Weather Influence on Alarm Occurrence in Home Telemonitoring of Heart Failure Patients

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Abstract

The study investigated weather influences on occurrence of alarm conditions among heart failure patients subjected to home telemonitoring.

The telemonitored patients were located in the vicinities of five Austrian cities: Vienna, Graz, Innsbruck, Klagenfurt and Linz. The associated daily weather conditions were obtained from the Austrian Central Institute for Meteorology and Geodynamics. The investigations included correlations between patient's vital signs: systolic and diastolic blood pressure, heart rate, and weight, and weather conditions: air temperature, humidity and atmospheric pressure. GNU-R statistical software was used for the analysis.

The results show statistically significant differences in measured blood pressure between the days with high thermal stress, particularly with falling temperatures, cold stress days. At the same time, blood pressure was associated with the highest number of patient alarm conditions requiring medical response.

Including weather data within the home telemonitoring alarm generation systems offers potential for enhancing decision support towards prevention or minimization of the occurrence of adverse events.

1. Introduction

According to the World Meteorological Organization awareness of associations between human health and weather/climate conditions should be included within the national public meteorological services [1]. The purpose is to enhance public understanding of environmental influences and lessen possible adverse outcomes. The most significant natural hazards are heat/cold waves – prolonged periods of extreme temperature and humidity. As an example, due to the hottest summer in Europe for the past 500 years an estimated 15,000 elderly people died only in France between August 4 and 18, 2003 [2].

Apart from the elderly, susceptible to the thermal stress are also people with extreme body mass and malnutrition – under- or over-weight, including infants, those previously experiencing heat related illnesses, patients with heart disease, high blood pressure or other chronic diseases, diabetes, lung, liver and kidney diseases, socially isolated and poor [3; 4]. In the case of heart failure patients, existing studies considered both hot and cold weather conditions, respectively related to high and low humidity. Consequences of decreasing temperature can include increased coronary risk, higher blood pressure, myocardial infraction and respiratory infections leading to deterioration of health status [5] and higher mortality rate [6]. A study on relationships between weather and myocardial infraction, conducted in Italy 1998-2002, showed that hot weather conditions increased the hospitalization rates particularly in young people, whereas cold weather boosted the average rate of hospitalizations of the elderly [7].

The current study explores influence of extreme daily weather fluctuations on heart failure patients' physiological status.

2. Methods

Four patient health status parameters were telemonitored: systolic and diastolic blood pressure, heart rate and weight. Alarm indicators were recorded when the monitored parameters exceeded manually adjustable threshold limits set by the physicians. Additionally, weight gradient threshold was defined as a 2 kg increase or decrease of body weight over two consecutive days [8]. Five different types of physician responses to the alarm situations were documented, of which *patient* *contact*, *medication adjustment* and *other actions* were considered to indicate true alarms, whereas *threshold adjustment* and *no action* indicated false alarms [9].

The telemonitoring included 65 heart failure patients in Austria between 2003 and 2008, out of which 49 were used in the current analysis after preprocessing [8]. Officially recorded weather conditions over this time period, including environmental temperatures, humidity, and atmospheric pressure, were available from the Austrian Central Institute for Meteorology and Geodynamics [10]. As the patients were spread throughout the country, weather data from the local weather stations closest to the patient locations were used in the analyses. Figure 1 shows geographical distribution of the patients and five associated weather stations: Vienna, Graz, Innsbruck, Klagenfurt and Linz.

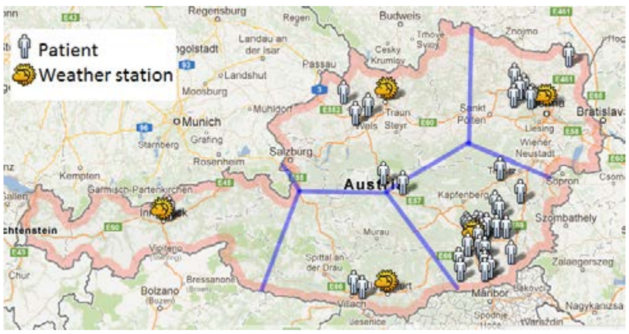

Figure 1. Geographical distribution of patients and associated closest weather stations (lines mark equidistant locations between the neighbouring weather stations)

Patient telemonitoring data and associated weather conditions were analysed using R statistical software [11]. The analyses were conducted in two stages. In the first stage, Spearman correlation coefficients were calculated between the average daily patient physiological measurements and recorded weather conditions (temperature, humidity, atmospheric pressure). In addition, effective temperature and comfort were computed according to the literature [6] and correlated with the physiological measurements. The analyses also included calculation of polyserial correlations between the weather conditions and occurrence of patient alarms.

Based on the obtained correlation results, the second stage of the analyses conducted tests for determining statistically significant differences between:

1. the averaged daily physiological measurements in two consecutive days when:
   a) the difference in mean temperatures between those days exceeded preset limits, ranging between 3°C and 8°C;
   b) one of the two consecutive measurement days had a difference between maximum and minimum temperature higher than preset limits, ranging between 7.2°C and 21°C;
   c) the difference between maximum and minimum temperatures over the two consecutive measurement days exceeded preset limits, ranging between 10.3°C and 22.3°C;
2. the averaged daily physiological measurements on the first and the third day in a sequence, when the difference in mean daily temperatures between the first two days exceeded preset limits, ranging between 3°C and 8°C;
3. the averaged daily physiological measurements on the days immediately preceding and following a day when the difference between maximum and minimum daily temperatures exceeded preset limits, ranging between 7.2°C and 21°C;
4. the average daily environmental temperatures on the days with and without true alarm occurrences.

The considered temperature ranges were based upon the frequency of occurrence of such environmental conditions limiting the extracted sample sizes to a minimum of 10 and maximum of 5,000.

Two-sided u-test and t-test for matched pairs in combination with Shapiro-Wilk normality test were employed for determining the significance of differences between the considered datasets. Apart from p-values the calculations also included 95% confidence intervals (CI).

3. Results

Table 1 shows the number of occurring true patient alarms as a consequence of exceeded physiological threshold limits by the telemonitored parameters. A maximum of five thresholds could be exceeded at any measurement instance in time: maximum or minimum systolic and diastolic blood pressure, heart rate, weight and weight gradient. However, no cases with more than three simultaneously exceeded thresholds occurred.

Table 1. Participation of exceeded lower (MIN) and upper (MAX) physiological (systolic, diastolic blood pressure, heart rate and weight) thresholds in the total number of true patient alarms

True alarms due to exceeded:	Systolic b.p.		Diastolic b.p.		Heart rate		Weight		Weight gradient	Total true alarms
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX		
1 Threshold	39	23	12	29	15	14	15	21	6	174
2 Thresholds	15	33	11	41	4	8	6	21	15	77
3 Thresholds	7	6	5	6	0	6	2	8	2	14

As the next step, the study analyzed correlations between the telemonitored physiological parameters and weather conditions, effective temperature and comfort. As an illustration, Figure 2 summarizes statistically significant correlations between diastolic blood pressure and weather conditions including effective temperature.

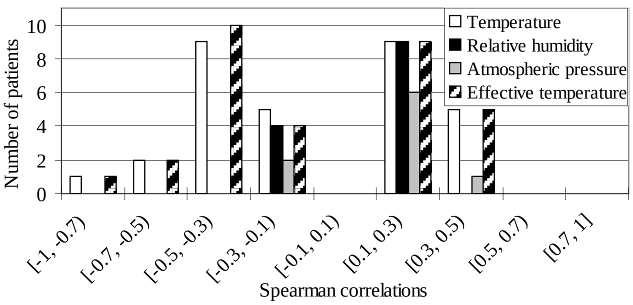

Figure 2. Statistically significant correlations between diastolic blood pressure and weather conditions for individual patients (values around zero were not statistically significant)

The highest detected statistically significant correlations in Figure 2 included temperature and effective temperature. Similar influences were observed on the other physiological parameters and alarms.

Following such findings, the study focused on analyzing differences in patient physiological parameters between the days with extreme temperature variation, heat or cold stress. Thermal stress due to the rising temperatures, heat stress, had no statistically significant influences on patient physiological measurements. Thermal stress due to the falling temperatures, cold stress, was statistically significant for systolic and diastolic blood pressure when the mean temperature difference thresholds were between 6.4°C and 6.8°C ($p<0.05$, 95%CI: (-16, -1) and (-8, 0) mmHg, for systolic and diastolic blood pressure, respectively, sample sizes: 17 and 16), and additionally statistically significant only for systolic blood pressure when the mean temperature difference thresholds were 6.1°C and 6.2°C ($p<0.05$, 95% CI: (-10, 0) mmHg, sample sizes: 29 and 28). The obtained negative CIs indicated rising blood pressures. Figure 3 presents the obtained results for 6.8°C temperature difference threshold.

Considering the day immediately following two consecutive days with large mean temperature variations, statistically significant differences were identified for both heat and cold stress. Falling temperatures, with mean daily differences of 5.7°C and 5.8°C, distinguished significantly different heart rates ($p<0.04$, 95% CI: (0, 4) bpm, sample sizes 68 and 64). Rising temperatures, with mean daily difference of 6.7°C and 6.8°C, distinguished significantly different diastolic blood pressures ($p<0.04$, 95% CI: (-4, 0) mmHg, sample size: 15).

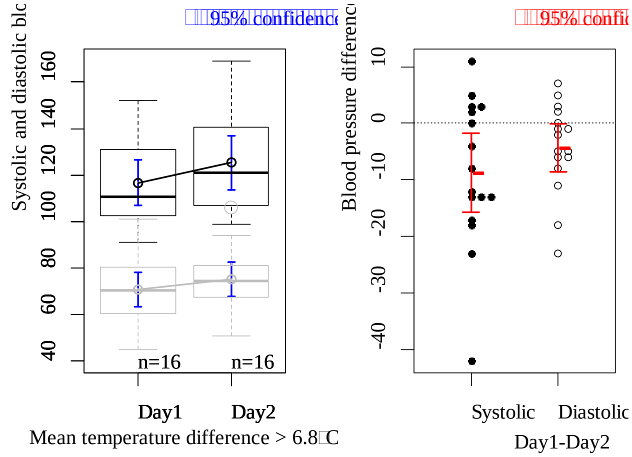

Figure 3. Box plots, means and statistically significant differences with confidence intervals for systolic and diastolic blood pressures over two consecutive days with mean temperature difference higher than 6.8°C

Moreover, statistically significant difference was identified between the daily averaged diastolic blood pressures measured on days when the maximum daily temperature difference exceeded any value between 19.8°C and 20.4°C and days immediately following such temperature variation ($p<0.04$, 95% CI: (0, 5) mmHg, sample sizes: 37, 36, 32). Similarly, statistically significant difference was identified between the daily averaged systolic blood pressures measured on days when the maximum daily temperature difference exceeded any value between 20.5°C and 20.7°C and days immediately preceding such temperature variation ($p<0.05$, 95% CI: (0, 8) mmHg, sample size: 23).

No statistically significant results were found in any other investigated cases.

4. Discussion

The presented results indicate that exceeding systolic and/or diastolic blood pressure thresholds is the most common cause of true positive alarm occurrence, triggering approximately 60% of the alarms. The conducted investigation and statistically significant findings relating the telemonitored blood pressure measurements to weather conditions thus have the highest potential for explanation and prediction of patient alarm situations.

Although statistically significant correlations are identified for a number of individual patients, such correlation values are in absolute terms rarely above 0.7, which is considered as typically desirable in research related to human subjects taking into account person-to-person variability [12]. Similarly, statistically significant but low correlation values are observed between the weather conditions and patient alarm occurrence. The highest of the observed correlations are in the majority of cases related to environmental temperatures. Therefore, the analysis includes differences in patient physiological measurements across the days with pronounced temperature variation, thermal stress.

The detected statistically significant differences in patient physiological measurements around the thermally stressful days are mostly found between the systolic and diastolic blood pressures. All such cases have 95% confidence intervals ranging from trivial (close to zero) to possibly important differences (~10 mmHg), comparable to effects of certain blood pressure medications [13]. Since the confidence interval ranges include values close to zero, we cannot reach a strong conclusion how important are the observed statistically significant differences. However, repeated thermal stress over several consecutive days would have multiplicative effect on the patient conditions as the current study does not distinguish such cases but rather focuses on any days satisfying the predefined thermal stress criteria.

Non-existence of the ever more significant findings with the increasing thermal stress could be attributed to the reduced sizes of the tested datasets due to rarer occurrences of such extreme environmental conditions. Also, a possible explanation could be related to patient avoidance of extreme outdoor temperature variations, during which they might rather stay in more temperate indoor environments. Further verification of such assumptions is needed.

Integrating the information on forecasted weather conditions into the home telemonitoring system could support the medical staff in timely decision making concerning patient health status and alarm situations. Heat/cold stress forecasts could be used to generate beneficial warnings to the patients and medical staff with the purpose of prevention and minimization of potentially adverse events. For example, 12, 24 and 48 hours before the forecasted thermal stress period patients could be advised of precautionary actions via their telemonitoring communication devices. The heat/cold stress prevention plan should be developed for the physicians to apply different measures of coping with such climate effects.

5. Conclusions

The highest number of true alarms occurring with the telemonitored heart failure patients was caused by the exceeding systolic and diastolic blood pressure thresholds. The days with high temperature variation revealed statistically significant differences in systolic and diastolic blood pressure measurements. Especially falling temperatures, cold stress days, showed statistically significant influences. Therefore, weather conditions could be associated with the patient alarm occurrences.

Future work will focus on defining the levels of weather alerts, with respect to the patient health status such as: watch, warning, advisory. The identified correlations between patient vital signs and weather conditions will be further investigated and confirmed in a prospective setting.

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