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Applicability of an Earbud Based Biometric Sensor for Measuring Cadence and Heart Rate During Cycling

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ABSTRACT

PURPOSE: The aim of this study was to examine the applicability of an earbud based accelerometer and optical emitter/sensor to monitor cadence (without a physical sensor on the bike) and heart rate during cycling exercise. METHODS: Twenty-one healthy subjects participated in this study (mean ± SD; 35 ± 9 years, 1.68 ± 0.9 m, 69.0 ± 13.5 kg). Each participant completed a single 29.5 min session using a stationary bike fitted with a magnetic benchmark cadence sensor. Subjects wore a benchmark chest strap heart rate monitor and a biometric audio earbud (DUT) in the right ear. Embedded within the audio earbud was an ultra-miniaturized biometric sensor module comprising an accelerometer, an infrared optical emitter, an optical detector, and optical lensing. Each trial consisted of the following: 4 min self-selected cadence utilizing a workload of 100 W, 2 sets of 3 min each at 60, 80, 95 rpm, 2 sets of 1.5 min at 80 rpm followed by 30 sec of high cadence resulting in cadences > 100 rpm, and one set of 1.5 min at 80 rpm, 30 sec at 0 rpm, 1.5 min at 80 rpm (power range 100-200 W). All data were recorded and averaged over 2 second intervals. RESULTS: Cadence during the trial was 79 ± 18 and 79 ± 16 rpm (mean ± SD) for the magnetic cadence sensor and earbud based accelerometer respectively. Analysis of the relation between the magnetic sensor and the earbud sensor resulted in a mean bias of 0.04 with limits of agreement (LOA) between -19 and 19. Correlation between the two methods of cadence measurement was high, r^2=0.72. Results improved when examining cadence between 50 and 100 rpm. With cadences between 50 and 100 rpm bias was -0.17, LOA of -8 and 7 rpm, r^2=0.89. Heart rate during the trials averaged 127 ± 21.9 b/min and ranged from 75 to 182 beats for both devices with a bias of 0.06, LOA of -3 to 3 b/min, and r^2=0.99. There were no significant differences (paired samples t-test) between the devices for cadence or heart rate ($p \leq 0.05$) CONCLUSIONS: This study examined the use of an earbud based system to monitor cadence and heart rate during cycling. Cadence monitoring by the system performed well with better accuracy at steady state. Heart rate assessment via the optical sensors was accurate, and limits of agreement within an acceptable range, for heart rate monitoring during exercise.

INTRODUCTION

Heart rate (HR) is one of the most commonly used physiological variables in both the clinical and performance/athletic settings. Through various calculations or assessments, HR is frequently used to prescribe exercise to apparently healthy and diseased populations (Garber et al. 2011) and set intensity thresholds for amateur and professional athletes (Hofmann et al. 1994; Boulay et al. 1997). Additionally, during cycling cadence is utilized to find an energetically optimal pedaling rate generally shown to be between 75 and 90 rev/min (Marsh and Martin 1997; Brisswalter et al. 2000). Over the years, several companies have introduced a direct real-time heart rate monitor (HRM) which consists of a chest strap transmitter and a wrist watch-like receiver (Achten and Jeukendrup 2003). While cadence is measure utilizing a magnetic sensor attached to the bicycle crank and frame. Recently, advancements in technology have allowed for the development of alternative methods for direct, real time, sensors in a form-factor that may provide alternatives to chest strap HRMs and mechanical cadence sensors. The PerformTek® sensor (Valencell, Inc., Raleigh NC) uses an approach akin to reflective photoplethysmography (PPG) which allows the integration of sensor technology into music earbuds and headsets for measuring continuous HR. Moreover, a 3-axis accelerometer within the earbud allows for the assessment of cycling cadence without the need for additional sensors on the bike. To our knowledge, there are a limited number of reports that have examined the accuracy of strapless HRMs and none that have examined the use of an accelerometer in an earbud to monitor cycling cadence. Therefore, **the purpose of the study was twofold: 1) to examine the**

validity of the PerformTek sensor to measure continuous HR during dynamic indoor cycling and 2) to assess the validity of the of the PerformTek sensor to monitor cadence during dynamic indoor cycling.

METHODS

Participants
Twenty-one healthy subjects participated in this study (mean ± SD; 35 ± 9 years, 1.68 ± 0.9 m, 69.0 ± 13.5 kg) volunteered to take part in the study. Prior to commencing the study, all subjects received a detailed explanation of both the benefits and the risks involved with the study, completed a medical history form and gave written consent.
Procedures
Participants visited the laboratory one time during the study. During preliminary preparation, subjects were asked to sit on the bike while the benchmark chest strap (polar cx800, Polar Electro, Kempele, Finland) was positioned on the chest and the earbuds (PerformTek, Valencell Inc., Raleigh, NC) were inserted to their ear. Additionally, a magnetic benchmark cadence sensor (polar Wind cadence, Polar Electro) was affixed to the bike. The data collected via the chest strap and magnetic cadence sensor were transmitted via radio frequency to a watch and earbud sensor data were transmitted via Bluetooth signal to a laptop PC for collection and analysis. Following preliminary preparation, the participants were asked to complete a 2-min orientation trial to familiarize themselves with the workloads and cadence ranges followed by the completion of a 29.5 minute cycling protocol trial consisting of the following: 4 min self-selected cadence utilizing a workload of 100 W, 2 sets of 3 min each at 60, 80, 95 rpm, 2 sets of 1.5 min at 80 rpm followed by 30 sec of high cadence resulting in cadences > 100 rpm, and one set of 1.5 min at 80 rpm, 30 sec at 0 rpm, 1.5 min at 80 rpm (power range 100-200 W). Once the trial commenced, heart rate and cadence were recorded concurrently by the magnetic cadence sensor, chest strap, and earbud. Each device recorded a two-second average HR and cadence for a total of 885 data points per subject during each trial .
Statistical analysis
Statistical analysis was examined validation using bias, 95% limits of agreement, Pearson product–moment correlation coefficients, and paired samples T-test.

RESULTS

Significant positive correlations ($p < 0.05$) were observed between the earbud sensor and the chest strap (Figure 1B) and between the earbud sensor and magnetic cadence sensor (Figure 2B). Further examination of mean, bias, 95% confidence intervals, and sample distribution (Table 1 and Figures 1 and 2) demonstrate significant ($p < 0.05$) validity of the earbud sensor.

Table 1 Summary statistics for earbud heart rate and cadence

	heart rate		cadence overall		cadence 50-100 rev/min		cadence >100 rev/min	
	Chest strap	earbud	Magnetic sensor	earbud	Magnetic sensor	earbud	Magnetic sensor	earbud
Mean ± SD	127 ±22	127 ±22	79 ±18	79 ±16	79 ± 12	79 ±12	124 ±15	107 ±23
Bias	0.06		0.04		-0.17		-17	
95% LOA	3 to -3		19 to -19		7 to -8		10 to -45	
Correlation (R^2)	0.99		0.72		0.89		0.05	

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Figure 1A-D. Summary of heart rate data. A) Heart rate average for trial; B) regression between earbud and chest strap; C) Bland-Altman Analysis; D) frequency distribution.

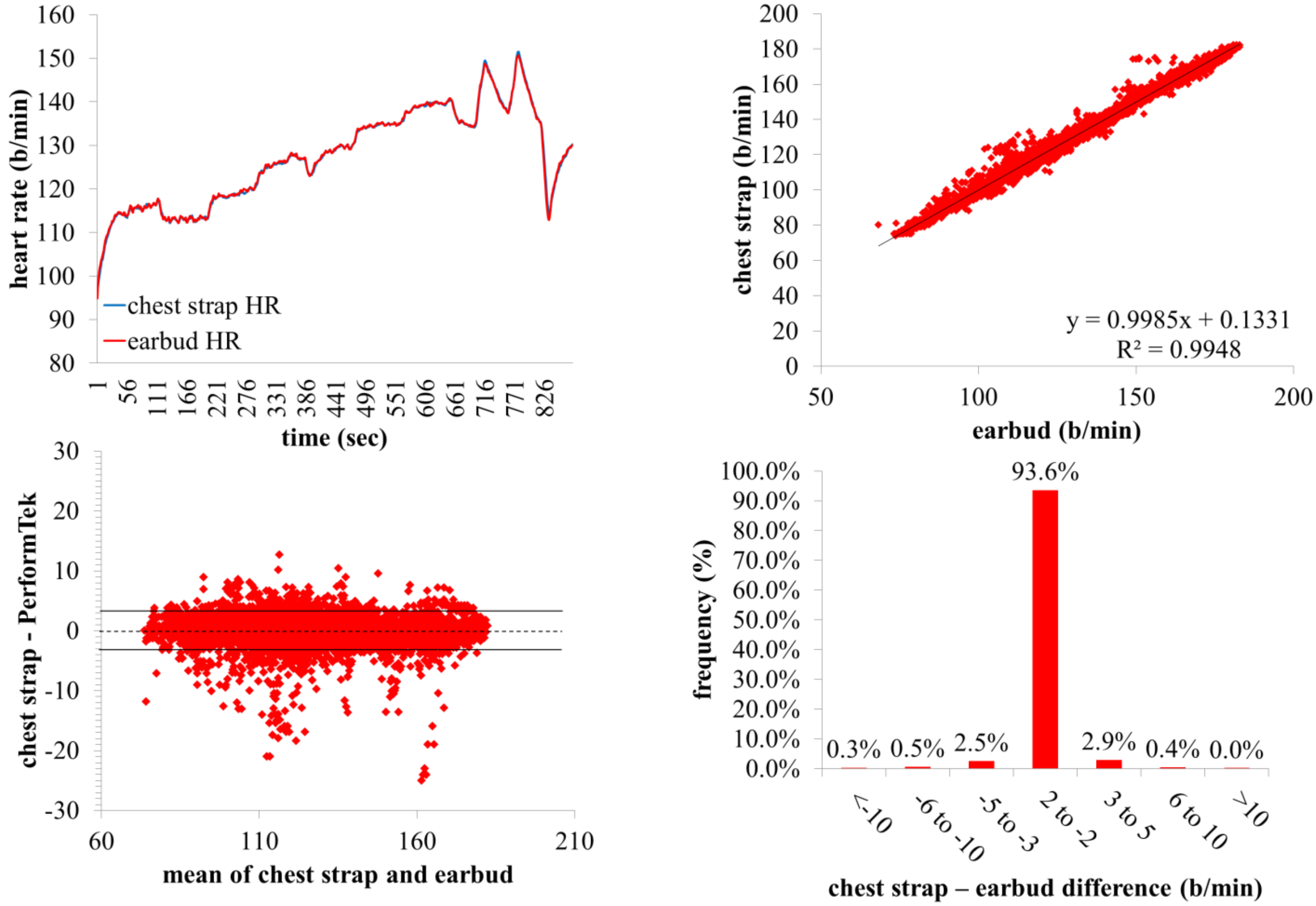
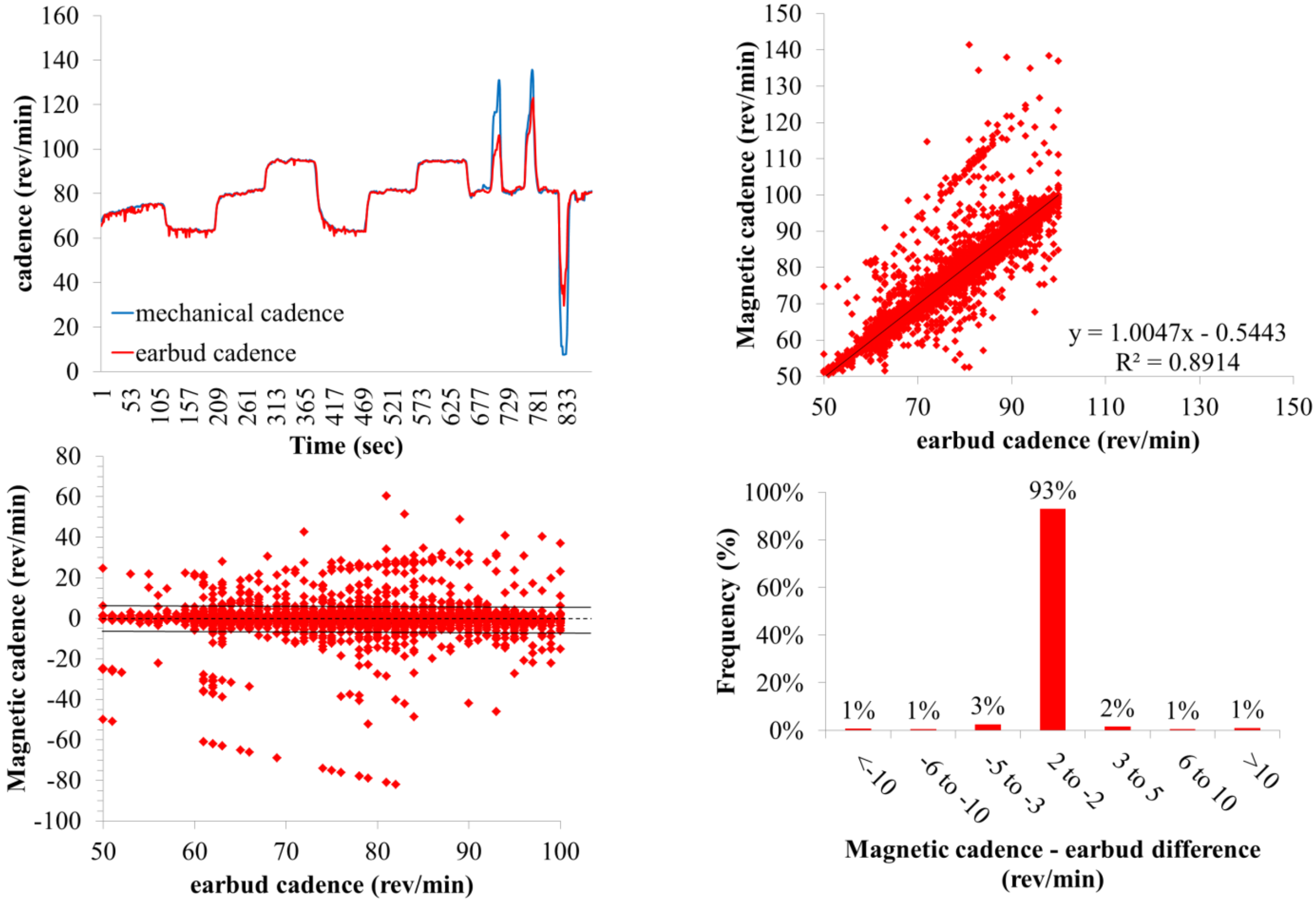


Figure 2A-D. Summary of 50-100 rev/min cadence data. A) average for trial; B) regression of earbud and magnetic sensor; C) Bland-Altman analysis; D) frequency distribution.



CONCLUSIONS

An earbud based sensor provides a valid measure of heart rate during dynamic cycling resulting in a wide range of observed heart rates.

Measurement of cadence utilizing an earbud based accelerometer provides valid measurement of cadences across ranges generally used by both recreational and professional cyclists.

Validated earbud based sensors provide a seamless system to the individual including the ability to listen to music and monitor biometrics and cadence without the need for additional sensors or mechanical devices on the bike.