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Proceeding Paper

"Smart Clothing" Technology for Heart Function Monitoring during a Session of "Dry" Immersion †

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Abstract: The study aimed at obtaining precise view of modification of heart rate variability (HRV) and respiratory rate with help of "smart clothes" (the Hexoskin Smart Shirt, Hexoskin Smart Sensors & AI, Montreal, QC, Canada) during 45-min session of "dry" immersion (DI), which is considered a model of Earth-based weightlessness. Eight healthy subjects aged from 19 to 21 years participated in the study. Hexoskin Smart Shirt provided a .wav sound file. For analysis, the ecg_peaks function of the neurokit2 library was applied. HRV parameters were calculated within 5-min segments with help of the pyHRV toolbox. Time-domain (HR, SDNN) and frequency-domain (HF, LF, VLF) HRV parameters, sample and approximate entropy were calculated. Thus, the "smart clothes" technology appears as a reliable telemetric instrument to monitor cardiac and respiratory regulation during the DI session.

Keywords: "dry" immersion; microgravity; "smart clothes"; heart rate variability; autonomic function

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1. Introduction

Weightlessness is efficiently simulated with help of such ground-based models as head down bed rest, unilateral lower limb suspension, parabolic flight, free-fall machine, and "wet" and "dry" immersion (DI) [1,2]. These Earth-based experiments allow exploring gravity-dependent physiological responses without launching humans into space [1,2]. DI is reproduced by immersion in thermally comfortable fresh water without direct contact with water [3]. DI is considered to be the closest to real space conditions, since it initiates a response to simulated weightlessness much earlier than, for example, a head-down position [3]. Moreover, DI does not require costly tools, such as aircraft or free-fall machine.

In recent years, suborbital space tourism is rapidly developed [4]. Typically, suborbital space travel lasts from 3–5 min to one hour [4,5]. Most experiments with modeled weightlessness last from a few days to a few weeks, simulating short-term space flight [1,6]. Only a few studies have reported on early effects of DI during long-term immersions [7,8].

It can be assumed that a 45-min DI session would have represented reliable conditions to study ultrashort-term (minutes) effects of the modeled weightlessness on a human body [9]. It has been earlier showed that following a 45-min session of DI muscle rigidity in subjects with Parkinson's disease is decreased, arterial blood pressure is decreased [8,9], and most HRV parameters are modified in direction of more "normal" values, either in older or younger subjects [8,9].

Assessment of a physiological function in laboratory conditions is regarded as "gold standard" methods. However, being in laboratory conditions means confound of the experimental environment (communication with experimenters, measuring procedures, and familiarization). In this respect, field conditions are preferential, but even in field conditions "…simply being in the field—no matter how physically challenging the task being performed—does influence physiology" [10] p. 10.

Therefore, it looks important to monitor physiological parameters under specific stressful conditions (extravehicle activities in space, exploratory activities on Martian surface, etc.) in a monitoring regime [10]. This means that the best way to assess a function is to conduct measurements within the framework of daily life activities, with minimal possible awareness of the subject that the experiment is actually going on. Using the "smart clothes" (textile sensors), along with "smartphone-based" technologies seems to be the most attractive and efficient solution to minimize intervening of a subject in the experimental environment.

"Smart clothes" technology is an emerging field in physiological studies because it is suitable for monitoring body functions in daily life activities and under stress. Typically, "smart clothes" allow monitoring heart rate (HR), heart rate variability (HRV), skin sympathetic response, respiratory rate, skin temperature, and motility [11–13]. Recently, we found "smart clothes" reliable for monitoring the cardiac function during stress tests [14].

Altogether, the aim of the study was dual. First, we aimed at testing the reliability of "smart clothes" technology as a research instrument in ground-based space experiments. Since the Hexoskin Smart Shirt provides a reliable electrocardiographic signal [11–13], it was chosen as a tool for recording physiological parameters. In addition, we assessed HRV parameters in the regime of continuous monitoring during 45-min DI session, with specific interest to first several minutes of immersion and time period right after the immersion.

2. Materials and Methods

2.1. Subjects and Protocol

Eight apparently healthy subjects, without chronic somatic and neurological disease, aged 19 to 25 years, were recruited to the study from November 2021 to February 2022. All subjects signed their informed consent before the study. Their anthropometric characteristics are presented in Table 1. The study protocol was approved by joint Ethic committee of the Ministry of Health care of the Republic of Karelia and Petrozavodsk State University (PetrSU) (Statement of approval No. 31, 18 December 2014). In anamnesis, none of the subjects had brain trauma, arterial either hyper- or hypotension, thrombophlebitis, acute inflammatory diseases, cardiac arrhythmia, which were non-inclusion criteria for DI [9].

Table 1. Anthropometric characteristics of the subjects participated the study.

Parameter	Men (n = 4)	Women (n = 5)
Body Mass, kg	67.8 ± 2.9	60.6 ± 5.9
Height, m	1.81 ± 0.03	1.68 ± 0.05
BMI [1]	20.6 ± 0.8	21.5 ± 3.2

[1] BMI, body mass index.

2.2. "Dry" Immersion Session

The DI is reproduced using the "Medical Installation of Artificial Weightlessness" (MEDSIM, Center for Aerospace Medicine and Technology, State Research Center of the Russian Federation "Institute of Medical and Biological Problems", Moscow, Russia), located at PetrSU. In our previous studies, the DI procedure was thoroughly described [8,9]. In brief, MEDSIM appears a bathtub filled with 2 m^3 of regularly aerated and filtered fresh water. The bathtub was covered with a waterproof fabric of a large size (3 × 4 m^2), which allowed wrapping the subject. Before DI, blood pressure (BP) was assessed with help of digital tonometer (UA-767, A&D Company Ltd., Tokyo, Japan). BP below 140/90 mmHg allowed to start the DI procedure [13]. The duration of the DI session was 45 min. After DI, the subjects stood lying supine for further 5–10 min and then with caution stood up, under visual control of experimenters.

2.3. ECG Acquisition and HR Data Processing

The HR data was acquired with help of the Hexoskin Smart Shirt (Hexoskin Smart Sensors & AI, Montreal, QC, Canada). The measurement setup is shown in Figure 1. After shirt was put on the subject, it was connected to the logger. The collected data from the logger was loaded into the HxServices software (v.4.05). The Hexoskin Smarth Shirt allows generating a zip archive, which contains several files, including the RR_interval.csv file (intervals between neighboring R waves on ECG). An example of such a file is presented on Figure 2. The file is in .csv format, consisting of two columns: time and interval. A representative graph of calculated HR is presented on Figure 3.

(**a**) (**b**)

Figure 1. Hexoskin Smart Shirt (**a**) and the measurement setup (**b**).

```
time [s],RR_interval [s/256](/api/datatype/18/)
5.37109375,0
5.9375,145
6.5,144
7.04296875,139
7.59765625,142
8.15234375,142
8.703125,141
9.2578125,142
9.80859375,141
```

Figure 2. Example file RR_interval.csv.

Extraction of ECG data and processing of HR signal is described in [15]. In brief, Hexoskin Smart Shirt provided a .wav sound file. To extract signal peaks from a .wav file, we used the ecg_peaks function of the neurokit2 library [15,16]. With a known value of the analogue ECG frequency for HxS (256 Hz), the time value between peaks was calculated (RR interval, RRi). The obtained data set of RRi was filtered with cutoff HR values < 45 and >180 beat per min [14]. HRV parameters were calculated for 5 min consecutive segments using the py-HRV toolkit [15,16]. For each record, the start time points of the beginning and the end of the DI session were marked; 11 time interval were taken into analysis: one 5-min interval before DI; nine 5-min intervals from the beginning to the end of DI; one 5-min interval after the end of DI (lying supine). To smooth the resulting series, the following technique was used: the original signal was divided into 30-s intervals, and for each such interval, using the pyHRV library; median values were computed (Figure 4).

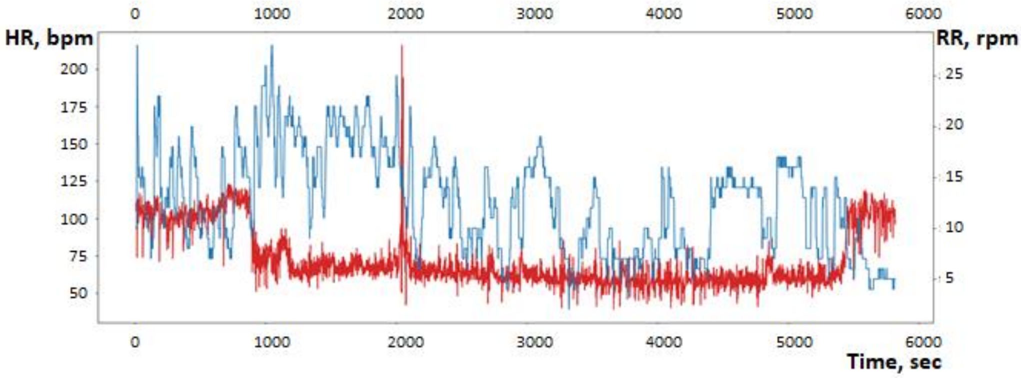


Figure 3. Dynamics of the heart (in red color) and respiratory (in blue color) rate through experiment. A signal inference is clearly seen in a form of a peaked HR value. HR, bpm, heart rate, beats per minute; RR, rpm, respiratory rate, respirations per minute.

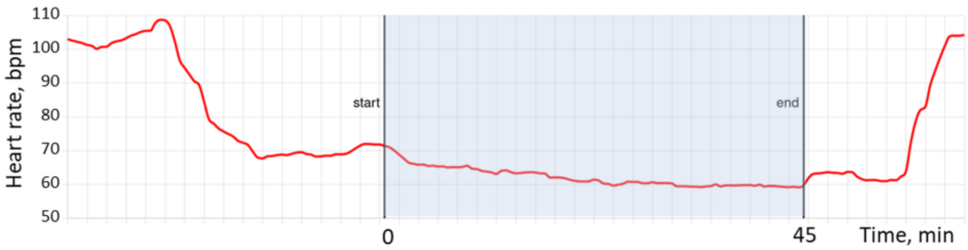


Figure 4. Graph of the average HR signal during the experiment. The dry immersion session is marked with a blue rectangle.

2.4. Outcome Measures

The HRV analysis was performed in accordance with international standards for measurement, physiological interpretation, and clinical use of HRV [11,15,16]. Data were collected continuously through the whole experiment. Then, it was subdivided into 11 study points: before (baseline test—preDI), then every 5 min, 9 times), and 5 min after DI (postDI).

The studied HRV parameters have the following physiological value [8,9,14,16]:

1. A time-domain parameter SDNN informs on the variation of parasympathetically-mediated respiratory sinus arrhythmia.
2. Frequency-domain parameters: HF power, 0.15–0.40 Hz (marker of the parasympathetic activity associated with respiratory activity); LF power, 0.04–0.15 Hz (marker of the sympathetic activity); VLF power, <0.04 Hz (indicator of renin–angiotensin and endothelial factors).
3. Nonlinear parameters: sample (SampEn) and approximate entropy (ApEn) values inform on the predictability and regularity of fluctuation of RR intervals.

2.5. Statistical Analysis

IBM SPSS Statistics 21.0 software (SPSS, IBM Company, Chicago, IL, USA) was used for data analysis. The Friedman test was used to compare HRV parameters between study points. The significance was considered at $p < 0.05$.

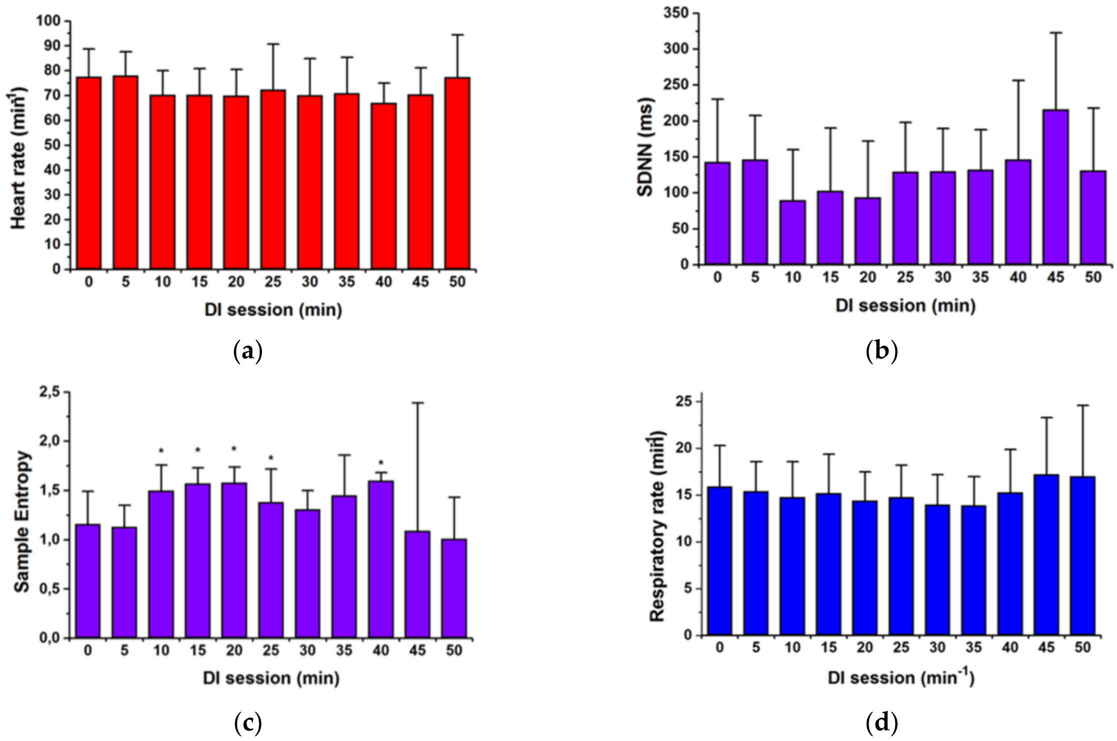
3. Results

Before the DI, in lying position, systolic BP was 107 ± 12 mm Hg and diastolic—67 ± 8 mm Hg. During the DI session, BP did not change significantly. To the end of DI systolic

BP was 104 ± 7 mm Hg and diastolic—60 ± 7 mm Hg. After the DI session DI systolic BP was 113 ± 8 mm Hg and diastolic—67 ± 5 mm Hg. The dynamics of HR is presented in Figure 5.

Before the experiment, mean HR was 77 ± 11 bpm. After lying supine for 5 min, HR decreased, in different individuals, by 10 to 30 bpm. After the onset of DI, HR slowly decreased further by 5 to 10 bpm (Figure 4). Respiratory rate also tended to decrease during DI, though insignificantly (see Figure 5).

Among the HRV parameters, only SDNN (p = 0.018) and sample entropy (p = 0.002) presented significant modification throughout the experiment (see Figure 5). Other time- and frequency domain parameters stood unchanged.



(**a**) (**b**) (**c**) (**d**)

Figure 5. Averaged HRV parameters and respiratory rate within the studied 5-min intervals. (**a**) heart rate; (**b**) SDNN; (**c**) Sample entropy; (**d**) respiratory rate.

4. Discussion

The aims of the study were 1) to explore the applicability of "smart clothes" technologies to monitor ECG and respiration through a session of DI, and 2) to evaluate HRV parameters during exposure to DI. We found that a "smart clothes" technology provided re-liable quality of biosignals (ECG, respiration). Some inference (noise) into biosignals was still present, most likely due to motion of subjects during blood pressure measurement. As for HRV, modification of its parameters generally correlated with those obtained in our earlier studies with conventional ECG recording instruments [8,9]. Namely, HR has decreased by 5 to 10 bpm, SDNN increased, and sample entropy increased in response to induction of the DI conditions. However, spectral characteristics of HRV (HF, LF, and VLF) did not present significant modification in comparison to preDI condition in comparison to our earlier studies [8,9]. Respiratory rate has insignificantly decreased almost in parallel with the heart rate—from 16 to 13 breathes per minute.

5. Conclusions

In conclusion, the "smart clothes" technology, that is textile sensors, appears as a reliable instrument to monitor cardiac and respiratory regulation with HRV parameters during ground-based model of weightlessness, e.g., the DI session.

6. Limitations and Future Studies

One serious limitation to the study can be identified. Namely, measurement of blood pressure provoked reaction to mechanical disturbance in a form of transient increase of the heart rate. In future studies, it would be reliable to integrate HRV data with respiratory rate to evaluate cardiorespiratory interaction during ultrashort-term "dry" immersion sessions. The "smart clothes" technology provides such an opportunity.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The datasets generated for this study are available on request to the corresponding author.

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Conflicts of Interest: The authors declare no conflict of interest.

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