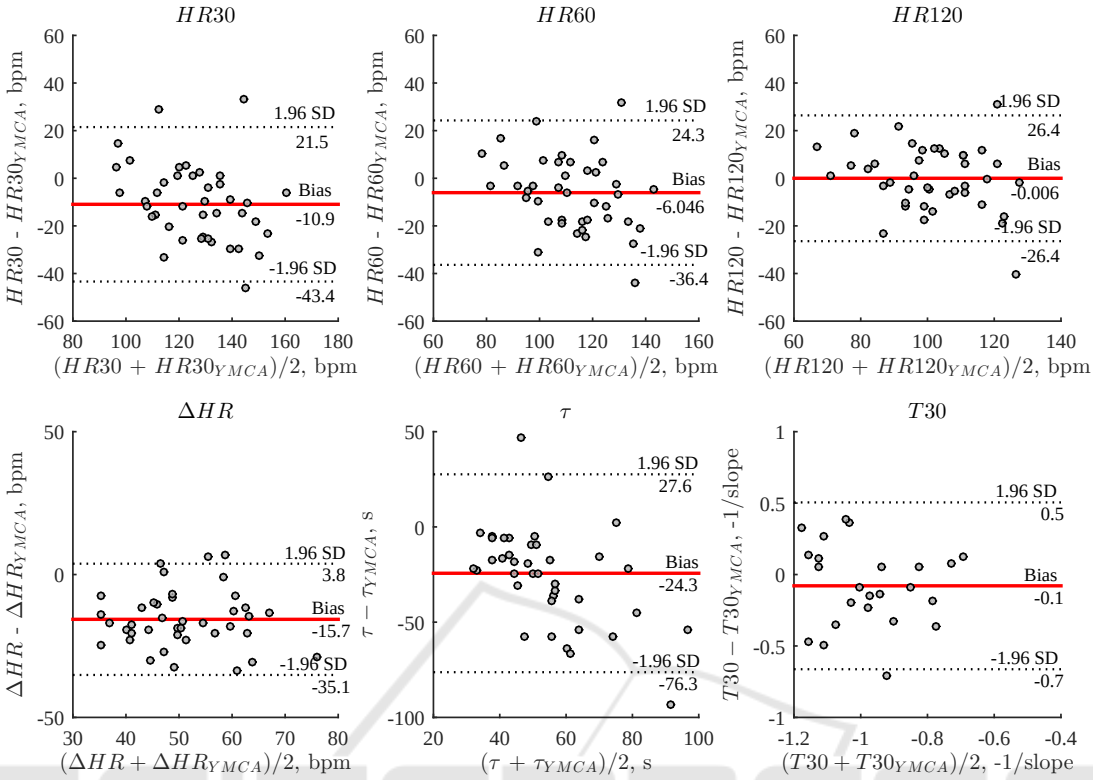

Figure 2: Comparison of HRR parameters estimated after stair climbing (rate of 96 steps/min) and by performing the YMCA bench step test. The parameters are estimated from the reference ECG.

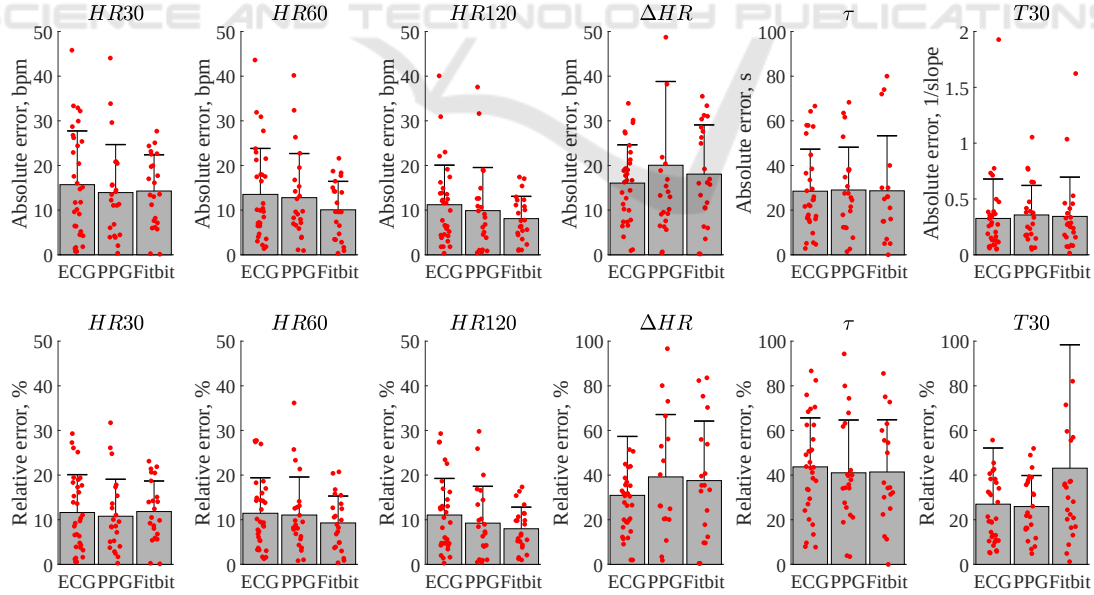

Figure 3: Absolute (top row) and relative (bottom row) HRR parameter estimation errors when comparing stair climbing at a rate of 96 steps/min to the YMCA bench step test.

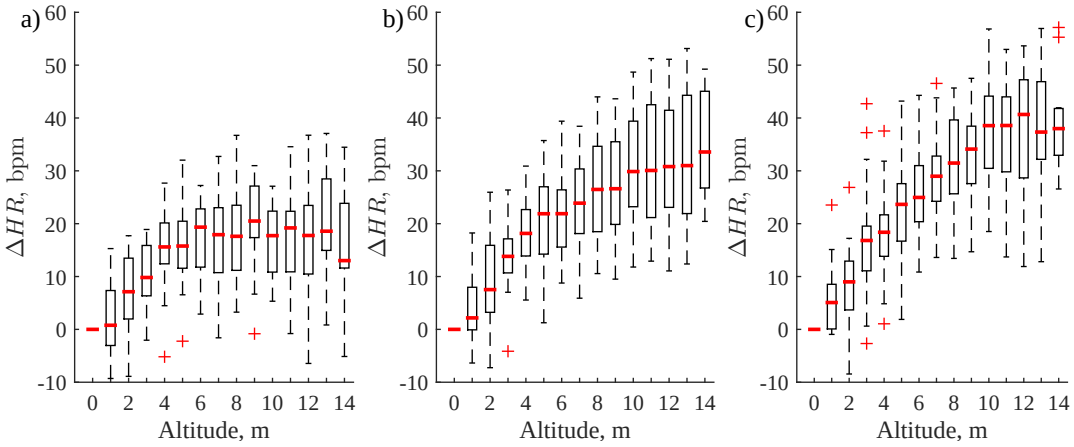

Figure 4: Δ*HR* as a function of altitude for different climbing intensity: a) 48 steps/min, b) 72 steps/min, c) 96 steps/min. Heart rate is averaged over 1 m of altitude. Altitude data was acquired using the custom-made wrist-worn device.

various studies. Common approach is to instruct patients (eg, after lung resection (Kubori et al., 2017)) to climb the maximum number of stairs at a convenient pace, and to stop only due to exhaustion, leg fatigue or chest pain. The ability to climb the stairs largely depends on respiratory system thus the total number of climbed stairs can be complemented with HRR parameters to better represent the status of cardiorespiratory system.

Clinical research shows that most established and reproducible HRR parameters are the decay of heart rate in 60, 120, and 300 s (Peçanha et al., 2017; Fecchio et al., 2019). While a single point measurement is well-suited in a controlled environment (e.g., laboratory), it is less reliable in free-living conditions because it requires accurate detection of the recovery onset. Exponential fitting or a short-term time constant should potentially be more stable than the decay measures since a large part of the recovery phase is involved for estimation. However, our current and previous (Sokas et al., 2019) findings show that this is not the case, probably due to sensitivity of these parameters to the slope of the HRR curve, which is affected by insufficient physical load reducing fitting reliability.

HRR parameters often show increased reproducibility after maximal exercise (Boullosa et al., 2014), which is more similar to the YMCA bench step test. Therefore, parameter estimation error can be reduced at higher climbing rates, assuming that the decay phase will be better expressed. Our study shows that 5 to 10 meters of climbing altitude is required to increase heart rate by 20–30 bpm and reach plateau.

Due to simplicity and similarity to ordinary stair climbing, we selected the YMCA bench step test as a reference test in this study. However, the results may differ if other stair climbing test is employed instead.

5 CONCLUSION

This study shows that most HHR parameters are underestimated after stair climbing however are still comparable to those obtained from the conventional bench step test. The decay of heart rate in 30, 60, and 120 s was estimated with the lowest error.

ACKNOWLEDGEMENTS

This work was financially supported by the Research Council of Lithuania (Agreement No. S-MIP-20-54).

REFERENCES

Boullosa, D. A., Barros, E. S., Del Rosso, S., Nakamura, F. Y., and Leicht, A. S. (2014). Reliability of heart rate measures during walking before and after running maximal efforts. *International Journal of Sports Medicine*, 35(12):999–1005.

Fecchio, R. Y., Brito, L., Leicht, A. S., Forjaz, C. L., and Peçanha, T. (2019). Reproducibility of post-exercise heart rate recovery indices: A systematic review. *Autonomic Neuroscience: Basic and Clinical*, 221:102582.

Golding, L. A., editor (2000). *YMCA Fitness Testing and Assessment Manual*. Human Kinetics Publishers, Champaign, IL, USA, 4th edition.

Hai, J. J., Siu, C. W., Ho, H. H., Li, S. W., Lee, S., and Tse, H. F. (2010). Relationship between changes in heart

rate recovery after cardiac rehabilitation on cardiovascular mortality in patients with myocardial infarction. *Heart Rhythm*, 7(7):929–936.

Jouven, X., Empana, J. P., Schwartz, P. J., Desnos, M., Courbon, D., and Ducimetière, P. (2005). Heart-rate profile during exercise as a predictor of sudden death. *New England Journal of Medicine*, 352(19):1951–1958.

Kubori, Y., Matsuki, R., Hotta, A., Morisawa, T., and Tamaki, A. (2017). Comparison between stair-climbing test and six-minute walk test after lung resection using video-assisted thoracoscopic surgery lobectomy. *Journal of physical therapy science*, 29(5):902–904.

Peçanha, T., Bartels, R., Brito, L. C., Paula-Ribeiro, M., Oliveira, R. S., and Goldberger, J. J. (2017). Methods of assessment of the post-exercise cardiac autonomic recovery: A methodological review. *International Journal of Cardiology*, 227:795–802.

Sokas, D., Petrėnas, A., Daukantas, S., Rapalis, A., Paliakaitė, B., and Marozas, V. (2019). Estimation of heart rate recovery after stair climbing using a wrist-worn device. *Sensors (Switzerland)*, 19(9).

Streuber, S. D., Amsterdam, E. A., and Stebbins, C. L. (2006). Heart rate recovery in heart failure patients after a 12-week cardiac rehabilitation program. *American Journal of Cardiology*, 97(5):694–698.

Thomson, R. L., Buckley, J. D., Noakes, M., Clifton, P. M., Norman, R. J., and Brinkworth, G. D. (2010). Heart rate recovery improves after weight loss in overweight and obese women with polycystic ovary syndrome. *Fertility and Sterility*, 93(4):1173–1178.