Optical Heart Rate Monitoring Module Validation Study

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Abstract - **Optical heart rate monitoring (OHRM) offers an unobtrusive solution for continuously measuring heart rate. An OHRM prototype, able to correct for movement artifacts during physical activity, proved to be valid to continuously monitor heart rate during activities including running, allowing monitoring cardiovascular condition in response to fitness and home activities.**

I. INTRODUCTION

Photoplethysmography offers an unobtrusive solution for measuring heart rate. Movement artifacts restricted applications of this technology to confined subjects in a medical environment [1,2]. Several signal processing methods have been studied to reduce motion artifacts. The results had big delay, [3] required offline processing [4] or showed insufficient improvements in heart-rate measurement [5] and therefore were not implemented for free-living applications. A prototype of Optical Heart Rate Module[1] (OHRM, Figure 1) has been developed to be unobtrusive and allowing to correct for movement artifacts during physical activity. The electronics of the module include an accelerometer to gather data with compensation of movement artifacts in the optical signal. OHRM was validated in December 2011 with a standard electrocardiogram (ECG) as reference in order to indicate further improvements. Additionally, heart rate was monitored with a chest-strap device to compare performances between OHRM and chest-strap device[2].

II. METHODS

Subjects were 10 women and 14 men, age 28±9 year, body mass index 22.1±2.8 kg/m^2. Five were Asian (medium colored skin), one was African (dark skin) the remaining 18 were Caucasian (white skin). The standard activity protocol included, respectively, lying, standing, walking to warm up, running at increasing speed up to exhaustion, walking to cool down, and sitting. The total protocol lasted 42±5 min, where speed profile was adapted to subjects' capacities. To allow a comparison between subjects, running activity was split in three speed intervals: speed ≤9 km/h, speed between 9 and 16 km/h and speed >16km/h.

Figure 1: The optical sensor (above) and the accelerometer (below) with the connection to the optical sensor mounted on the wrist.

Each second, OHRM output consisted of a heart rate measurement and of a proprietary index of quality (D) ranging from 0 (bad quality) to 6 (good quality). The reference was a 200Hz ECG, averaging the number of beats over approximately 7s. The resulting signal was linearly interpolated and re-sampled to compare it to OHRM and chest-strap device. Chest-strap device output consisted of one heart rate measurement each second. Noisy ECG data were unreferenced and discarded. Data were valid when D≥2. Uptime was calculated as percentage of valid data. Invalid data was automatically rejected by OHRM. Chest-strap data were collected from the watch in HR mode.

[1] Alpha (Philips research, Eindhoven, The Netherlands, http://alphaheartrate.com/)
[2] Polar RS400 (Polar Electro Oy, Kempele, Finland)

Errors were calculated each second as differences between OHRM or chest-strap device and ECG. The average error over each activity and over the total time for every subject indicates accuracy. Standard deviation of errors indicates precision. Two tailed paired t-tests compared accuracy and precision between activities or between OHRM and chest-strap device. Pearson correlation coefficient (r) was used to describe the association between OHRM performances and subjects' characteristics.

III. RESULTS

Overall OHRM showed high performances with a non-significant error of -0.1±0.3 bpm and a precision of 3±1 bpm (Table 1).

OHRM uptime (D≥2) was on average 86±14 % of the protocol time. The uptime during 'walk1' was significantly lower than the total uptime (73 % vs 86 %, $p<0.01$). Low blood perfusion of the skin after lying and standing reduced the signal amplitude and therefore the signal-noise ratio. This led to frequent data rejection. During 'run3' data uptime was also lower (55 %). During this task blood perfusion was high and heart rate was correctly measured by the OHRM. Nevertheless the index D was often lower than 2, leading to frequent rejection of accurate data. This is considered an evidence of a lack in specificity of this index during high speed running. Only 3 subjects were able to perform 'run3' therefore no t-test was performed for this activity. During activities with low uptime, accuracy and precision of the valid data were comparable to those during the total time ($p=0.26$ and $p=0.19$). This indicates that D has a high sensitivity. In this study D index was sensitive enough although there is evidence that specificity was insufficient during high speed running.

Precision tended to be higher in subjects with a higher body mass index ($r=0.35$).

OHRM had a higher accuracy (-0.1 bpm vs 0.3 bpm, $p<0.001$) but a lower precision (3.0 bpm vs 2.0 bpm, $p<0.001$) than chest-strap device. These differences were small and of no impact on any application. The absence of a belt makes OHRM less obtrusive than a chest-strap device, preserving accuracy and precision.

Improvements in the specificity of the proprietary index D could reduce the automatic rejection of valid data, increasing the uptime. Specific studies about the effect of high speed could indicate further possible improvements.

Table 1: Statistical analysis of all the activities.

	N	Uptime		O-E		CS-E	
				mean	stdev	mean	stdev
		%	min	bpm	bpm	bpm	bpm
Tot	24	86	35	-0.1	3	0.3	2
supine	24	96	10	-0.1	2	0.3	1.8
stand	24	83	4	-0.1	4.6	0.8	2.8
walk1	24	73	4	-0.5	3.7	0.3	1.9
run1	24	85	6	-0.4	1.9	0.4	1.2
run2	20	82	5	-0.4	1.8	0.3	0.9
run3	3	55	2	0.8	1.8	0.7	1.6
walk2	22	94	4	0.5	1.4	0	1.1
sit	24	94	3	0.1	1.8	0.1	1.6

N, number of subjects; Uptime, time in which the proprietary quality index (D) was >2 expressed in percentage and in minutes; O-E, difference between the heart rate as measured by the optical heart rate monitor and the electrocardiogram; CS-E, difference between the heart rate as measured by the chest-strap device and the electrocardiogram; Tot, total time of valid data; supine, lying down in supine position; stand, standing still; walk1, walking after resting; run1, running up to 9 km/h; run2, running between 9 and 16 km/h; run3, running at 20 km/h; walk2, walking after running; sit, sitting.

IV. CONCLUSIONS

This optical heart rate monitoring module is a valid and unobtrusive device to monitor heart rate, not restricted by movement artifacts during physical activities including running, allowing monitoring cardiovascular condition in response to fitness and home health care activities.

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