WEARABLE CHEST SENSOR FOR RUNNING STRIDE AND RESPIRATION DETECTION

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Endurance running is one of the most popular physical activities for its low barriers to entry and broad health benefits, but some runners experience unpleasant respiratory distress that prevents participation [1]. Wearable sensors are valuable for monitoring respiratory patterns and distress, and can accurately measure breathing rate and precise breath onset (flow reversal; FR) during running [2]. They may be particularly suitable for biofeedback applications to enhance awareness of physiological phenomena [3], such as locomotor-respiratory coupling (LRC). The aim is a laboratory evaluation of a self-developed wearable device for physiological monitoring during female running and identification of opportunities for improvement of the measurement setup regarding signal quality.

We developed a custom, wearable stride and respiration sensor (SRS) to collect data for algorithm development. It contained a smart textile sensor to measure chest expansion (respiration sensor) and a linear 3-axis accelerometer to measure vertical oscillation (stride sensor). The respiration sensor was integrated into a chest strap and connected to custom electronics with the accelerometer and data logging. The SRS was synchronized with two reference systems, a Cosmed Quark Spiroergometry System (CM; Cosmed, Rome, Italy) for respiration data, tibia-mounted Physilog® IMUs (Gait Up, Switzerland) for stride data. Eleven young female runners (18-30 years old) volunteered for this study and, after a four-minute walking warm-up programme, ran on a treadmill (h/p cosmos sports, Traunstein, Germany) for a total of 20 minutes with varying speeds between 7.5 km/h and 9.0 km/h every five minutes. The University Ethics board approved this study and informed consent was obtained from all participants. To evaluate the SRS, data of the reference systems were processed as described in [4] (stride data) and [2] (respiration data). We compared SRS events to the reference systems by calculating the number of true positives (TP), precision, and recall.

A custom extrema detection algorithm was implemented in R. The step detection algorithm identified minima in a time window of 150 ms before peaks above a

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threshold of 1.1 m/s^2 with an interval between peaks of at least 300 ms as steps. The FR detection algorithm identified minima and maxima with a minimum spacing of 900 ms as FR events (minima: exhale to inhale; maxima: inhale to exhale) in a zero-lag second order Butterworth filter with a cut-off frequency of 0.5 Hz pre-processed signal (Fig. 1).

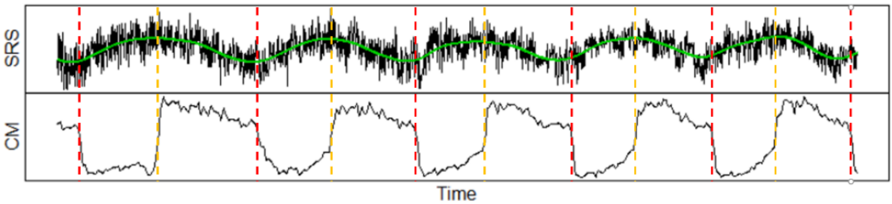

Fig. 1: SRS respiration sensor vs. CM reference (black: raw signal of five breath cycles; green: Butterworth filtered signal; red: FR exhale to inhale; orange: FR inhale to exhale)

The SRS detected steps with a precision of 99.7% and recall of 99.6%. TPs had a mean absolute difference of 22.7±29.4 ms (6.1% relative to mean stride duration) and a bias of 0.05 ms. The SRS detected FR with a precision of 91.9 % and a recall of 87.0 %. TPs had a mean absolute difference of 236.0±288.0 ms (25.6% relative mean breath duration) with a bias of -91.1 ms.

In general, the signal-to-noise ratio of the respiratory signal was low because of a (1) high baseline noise and (2) reduced sensor functionality with an increasing sweat rate. After the presented study, we have already addressed these issues by developing an improved measurement setup to capture capacity changes in picofarad range. First pilot test results illustrate an increased signal-to-noise ratio and in addition, this method enables a waterproof coating of the textile sensor to avoid sweat interference. In conclusion, the SRS proved to be a suitable wearable for LRC component detection during female running. Future improvement will enable low latency feedback for near-instant real-time breathing instructions by avoiding strong filtering and applying complex event detection strategies.

[1] Aliverti, A. (2016). The respiratory muscles during exercise. *Breathe*, *12*(2), 165–168.
[2] Harbour, E., et al. (2021). Enhanced Breathing Pattern Detection during Running Using Wearable Sensors. *Sensors*, *21*(16), 5606.
[3] McKee, D. (2008). Biofeedback: an overview in the context of heart-brain medicine. *Cleveland Clinic journal of medicine, 75*, 31-34.
[4] Aubol, K. G., et al. (2020). Foot contact identification using a single triaxial accelerometer during running. *Journal of Biomechanics*, *105*, 109768.

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