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Case Report

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Detection of health deterioration in a COVID-19 patient at home: the potential of ambient sensor systems

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Abstract

The COVID-19 pandemic created increased interest in monitoring patients at home to allow timely recognition of health deteriorations. Hospital care is particularly demanding in these patients because of the necessity for isolation to avoid further spread of the disease. Therefore, home care is a preferred treatment setting for these patients. This is, to our knowledge, the first report indicating the potential of an affordable, contactless, and unobtrusive ambient sensor system for the detection of signs of health deterioration in a patient with COVID-19 by a caregiver from a distance. Prospective data acquisition and correlation of the data with clinical events were obtained from an 81-year-old senior with COVID-19 before and, in particular, over a period of 10 days prior to hospitalization. Clinical signs included weakness, increased respiration rate, sleep disturbances, and confusion. The visualization of a combination of this information on a dedicated dashboard allowed the caregiver to recognize a serious health deterioration that required a lifesaving hospitalization. The potential of such ambient sensor systems to detect signs of serious health deterioration in patients with COVID-19 opens new opportunities for use in asymptomatic or oligosymptomatic patients who live alone and are sent back to their homes for isolation in quarantine after diagnosis.

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INTRODUCTION

The COVID-19 pandemic has created great challenges for our healthcare system[1]. One major challenge is preventing transmission of the virus by early diagnosis through testing in asymptomatic or oligosymptomatic individuals. In this regard, great progress has been made with increasing availability of reliable test kits. Another challenge is to recognize deterioration of the health conditions during the course of COVID-19. This is of particular importance in view of the great variability of the clinical presentations of COVID-19, ranging from asymptomatic patients to patients with severe symptoms[2]. Furthermore, most of the patients who tested (or are suspected to be) positive for COVID-19 are in self-isolation at home. In view of the shortage of healthcare professionals and hospital beds around the world, new approaches including remote patient monitoring are needed[3-7].

Remote health-monitoring in older adults

Home monitoring systems are increasingly used to monitor patients and seniors living alone in their apartments for the detection of emergency situations. More recently, multimodal ambient sensor systems are also used to monitor digital biomarkers to detect clinically relevant health problems over longer periods of time[8-10]. The system includes passive infrared (PIR) motion sensor units in each room of the apartment, magnetic door sensors and a bed sensor which is capable of measuring motion in bed, respiration rate, and heart rate based on ballistocardiography[9,10]. The system allows continuous remote measurement of activity, behavior, socialization time, sleep parameters, respiration rate, and heart rate in bed, which serve as digital biomarkers for the detection of clinically relevant health problems over longer periods of time.

Symptoms among patients with COVID-19 include fatigue, cough, muscle and headaches, decrease in taste and smell, difficulty breathing, gastrointestinal symptoms, fever, and confusion with agitation in elderly patients. Whereas cough, difficulties with breathing, and fatigue appear to be the leading symptoms of COVID-19, an elevated temperature (> 100 °F or > 37.5 °C) is not as common as frequently believed[3].

The potential of wearable sensor data and self-reported symptoms for COVID-19 detection has been previously reported[3]. Whereas wearable devices such as smartwatches, smartphones, or fitness trackers would be ideal for tracking a variety of health-relevant markers including physical activity, heart rate, and sleep, post-implementation-based experience, including our own, points toward a clear preference for unobtrusive contactless sensing devices. This is particularly true for older adults who are at high risk for a more serious course of diseases and a high mortality rate. Difficulties in handling wearable devices, added discomfort of having to think about charging and wearing the device[11,12], and skin irritations related to long-term biosensor wear (intensified by sweat during summertime) are major barriers to widespread and uncomplicated use of wearable sensors in this population. In contrast, contactless, unobtrusive passive ambient motion sensor systems have shown to be reasonably well accepted by the elderly as well as their caregivers.

A contactless ambient sensor system for remote health-monitoring instead of for home monitoring of health conditions

The ambient sensor system used for this study has previously been described[8-10]. Physical activity in the apartment and bathroom visits are quantified using a commercially available PIR motion sensing system and visualized on a dashboard (DomoHealth SA, Switzerland). The system includes PIR motion sensor units for each room that is used in the home and two magnetic door sensors that communicate wirelessly with a base unit. The motion sensors measure motion in equipped rooms once every 2 s (0.5 Hz). All sensors communicate with the base unit through the ZigBee protocol. The base unit collects the data and sends them to the cloud in real time using the Global System for Mobile Communications (GSM) network. The subject's kitchen, living room, entrance, bedroom, and bathroom were equipped with one PIR sensor based on the room size of the patient's apartment. Motion signals were collected room by room and combined as total activity in the apartment. Normalized daily PIR sensor activity refers to the time the PIR sensors were registering activity at home, normalized by the total time spent at home for a given day. It is thus corrected for the influence of time spent out of home. A bathroom visit was identified as such if, in a 30 min window, at least one sensor firing in the bathroom was recorded. Nighttime was defined as the period from 8 p.m. to 6 a.m. (local time) based on the daily activity habits of this particular patient. The validity of the pervasive computing = based continuous physical activity assessment has been previously reported[4]. Data processing and visualization were done using the Python programming language version 3.6 (Python Software Foundation).

Heart rate, heart rate variability, respiration rate, and presence were recorded in bed with the commercially available EMFIT QS device (Emfit Ltd, Finland), a contact-free piezoelectric sensor placed under the subject's mattress. These sensors use thin quasi-piezoelectric films that measure even light pressure differences produced by the beating heart. The EMFIT QS sensor was fixed under the participant's mattress, in proximity to the chest. The device requires no further manual intervention. Data were transmitted to the cloud in real time through local WiFi and, subsequently, the GSM network. The device extracts a variety of vital signs, including heart rate, respiration rate, heart rate variability, movements in bed, sleep duration, and sleep onset delay. Recent results suggest that this sensor can accurately measure heart rate and respiration rate[13,14].

Sensor data were visualized on a dedicated dashboard (entry door openings, activity in different rooms, fridge openings, bathroom visits and bed presence) and the DomoCare® app (heart rate, respiration rate, sleep quality, and preventive warnings) to be used by caregivers to easily monitor the health and behavior of a system user. These monitoring tools were used by the son of the patient living at a distance of < 300 km from his father.

Remote detection of health deterioration in a patient with COVID-19

Whereas various approaches to detect signs and symptoms of COVID-19 have been reported[3,6,13], this is, to our knowledge, the first medically documented report about early signs and indications for a serious deterioration of COVID-19 based on an affordable, contactless, and unobtrusive ambient sensor system for home monitoring.

Data from the present case were collected as part of a home monitoring project in Switzerland (StrongAge Project), where elderly community-dwelling adults are monitored with a combined ambient sensor and pervasive computing system in their apartment. The aim of the study is to evaluate the potential of modern sensor technology to get timely information about emergencies such as falls, as well as evaluate the possibility of obtaining preventive information with regards to the health status in the setting of an unobtrusive home monitoring system[8-10]. Furthermore, we explored the potential of the presentation of data on a dedicated dashboard to allow early recognition of signs of health deterioration from a distance. The research protocol has been approved by the Ethics Committee Kanton Bern CH. The patient gave written informed consent for the study and the publication of the results.

CASE REPORT

We present a case study of an 81-year-old man living alone in a large historical chalet in a secluded mountain valley of Switzerland, being dependent on a small primary care hospital only. The senior had a history of cardiovascular disease, including aortic valve replacement, hypertensive cardiopathy, chronic atrial fibrillation with cardio-embolic stroke, and partial respiratory insufficiency. Despite these health problems, he was physically very active by using a pedometer on his smartphone with the aim to make 7000-10,000 steps per day near his remotely located home, which also allowed physical activity during quarantine.

Symptoms started on 10 December 2020 with signs of mild upper respiratory tract infection and rhinitis. On 11 December, the senior had a screening test for COVID-19, which turned out to be positive. On the same day, symptoms of dry cough started. However, doctors from the nearby local hospital felt that the health situation of this well-known patient permitted the patient to go home with the advice to report any deterioration of the situation. On 15 December, the patient was called by his doctor regarding his health situation. The patient reported a general feeling of slight discomfort without specific symptoms. The doctor advised him to call the hospital in case of any deterioration. During the following days, breathing became increasingly difficult. The senior experienced signs of restlessness, sleep disturbances, gastrointestinal symptoms with increased toilet use, and he felt increasing weakness.

The son followed the sensor data of his father on the dedicated dashboard and the DomoCare® app [Figure 1]. He became increasingly concerned about changes of the signal patterns, in particular in view of the positive COVID-19 test result a few days before. Based on the changes in the sensors recordings, he recognized a serious deterioration of his father's health status on 19 December and decided to visit him on 20 December, although his father reported that he was well during daily telephone contacts including on the evening of 19 December. On the later morning of 20 December, the son found his father in critical condition with serious breathing problems, agitation, and confusion and transported him to the local hospital in the afternoon of 20 December.

The main findings at hospital entry included severely reduced general well-being, dehydration, tachypnea with shortness of breath, and bilateral pulmonary rales. BMI was 26.7, body temperature 36.1 °C, heart rate 97/min, and oxygen saturation 88%. Inflammatory markers in the peripheral blood markers were markedly increased including a CRP value of 123 mg/L (normal: < 10 mg/L). The INR value under anticoagulation with coumadin was very low, while the serum value for bilirubin was increased. The chest X-ray revealed bilateral interstitial infiltrations and a small bilateral pleural effusion.

Medication at hospital entry included coumadin for anticoagulation, bisoprolol for heart control of atrial fibrillation and heart failure, torasemide as a diuretic, and allopurinol for gout treatment.

Therapy was initiated with oxygen supply, remdesivir, dexamethasone, and fluid substitution. On the following day, the patients showed increasing signs of agitation and confusion; differential diagnosis of these symptoms included signs of hypoxia or mild COVID-19 encephalitis. Because of choreoathetosis, therapy with an antidopaminergic medication was started. During the following days, the senior recovered slowly and was discharged on 31 December 2020 in satisfactory general condition and without further oxygen supply, resuming his previous activities with support of the local homecare organization.

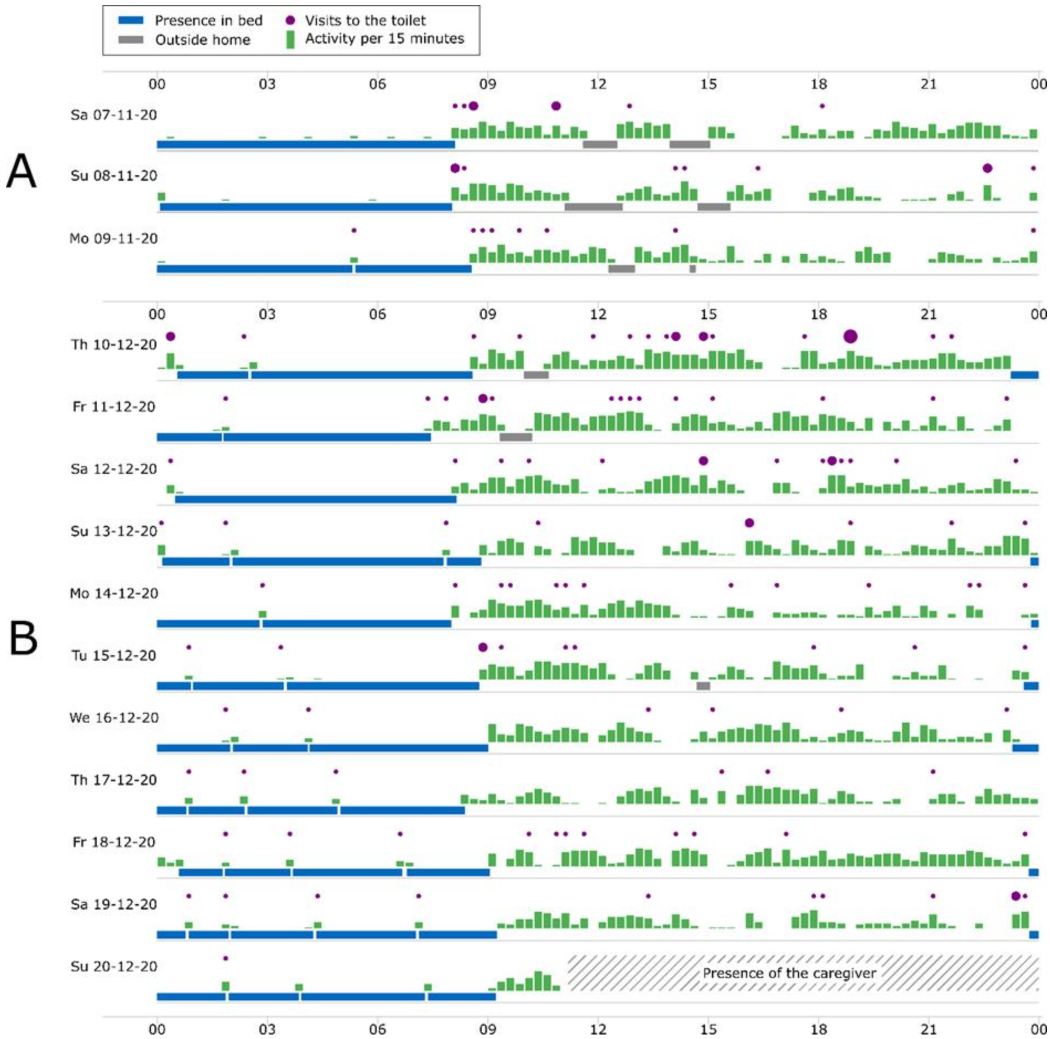

Figure 1. Dashboard for caregivers with visualization of daily activities (normalized units) based on sensor data from passive infrared (PIR) motion sensors in each room of the home which is regularly used, a door sensor at the entry door of the home, and an EMFIT QS bed sensor. The figure shows three representative days for the situation in November before COVID-19 (A) and the days from diagnosis to hospitalization 10 days later (B).

Signs of deterioration of COVID-19 by the Ambient Sensor System

The EMFIT QS bed sensor started to indicate a steady increase of the breathing rate from 21 December to the day of hospitalization on 21 December. Heart rate did not increase significantly under beta-blocker therapy, whereas heart rate variability showed signs of increasing stress with a decrease of low-frequency components and an increase of high-frequency ones. In the mornings, the patient got up from bed later. Total activity during the day increased but showed an increasingly disrupted motion pattern. Time spent outside the home decreased with no further home exits the last few days before hospitalization.Activity during the night, bed exits, and the number of bathroom visits increased markedly over the days before hospitalization.

Figure 1 shows the dashboard with visualization of the sensor data. The dashboard has been developed for use by caregivers in order to allow timely recognition of significant changes of signal patterns over time and, with that, to allow preventive interventions. Data are shown over three days in November, when the patient was in stable health conditions with normal activity patterns over longer time periods, and during 10 days

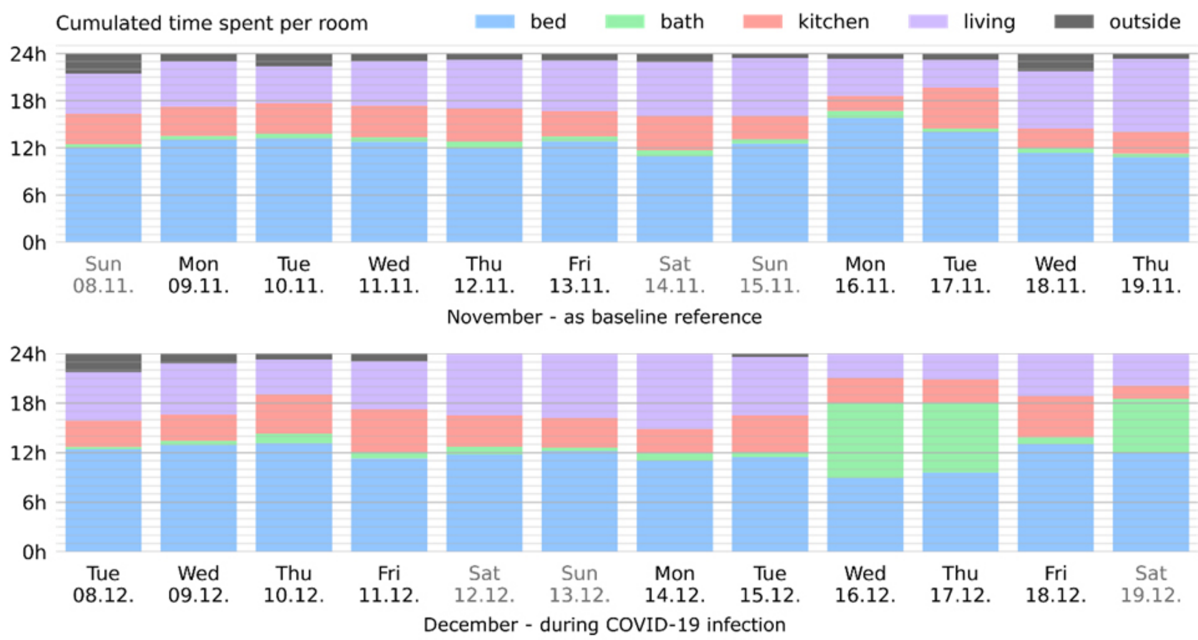

Figure 2. The dashboard indicates the time spent in different rooms of the patient's home. A clear change of the living behavior becomes evident between the data from one month prior to COVID-19 in November to the use period prior to the hospitalization for COVID-19 on 16 December.

after positive testing for COVID-19 until hospitalization. In November, the patient left home two times per day, he had no or only one bathroom visit per night, and he was very active in the mornings with decreasing activity over the day. During the COVID-19 evolution, activity signals showed increasingly disruptive patterns; the patient did not leave home anymore (although he was allowed to do this in the vicinity of his remotely located home), and activity and bathroom visits at night increased.

Figure 2 shows the time spent in different rooms of the senior's home over a period of 10 days prior to hospitalization. A clear change of the living behavior can be recognized compared to the data from before the event.

Figure 3 shows the diurnal and nocturnal activity signals (normalized units), outings (leaving the apartment), and bathroom visits at night per day over the time period from 10 days before COVID-19 diagnosis to the day of hospitalization 10 days after diagnosis. We found a decrease in the number of outings from an average of two to zero outings/day before hospitalization, an increase of daytime in-home PIR sensor activity from 0.36 to 0.45 normalized units before hospitalization, a four-fold increase of nighttime activity from 0.1 to 0.4 normalized units, and an increase in bathroom visits from one to alomst four visits per night.

Figure 4 shows the results with regard to respiration rate and heart rate at night as well as heart rate variability. The mean value for respiration during the three weeks prior to the positive COVID-19 test was 14.2/min and constantly increased to 23/min shortly before hospitalization. Average heart rate at night was relatively stable with values around 65/bpm with permanent atrial fibrillation under beta-blocker therapy, whereas high-frequency heart rate variability (HF) decreased from a mean of 52 normalized PSD to a value of 42 and low-frequency heart rate variability (LF) increased from 48 normalized PSD to a value of 63, indicating an increasing stress situation.

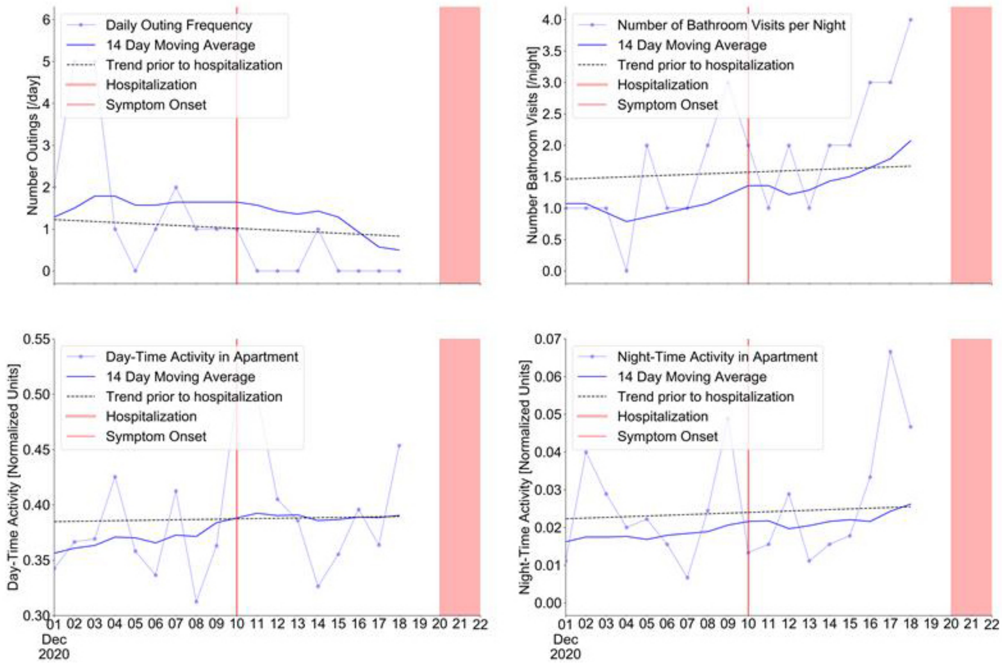

Figure 3. Evolution of sensor signals from a combined ambient passive infrared motion sensor system to monitor outings (leaving home), daytime and nighttime activity (normalized units), and bathroom visits at night.

Conversely, HRV-LF refers to the same between 0.15 and 0.4 Hz.

DISCUSSION

Our results indicate a great potential of an affordable, contactless, and unobtrusive ambient sensor system for the detection of serious health deterioration in elderly individuals being in their homes with a positive COVID-19 test.

In our case, signs of health deterioration started shortly after diagnosis of COVID-19 and increased over the following days to a critical situation until hospitalization. The deterioration of the health situation was characterized by an increase of the respiration rate, an increase of signs of stress based on changes in heart rate variability together with a disruptive pattern of daily activities as a sign of agitation and confusion, and increasing restlessness with increasing numbers of bathroom visits at night. Although these signs are not typical and even more not diagnostic for COVID-19, they are clear indicators for increased disease severity in patients with a positive test for COVID-19 staying at home in quarantine. In contrast to the indicators for health status deterioration which can be collected by the ambient sensor system, fever is a less typical sign of a serious course of the disease, which was confirmed by our case where the seriously ill patient presented at the hospital with a normal temperature of 36.1 °C. A main advantage of our ambient sensor system is that it allows for instead of an even more reliable information about health status deterioration by combining different sensor signals. This has to be taken into account when programming the system: increased respiration rate by itself is unspecific and can be found not only in patients with pulmonary diseases such as pneumonia but also in patients with heart failure decompensation[6] and patients with pulmonary embolism[5]. Changes in heart rate are also unspecific, and their importance for COVID-19 diagnosis may be overestimated. It has been found that only a minority of symptomatic patients (30.3%) who tested for COVID-19 had a resting heart rate of (RHR) greater than two standard deviations above the average baseline value during symptoms; the change in RHR on its own did not allow significant discrimination

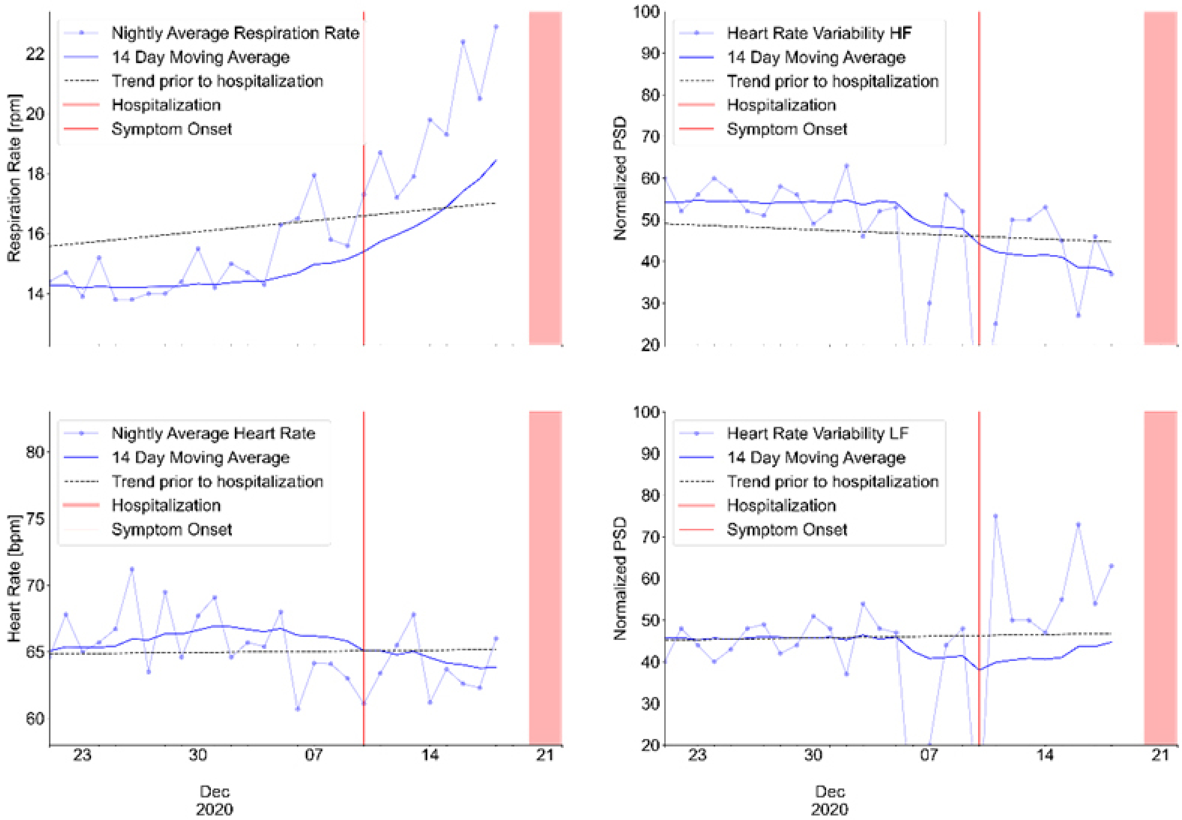

Figure 4. Evolution of sensor signals from an EMFIT QS bed sensor device indicating changes in respiration rate (respiration cycles/min), heart rate (beats/min), high frequency (HF), and low frequency (LF) heart rate variability (HRV-HF refers to the normalized power spectral density between 0.04 and 0.15 Hz; conversely, HRV-LF refers to the same between 0.15 and 0.4 Hz).

between COVID-19 positive and COVID-19 negative participants[3]. In contrast, the same study showed that the sleep and activity of COVID-19 positive participants were impacted significantly more than COVID-19 negative participants. Therefore, the combination of changes in respiration rate with signs of decreased activity, sleep disturbances, and disrupted activity patterns due to agitation and confusion are clear indicators of serious health deterioration, particularly in elderly patients. Such information can be used for timely information of health professionals taking care of such patients, either in the setting of regular home care or hospital at home. The potential of such an early warning system for asymptomatic or oligosymptomatic patients in quarantine at home after positive testing for COVID-19 is of particular importance in view of the shortage of health professionals and hospital beds - especially in rural and hard to reach areas such as in this situation in Switzerland - and even more due to the need for isolation of these patients to prevent further spread of the infection.

This study has several limitations to be addressed. The major limitation is the fact that the clinical experience is based on a single case report, and the findings can only be seen as a description of a promising concept. However, we showed in several previous publications that the contactless ambient sensor system which was used in this case can reliably detect particular health situations under different clinical conditions. Furthermore, this single case report does not allow indicating "normal" values with SD for single parameters. In addition, our findings are not specific to patients with COVID-19 but have to be seen as unspecific but reliable indicators for health deterioration independent of the primary diagnosis.

In conclusion, our previous work, together with this case report, indicates that contactless ambient sensor system signals have great potential not only for the detection of emergency situations but increasingly also for use as digital biomarkers for the detection of serious health problems and their deterioration. The systems are unobtrusive and allow system users to keep privacy and independence. The potential of such ambient sensor systems to detect signs of serious health deterioration in patients with COVID-19 opens new opportunities for use in asymptomatic or oligosymptomatic patients who are living alone and are sent back to their homes for isolation in quarantine after diagnosis. Early recognition of serious health deteriorations and timely hospitalization may be lifesaving under these circumstances.

DECLARATIONS

Authors' contributions

Contributed to the study design and conception: Saner HE, Schütz N, Buluschek P, Pasquier GD, Nef T
Involved in data analysis: Saner HE, Schütz N and Buluschek P
Involved in preparation of the manuscript: Saner HE, Schütz N, Buluschek P
All authors contributed to data collection and management, have been involved in data interpretation, have reviewed and approved the manuscript.

Availability of data and materials

The original contributions presented in this study are included in the article, further inquiries can be directed to the corresponding author.

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Conflicts of interest

Buluschek P and Pasquier GD are working at Domosafety S.A., one of the manufacturers of the used sensor system. The other authors declare no conflict of interest related to this manuscript.

Ethical approval and consent to participate

The study concept involving human participants has been reviewed and approved by the Ethical Committee of the Canton Bern, Bern CH (2016-00406). The patient provided written informed consent to participate in this study.

Consent for publication

Not applicable.

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