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Conference Abstract

Validity of a Commercial Wearable Sensor Measuring Respiratory Frequency in Cycling

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1. Introduction

Evidence suggests that respiratory frequency (f_R) is a valid marker of physical effort during cycling exercise (Nicolò et al., 2017b; Nicolò & Sacchetti, 2023). This variable is closely associated with perceived exertion in different exercise conditions, especially during high-intensity exercise (Nicolò & Sacchetti, 2023). Unlike other physiological variables such as oxygen uptake (VO_2), heart rate (HR) and blood lactate, f_R better reflects the effort experienced by the athletes during intermittent and continuous exercise (Nicoló et al., 2014a). This is also evident in different exercise protocols, including time trials, time-to-exhaustion tests, and all-out exercise (Nicolò et al., 2014b, 2015, 2016, 2017a). Moreover, f_R exhibits a faster response to exercise onset and offset compared to the aforementioned variables. These findings reinforce the notion that f_R provides valuable information during cycling exercise.

The need to monitor f_R during cycling exercise is satisfied by the growing diffusion of unobtrusive wearable technologies (Massaroni et al., 2019; Nicoló et al., 2020). Among these, strain sensors measuring respiratory-induced chest movements are particularly suitable for exercise monitoring as they can be embedded into straps or clothes commonly worn by athletes during training and competitions. However, the increasing availability of commercial wearable devices measuring f_R during exercise is often not accompanied by rigorous validation studies testing their performance.

This study's purpose was to preliminary test the validity of a commercial vest measuring f_R during a cycling protocol, including an intermittent test and a ramp incremental test. This protocol was chosen to test the vest's performance when both abrupt and progressive increases in f_R are expected.

2. Materials and Methods

The validation protocol was performed on an electromagnetically braked cycle ergometer (Lode Excalibur Sport, Groningen, The Netherlands). The commercial device was a Tyme Wear™ (TW) vest (Boston, MA, USA), integrating a strain sensor and recording a respiratory waveform at 25 Hz. This signal was compared with that of a reference respiratory signal recorded at 50 Hz with a metabolic cart (Quark PFT, Cosmed, Rome, Italy). The HR was recorded breath-by-breath with the same metabolic cart.

2.1. Subjects

6 male cyclists (age 23 ± 2 years, stature 173 ± 7 cm, body mass 69 ± 7 kg, VO_{2peak} 59.4 ± 5.9 $ml \cdot kg^{-1} \cdot min^{-1}$) volunteered to participate in the study.

2.2. Design

The validation protocol included an intermittent exercise test and a ramp incremental test. The intermittent test consisted of 10 bouts of effort-modulated exercise of 10 s interspersed by 50 s of recovery. The effort level increased by 10% in each bout and was 100% in the last work bout. The ramp incremental test started from 20 W, and the power output increased by 30 W·min^{-1} until exhaustion ensued.

2.3. Data Analysis

The raw data of both the reference and the commercial devices was processed using custom-made algorithms to extract f_R breath-by-breath data. The f_R values from the two devices were then averaged over 1 s and 30 s to compute the Mean Absolute Error (MAE) and the Mean Absolute Percentage Error (MAPE).

3. Results

The TW raw signal was suitable for extracting f_R during exercise, although the signal-to-noise ratio worsened during cycling sprints (Figure 1A). The time course of f_R recorded with the TW vest resembled that obtained with the reference system both during the intermittent and incremental tests. When the comparison with the reference system was made on second-by-second f_R data, MAE and MAPE values were 1.30 ± 0.38 and 3.77 ± 1.16, respectively. When the comparison was made on 30-s windows, MAE and MAPE values were 0.49 ± 0.23 and 1.55 ± 0.82, respectively.

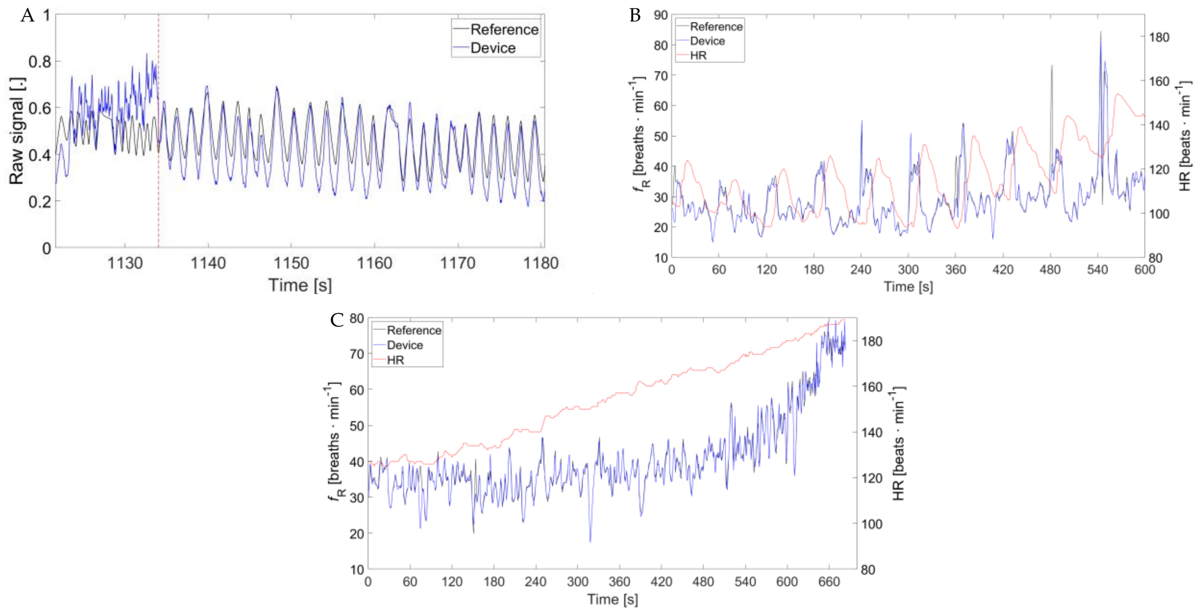

Figure 1. Comparison between the raw respiratory signal of the reference system (black line) and the commercial device (blue line) during the last bout of the intermittent test for a single participant (A). The vertical dashed red line separates the 10 s of work from the 50 s of recovery. Time course of second-by-second f_R (both for the reference and the commercial device) and HR (red line) data during intermittent (B) and incremental (C) exercise for the same participant.

4. Discussion

This study assessed the validity of the TW vest in measuring f_R during cycling exercise. The performance of the commercial device was good when f_R was extracted from the respiratory waveform with a custom-made algorithm. MAE and MAPE values suggest that the performance of the TW vest is similar or even superior compared to that of some other commercial devices tested in previous studies (Kim et al., 2013; Elliot et al., 2019; Antonelli et al., 2020), although the comparison is complicated by the different validation methodologies used. Besides, further investigation is needed to increase the study sample size.

The similar f_R time courses of the TW vest and the reference system suggest that the TW vest is suitable for detecting the fast f_R response commonly observed during intermittent exercise. This is important considering the delayed response of HR observed at the onset and offset of the intermittent exercise bouts (Figure 1B), which is in line with the HR delay found in previous studies (Nicolò et al., 2014b, 2017a). The responses of f_R and HR also differed during the incremental test (Figure 1C), where HR increased almost linearly while f_R increased in an exponential fashion. These findings support the notion that f_R is modulated to a greater extent by central command (i.e., the activity of motor and premotor brain areas) than HR, especially during high-intensity exercise (Nicolò et al., 2016, 2017b). This explains why f_R is a better marker of physical effort than HR. These findings suggest that HR monitoring should be complemented by f_R monitoring during cycling.

5. Conclusions

The TW vest appears suitable for measuring f_R during cycling when a custom algorithm is used to extract f_R from the respiratory waveform. These preliminary findings encourage the use of wearable devices embedding strain sensors to measure f_R during cycling training and competitions.

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