Technical Feasibility of QuasaR™'s (Wearable Medical Device) Haptic Feedback Building Cardiac Endurance

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Abstract

Background

Think Biosolution is an original design manufacturer (ODM), building privately labelled wearable medical devices and customized software platform for telehealth brands in the EU and USA. Product Overview: The The QuasaR™ device is worn on the user's chest with a strap. The QuasaR™ device is built using our patented optical sensor for measuring biometric data such as heart rate, respiratory rate, blood oxygen saturation, heart rate variability. The wearable device has additional sensors to measure temperature, movement and location. The data is then transferred to an EMR compatible (HL-7/FHIR) and HIPAA compliant cloud server using a smartphone or a hub. This information can be viewed by the user, physician or a coach using a customized "smart" dashboard on a smartphone and/or a desktop.

We have 3 smart platforms with increasing feature sets for the remote health monitoring marketplace, (1) Continuous Monitoring Platform: Periodically tracks patient's vitals and motion, and the dashboard automatically tags and summarises clinically important events (Such as a sudden increase or decrease in heart rate). (2) Stress Monitoring Platform: In addition to tracking the patient's vitals and motion, the dashboard automatically tags and summarises stress events. (3) Care Platform: In addition to tracking the patient's vitals, motion and location, the caregiver can use the dashboard to set up reminders for the patient to exercise.

Objective

In this feasibility study, we try to understand whether QuasaR™'s haptic feedback can actually help athletes to build cardiac endurance faster than training with a professional running coach, while reducing the risk of injury. If successful, this haptic feedback based endurance building feature will be a key feature of a new platform called Smart Running Coach.

Methods

We first discuss the method by which we measure heart rate running speed index using QuasaR™ device. We then discuss the method by which we our haptic engine can keep a participant run at a particular speed. We then discuss how the athletes training for the first and second month.

Results

We analyzed thirty subjects (Mean age is 39 years, weight is 78 kg, height of 163 cm). For QuasaR™ device while the subject is resting, the measured heart rate [Avg=66.3 BPM, Min= 43.1 BPM, Max=83.0 BPM}. The average heart rate running speed index before the study was 0.39. While training for a month changed the average heart rate running speed index to -25% i.e. 0.29. Training with QuasaR™ device in the subsequent month further changed the average heart rate running speed index by -42% i.e. 0.22 (compared to starting values).

Conclusions

QuasaR™ device can increased the average heart rate running speed more efficiently than training with a running coach.

Introduction

Professional and amateur athletes who wants to do endurance training, often works with a professional coach and an indoor sports laboratory to precisely determine their training. However, such coaching is often expensive and needs to be reinforced on a monthly or even a weekly basis for continuous monitoring of training adaptation. Professional athletes and coaches are also using GPS trackers coupled with single lead ECG based heart rate trackers to monitor endurance while exercising outside. Therefore, the development of a non-invasive and automated training method with a wearable device will make endurance training accessible to potential endurance athletes.

The primary objective of endurance training is to lower the athlete's heart rate while running. In order to do so the athletes are made to run at a particular speed called vVO2max (velocity at maximal oxygen uptake). For professional athletes the vVO2max training is executed in indoor sports laboratory, whereas for amateur athletes the training is done with a pacer i.e. a secondary athlete who helps the primary athlete maintain running speed. vVO2max is the minimum speed for which the athlete's maximal oxygen uptake is reached (after a few minutes of exercise at this intensity); at higher paces, additional power is entirely delivered by anaerobic processes. At vVO2max pace, blood lactate in the muscles reaches levels around 8-10 mM. In addition to running at their vVO2max, an optimal training program should prevent overtraining and stress-related injuries.

Heart rate has a sigmoidal relationship with running speed (or any exercise intensity). It has been reported in sports science literature, that the autonomic nervous system has a direct effect on heart rate and is an important factor in acute and chronic adaptation to training. However, there are many well-established factors such as duration and intensity of exercise, cardiac drift, dehydration, day-to-day variation, and environmental factors that influence heart rate response and may disturb the relationship between heart rate and running speed in a single exercise. Consequently, the relationship between heart rate and running needs to be assessed over longer timescales such as a few weeks or months.

II. Method

A. QuasaR™ Device

The QuasaR™ device is built using a custom PCB based and has the following components, a color sensor made by AMS, 9DoF MEMS sensor, MCU, Bluetooth module, power management IC, human body temperature sensor, GPS system and a haptic motor. The color sensor with a red and an infrared LED on either side of it at a distance of 12.5mm is used as the sensor module. The QuasaR™ device is further enclosed in a 3D printed plastic enclosure and is held in position using a chest-belt where the pressure on the upper sternum is adjustable. The device is shown in Figure. 1.

Figure 1.QuasaR™ device and strap system

The QuasaR™ device measures heart rate once every two minutes using the continuous capture mode where the IR LED is kept on for 10 seconds, and the color sensor is set up to capture at 30 frames per second. Simultaneously running speed is computed using the 9DoF motion sensor,

B. Heart rate running speed index

The QuasaR™ device combines the running speed data with the heart rate data to first plot a graph as shown in Fig. 2. The linear relationship between heart rate and running speed is the basis of computation of heart rate running speed index, which represents the absolute difference between the theoretical and actual running speed.

The device first compute $HR_{standing}$ from resting heart rate (HR_{rest}) with an equation $HR_{standing} = HR_{rest} + 26$ (based on observations of Hynynen et al.). We then compute the slope of heart rate as a function of running speed "k" as,

$K = (HR_{max} - HR_{standing})/(RS_{max}-RS_{standing}) = (HR_{max} - HR_{standing})/(RS_{max})$

This slope is shown as a red line in Fig 2. The heart rate running speed index is then computed using,

Heart Rate Running Speed Index = $S_{Avg} - ((HR_{Avg} - HR_{standing})/K)$

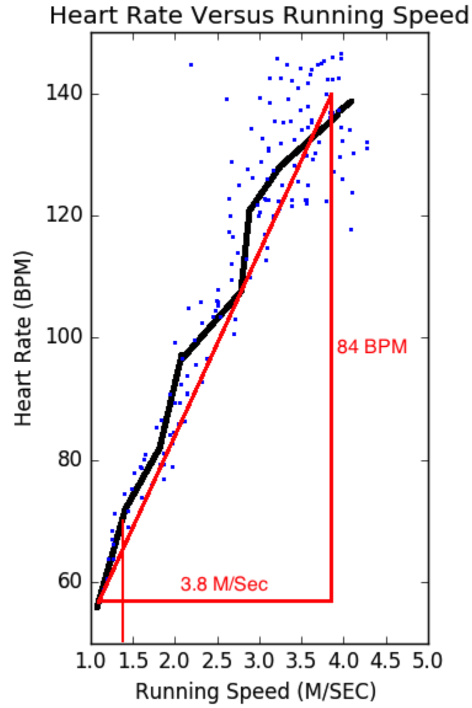

Figure 2. Heart rate versus running speed and therefore the derived value K.

C. Haptic engine

Table 1. Haptic engine feedback modes.

Speed	Vibration Type	Vibration Intensity (A.U.)
>10% More	Buzz	1
>10 % Less	Buzz – Pause - Buzz	1
>20% More	Buzz	2
>20% More	Buzz – Pause - Buzz	2

Since the QuasaR™device can measure speed and has a built-in haptic motor, the QuasaR™device's haptic engine can combine both to keep the users running at a particular pace. The haptic engine is an automated reminder engine that vibrates in two separate intensities depending on how much faster and slower the participants is to the target speed. If the participant is 10% or more faster or slower it vibrates with a certain intensity (4 in arbitrary units), and if the participant is 20% or more faster or slower it vibrates with double the intensity (8 in arbitrary units.). Also, in case the participant is running faster than the target speed the device vibrates in a particular way (continues to vibrate), and if the participant is running faster than the target speed the device vibrates in a particular way (vibrate – pause - vibrate). Our previous studies have shown that this haptic feedback can help runners maintain their pace.

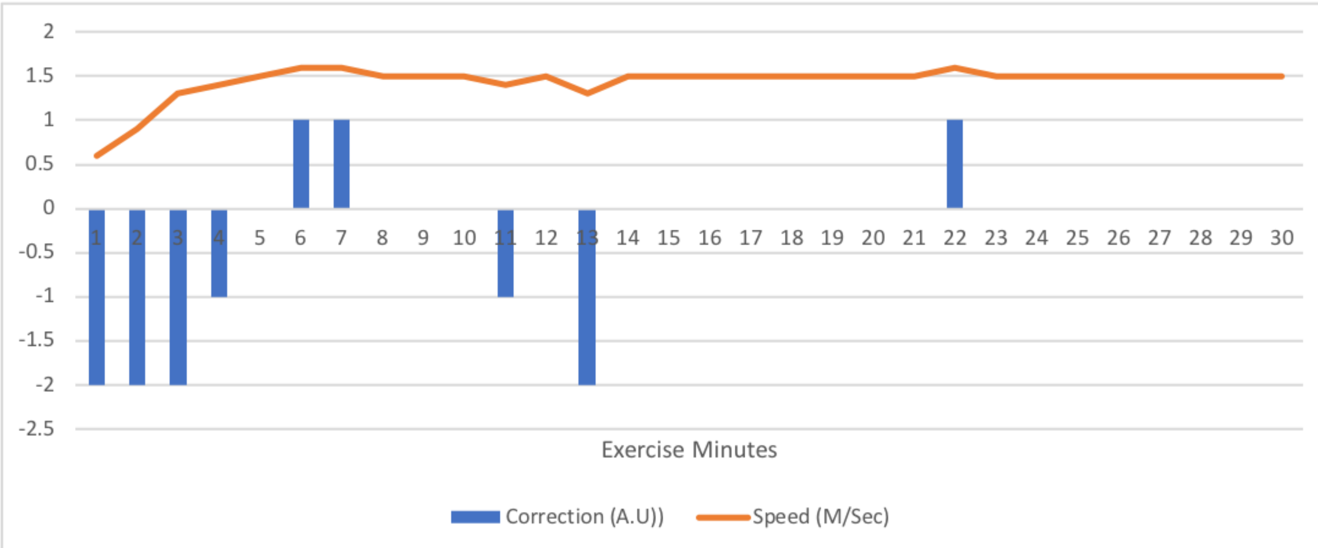

Figure 3. Example of how haptic engine keeps participant in target speed

D. Exercise regimen

The vVO2max of each participants were calculated at the beginning of the study. This was the target speed at which they agreed to train, for the times a week for the next eight weeks. The daily running schedule was for an hour. For the first four weeks they ran a given pre-determined distance in the first hour (which on average should keep them running at their vVO2max). In the next four weeks they ran in the same route but with QuasaR™ device and haptic feedback turned on. The haptic feedback as motioned in the above section gave live two sets of haptic feedback when the athlete's missed their ±10% or ±20% of their target speed.

Each athlete's heart rate running speed index was measured three times, one at the beginning of the study, once after four weeks of training on their own, and finally after four weeks of training with the once at the end of the eight weeks i.e. after four weeks of training with QuasaR™ device and haptic feedback turned on.

IV. Results and Discussions

A. Participants and Recruitment

Random selection of subjects who volunteered to be part of the study from within the office space of the National Digital Research Centre (NDRC), Dublin 8, provides us with a convenient sample. Of the 30 healthy subjects 66% (n=20) identified as male (mean age was 34 years) and 33% identified as female (mean age was 29 years). The participants had an average weight of 76 kg, average height of 168 cm. Exclusion criteria include refusal to give voluntary written informed consent. All the subjects identified themselves as amateur athletes and ran at least 100 minutes per week for a year before the start of the study. Most athletes ran outside in running tracks or parks in the Dublin 8 region during the duration of the study i.e. October 2018 to April 2019

B. Comparison of heart rate running speed index

In this section we show the heart rate running speed index computed from the thirty participants is shown in Table 2 and Fig.4 . The average heart rate running speed index before the study was 0.39. While training for a month changed the average heart rate running speed index to -25% i.e. 0.29. Training with QuasaR™ device in the subsequent month further changed the average heart rate running speed index by -42% i.e. 0.22 (compared to starting values).

Also, their corresponding vVO2max i.e. the speed at which they were supposed to run for the eight weeks period.

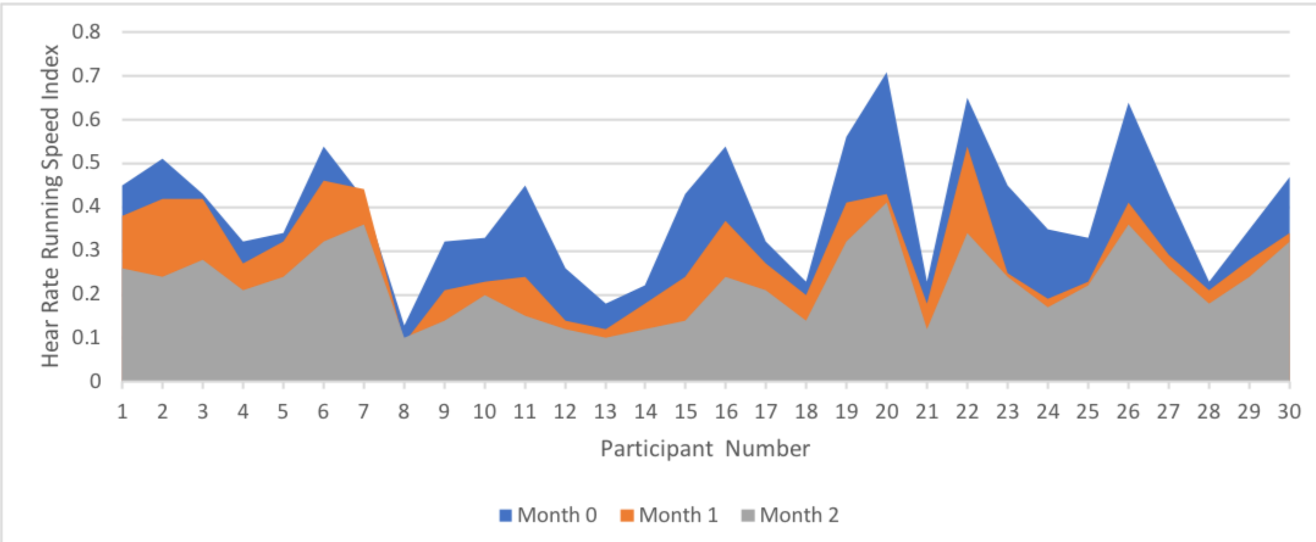

Figure 4. .Heart Rate Running Speed Index measured from each participant at the end of Month 0, Month 1 and Month 2.

Table 2. Heart Rate Running Speed Index measured from each participant at the end of Month 0, Month 1 and Month 2.

Participant Number	vVO2max (M/Sec)	Heart Rate Running Speed Index		
		Month 0	Month 1	Month 2
1	1.5	0.45	0.38	0.26
2	1.6	0.51	0.42	0.24
3	1.4	0.43	0.42	0.28
4	1.3	0.32	0.27	0.21
5	1.5	0.34	0.32	0.24
6	1	0.54	0.46	0.32
7	1.2	0.42	0.44	0.36
8	1.4	0.13	0.09	0.1

9	1.4	0.32	0.21	0.14
10	1.1	0.33	0.23	0.2
11	0.9	0.45	0.24	0.15
12	0.8	0.26	0.14	0.12
13	1.4	0.18	0.12	0.1
14	1.3	0.22	0.18	0.12
15	1.2	0.43	0.24	0.14
16	1.4	0.54	0.37	0.24
17	1.4	0.32	0.27	0.21
18	1.3	0.23	0.2	0.14
19	1.2	0.56	0.41	0.32
20	1.4	0.71	0.43	0.41
21	1.3	0.23	0.18	0.12
22	1.3	0.65	0.54	0.34
23	1.5	0.45	0.25	0.24
24	1.4	0.35	0.19	0.17
25	1.5	0.33	0.23	0.22
26	1.4	0.64	0.41	0.36
27	1.2	0.43	0.29	0.26
28	1.1	0.23	0.21	0.18
29	1.2	0.35	0.28	0.24
30	1.1	0.47	0.34	0.32