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PORTABLE MEDICAL MONITORING: AN E-NURSING INTERFACE FOR ELDERLY CARE EMERGENCIES

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ABSTRACT

We present a prototype called 'Portable Medical Monitoring Computer' that was developed to provide a possible solution to the growing demand for effective, appropriate and efficient elderly care, especially in emergency situations. It supports registered nurses in nursing homes with vital sign parameters and other medical information about residents who are suffering a medical emergency. The application was designed for a portable computer featuring a touch screen, which allows users to access information next to the casualty at the point-of-treatment. The main goal of this project was to design a usable interface for this emergency deployment scenario. This front-end application receives a variety of information, including vital sign information from the existing wireless sensor network called *ReMoteCare*. Our application prototype has the potential to significantly help serve the future needs of caregivers during an emergency situation through its easy to use, straight forward interface that allows quick and accurate access to vital sign and medical data. The paper reports on the design and development of the prototype, developed after consultation with nursing staff, describes the testing of the prototype and discusses the results of this testing.

KEYWORDS

Touch Screen, Gesture Interface, Medical Emergency, Wireless Sensor Network, e-Nursing

1. INTRODUCTION

How can societies cope with a growing demand for elderly health care with fewer young people to look after elderly people? The recent United Nation report on future demographic development confirmed once more that the population group of elderly people (over 60 years) is growing dramatically (United Nation 2009). In developed countries the elderly population is growing rapidly whereas fewer children are being born. The 2008 United Nation report on world population projects that the number of people aged 60 or over will rise from 264 million to 416 million in the next forty years, representing an increase of more than 50 per cent. Clearly, these facts create new challenges in elderly health care which must be addressed.

Consequently, a limited or decreasing number of health care personnel will be forced to look after a growing number of the elderly. As the number of young people is not expected to increase other solutions must be found. A software framework called *ReMoteCare* provides a wireless sensor network (WSN) platform to read vital signs, track people, and monitor them via video. It has the potential to wirelessly check multiple patients simultaneously at various locations without interrupting their mobility or impacting on their quality of life. *ReMoteCare's* key features make it an interesting candidate for addressing the problem of monitoring more elderly people in a nursing home simultaneously with the same number of personnel.

The solution described in this paper is to equip nursing homes, which offer medical care, with wireless portable computer systems (*Portable Medical Monitoring Computer*: PMMC) and their elderly residents with wireless vital sign sensors. Vital signs and location data of each resident will be sent by sensors to a triage server. The system will inform the health care personal immediately once an incident involving an elderly person has occurred and provide them with life saving details on a portable medical system. The need for that kind of information at the point-of-treatment was expressed by a nursing home manager in one of our interviews as follows: "*It would be great if everybody's information is next to them [the casualties], you go in [the application] and tap on it*". Other projects such as *CodeBlue* (Lorincz et al. 2004) and *AlarmNet* (Virone et al. 2006) working with WSN have front-end applications but none of them was actually engineered for the people using them. In contrast, the PMMC is designed to support nurses with live information from the WSN about the casualty and with medical background information next to the casualty at the point-of-treatment on a portable system.

This paper is organised as follows: In Section 2, we introduce the reader to the *ReMoteCare* system followed by a scenario describing how such a system could help in a nursing home (Section 3). In section 4 the research methodology will illustrate how the authors applied a user centred design approach to design the interface. The findings will be presented in 5 with an illustration of the user interface implementation and its features in section 6. Section 7 presents the findings of the usability tests we conducted and comments and recommendations for the interface will be given in Section 8. Finally we will conclude that the application has significant potential to support nurses in medical emergencies with crucial information.

2. REMOTECARE PROJECT

The *ReMoteCare* project is an enhancement by the University of Technology in Sydney (UTS) of Harvard's *CodeBlue* project. It is a software platform using a wireless sensor network to gather medical data in pre- and in-hospital emergency care, disaster response, and stroke patient rehabilitation scenarios (Lorincz et al. 2004). This generic architecture allows automatic wireless monitoring and tracking of patients and first aid responders. By combining different services and protocols while interconnected to many different devices (for instance laptop, wireless sensors, location beacons, and so forth), *ReMoteCare* acts as an information panel.

The wireless devices, called *motes,* are small, wireless, low-powered devices that are also low in computational capacity (see #1 in Fig.1). Attached to these motes are different sensors such as an electrocardiogram (ECG) for capturing the heart rate or a pulse oximeter (see #2 in Fig.1) to check the oxygen saturation in the blood (Navarro et al. 2009; Lorincz et al. 2004). Data gathered by the motes is processed in a way to minimize radio traffic and is sent via their radio devices to an access point (called *Stargate*, see #3 in Fig. 1) which will forward it to the server (see #4 in Fig.1).

ReMoteCare extends *CodeBlue* by a video surveillance feature in the access points (Fisher et al. 2008). The video functionality enables the Stargate to monitor the area of its radio range. In case of an emergency the personnel in a nursing home for instance, can get a better impression of the scene. The video stream is provided by the *Stargate* on a HTTP socket so that any TCP/IP device can get access to it. As a universal interface for vital sign data a Simple Network Management Protocol (SNMP) serves as an interface (Lim et al. 2008).

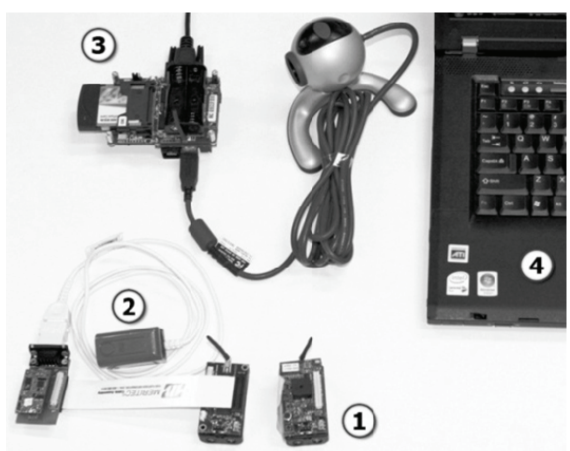

Figure 1. ReMoteCare System

The PMMC high-fidelity prototype described in this paper is built on top of this *ReMoteCare* system and extends it with an appropriate front-end application for nurses. Its proposed deployment is illustrated in the next section.

3. SCENARIO

The scenario illustrates an everyday situation with nurses looking after the elderly in an imaginary nursing home that provides medical service to its residents. There are docking stations with PMMCs spread throughout the nursing home.

Sunset is a nursing home, with a park attached, situated outside of the city. All 60 residents are active and mobile and can organize their daily routine on their own. For their security, they have wireless sensors attached to them that monitor vital signs and provide location information to the triage system. The entire indoor and outdoor area is equipped with access points to receive the vital signs from the sensors.

John is a 88 year old resident who is highly mobile and loves to spend the day in the park. One day he feels tightness in his chest accompanied by a piercing pain in the heart area. The pain causes him to lie down as his breathing is laboured. The sensors attached to John send the vital sign data continuously to the next access point. The server detects an abnormality in his heart rate and sends an emergency call to all the PMMCs which raise the alarm with an auditory warning signal.

Bob is working for Sunset as a registered nurse and shares the shift with others today. He hears the alarm from the next PMMC docking station and runs to it. On the screen he can see the emergency call with John's information and the live footage is showing John lying on the ground. In a split-second he accepts the call by confirming a prompter on the touch screen. Live vital sign parameters and medical information about John is now available on the PMMC, including his current location; Bob picks up his medical equipment and the PMMC from docking station and runs to John.

Upon arrival Bob's suspicion that John is suffering from a heart attack is confirmed. On the PMMC Bob can access John's ECG and medical information which gives him an exact description of John's diseases and medication. Having this information at the point-of-treatment Bob can deal with John appropriately. Formerly he had to commit every patient’s details to memory.

4. RESEARCH METHODOLOGY FOR USER CENTRED DESIGN

"*Know thy user, for they are not you*" (Tidwell 2006, pp.3) is the well known maxim in the user-centred design (UCD) approach which focuses early and intensively on the user for whom the system will be designed. Many software projects fail due to the lack of knowledge about the user, resulting in applications that are designed without realizing the user's true needs.

The PMMC project followed the UCD approach to create a usable and needs engineered application. For the purpose of gathering information about potential users and application requirements semi-structured interviews were conducted which contained questions covering the same question fields for each interviewee (Preece et al. 2006). The advantage is that more questions can be asked to investigate specific fields in depth if relevant information is available while maintaining a guiding framework of questions. Interview questions covered different sections about the potential user(s), their tasks and goals in a situation where the elderly people required first aid, information needed at the point-of-treatment, and about the different hardware solutions.

All questions were constructed in an open-end fashion with the exception of the information needs in an emergency situation. The interviewees were presented with a list of vital signs and medical background data and were asked to rate their importance for this situation; the rating scale was kept very simple with the entities *‘low’*, *‘normal’*, or *‘high’*. Furthermore they were shown a possible hardware platform choice, a 12 inch notebook with a weight of roughly 2 kg, to give them an impression of a future device’s size. Interviewees were asked to comment how they would feel if they had such a computer with them in their everyday work.

In late 2008, interviews were conducted in Sydney, Australia and comprised the following: a nursing professor at UTS, a nursing home manager who is also a registered nurse (RN), and three RNs who are working in hospitals, but had experience in elderly care.

Qualitative research methods were applied to analyse the findings. This research approach can be conducted easily and forms a base for further investigations in this field (Auerbach & Silverstein 2003). Qualitative research is also a common technique in the user-centred interaction design. One of its major goals is to describe patterns and themes in the data and to extract requirements and design goals from the data (Preece et al. 2006; Strauss & Corbin 1990).

5. INTERVIEW RESULTS

The end-users are RNs as they are the caregivers who work in Australian nursing homes and are responsible for medical emergency responses in which they would use the PMMC system. The medical experience level of registered nurses in their field may differ depending on their training, educational level, as well as their former employment record. In Australia, a RN has to do three years of study and is trained in medication, medical assessments and reports. Generally speaking, RNs are highly trained clinicians who can interpret medical information and vital signs. They are trained to respond to emergencies both during their degree and with regular training sessions at their work place. The only identified limitations concerning the interface were possible colour blindness and a language barrier; the latter may be explained by Australia's high immigration rate in the health sector (Australian Government 2009).

The interviews clearly show that it is absolutely necessary to provide PMMC users with the casualty's five vital signs as a live feed: *Pulse*, *blood pressure*, *blood oxygen saturation*, *respiration rate*, and *core temperature*. Nurses without the PMMC have to measure the vital signs manually and are not able to retrieve a long term triage. In some special heart related emergency cases RNs would to inspect an electrocardiogram, (ECG) to get a complete health picture. ReMoteCare's sensors cannot measure respiration, core temperature or blood pressure at this stage of development.

For accurate diagnosis it is necessary to get additional background and related medical information about a casualty, apart from the crucial vital signs. The rating results of the actual medical information needs were not as clear as with the vital signs. Interviewees rated the pieces of information differently, which suggests that there are different needs in different institutions. Nevertheless there was a pattern showing that the following information pieces seemed to have a high importance in the emergency response situation: *Allergies*, *current medication* and *resuscitation order*.

These and other medical information are usually given to all caregivers and memorized before they start their shift. Most aged care facilities have software at their command that manages and stores residents' medical information. Although this is available to RNs, it is not available next to a casualty in an emergency situation. The best practice method for RNs is to make written notes to remember important details. As not everything will be remembered by caregiver or is written down when required, the PMMC system supports the caregivers with this information at the point-of-treatment. The next section shows how these findings are implemented in PMMC's graphical user interface (GUI).

6. THE USER INTERFACE

The GUI introduced in this section has been developed using *design patterns* and *guidelines* for its design. Design patterns describe a proven solution to a well known problem and give reasoning when they should be applied (Tidwell 2006). The great advantage for designers is that one can focus on the specific problems which come along with the context of the application; at the same time the high-quality interface is ensured thanks to the proven concepts.

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6.1 Hardware Platform Choice

As the PMMC application has to support RNs anywhere on the premises the hardware platform has to be mobile, which determines the interface design and programming language.

As medical applications generally must be able to display numerical as well as graphical information it is necessary to have a large screen (Wiklund 2005). A compromise of a reasonably big screen with a reduced physical system size can be achieved with touch screen based computers, as they do not need conventional desktop input devices such as mouse or keyboard (Saffer 2008).

A DELL Latitude XT tablet PC was chosen as a potential future computer platform for PMMC, equipped with a 12 inch finger-sensitive touch screen and a weight around 1.6kg or 3.57lbs. Interviews showed that such a computer would not be carried around by nurses but would rather sit in a docking station. In case of a detected emergency the PMMC would raise an alarm upon which RNs would pick it up with other first aid equipment.

6.2 One Window Drill-Down

The main goal of this application is to support nurses at the point-of-treatment with the casualty's medical information. The identified mobile and stressful emergency response situation directly impacts the interface design. In order to be a supportive application it has to be lucid and information had to be accessible with minimum interaction steps. Furthermore the only user input device is the touch screen; hence the *one-window-drill-down* pattern was applied to reduce the cognitive effort of having multiple windows (Tidwell 2006). Fig. 2 shows the general layout for all screens.

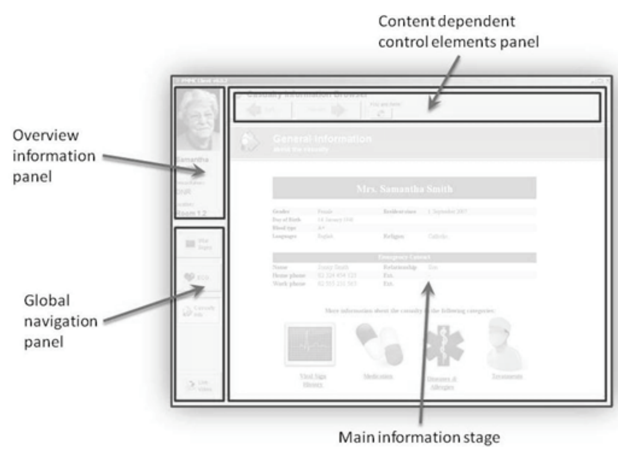

Figure 2. One Window Drill-Down

The different medical information needed for emergency response was split in three logic groups namely: *vital signs*, *ECG*, and *casualty's medical information*. The different information is displayed on the main information stage (see Fig. 2). Toggle buttons (also called *click-and-stick* buttons) on the left global navigation (see Fig. 2) allow users to switch through those different information groups. The fourth toggle button invokes the live video stream from the room or area where the casualty is located. This feature should help the users to inspect the scene closer.

On the left upper corner is the overview panel showing the casualty's picture, name, resuscitation order, and the current location in the nursing home. Location information paired with the video stream enables RNs to find the casualty quickly on the premises. The top bar is reserved for content related control elements if the particular screen requires this feature (see Fig. 4).

All screens have the same basic layout in order to reduce the cognitive load with this flat navigation hierarchy when switching through different content screens.

6.3 Vital Sign Screen

The *vital sign* screen (see Fig. 3) is the most important one for nurses, as it shows the casualty's health condition with live vital signs for the WSN. Each vital sign parameter has a numerical representation on the right hand-side as well as a graph on the left to show the recent changes in that particular parameter. PMMC receives the casualty's individual thresholds for each vital sign from the server. If a parameter is above threshold, the application raises a visual and auditory alarm to attract the nurse's attention to this particular problem.

Figure 3, for example, shows that the respiration has a highlighted pink (and flashing) background and a warning message below the value explaining why the parameter is out of range. In case the user is currently on a different screen while a vital sign threshold is breached, the application will switch to the vital sign screen to get the users undivided attention for this problem.

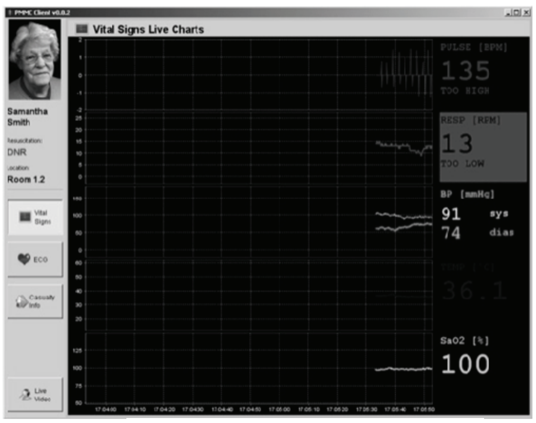

Figure 3. Vital Sign Screen

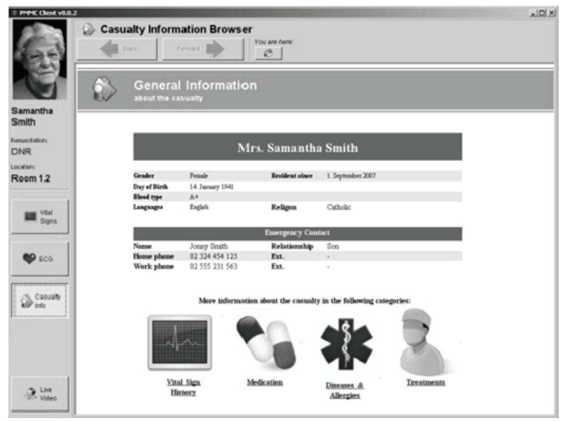

Figure 4. Built-in HTML Browser

Furthermore the pulse is supported by an *earcon*, a auditory signal to support a numerical relation (Scarletti 1994), in sound of a 'beep' to keep the nurse informed about the casualty's heart rate even if the caregiver is not looking on the screen.

6.4 Built-in Medical Information Browser

Interviews showed that the need for medical information had a great variation. To allow flexible and easy to replace content the PMMC features a built–in HTML browser to display the individual casualty's medical data (see Fig. 4). With HTML set up for medical information the content can be easily adapted to different institution or scenarios.

The browser has the same basic range of functions as any 'normal' web browser, which display HTML pages and allow for browsing along the hyperlinks from one document to the other. The difference with this one is that it was adapted to the specific needs of a touch screen and requirements of a response situation.

The website provides the PMMC user with all necessary medical information of casualty who suffers from a medical emergency. Hence the user does not so search for the particular person. From the home page showing the demographic data and emergency contact, 4 main categories are linking to more information: *vital sign history*, *medication*, *diseases & allergies*, and *treatments*.

The user experience goal was to enable nurses to get to information as quickly as possible in other words with as few interactions steps as possible. The HTML pages are linked between each other starting from the homepage which leads to all other pages. For this reason the user is not required to entering a URL. Instead of a address bar a breadcrumb bar is shows the current location of users in the page hierarchy. These breadcrumbs are clickable and allow them to navigate quickly between different levels.

To support a fast and intuitive way to control the browser, we have enabled finger gestures in the prototype system. The functions for browsing back or forward in the page history as well as for page up/ down are gestured enabled. Thus, the time to hit the back and forward button is reduced (Moyle and

Cockburn 2003), as the gesture can be performed anywhere on the browser screen. In addition scrolling could be removed, saving precious screen space.

Figure 5 shows how the gestures have to be performed to either scroll up or down or to browse back or forward in the page history. Gestures performed on the screen will draw a red line on it to provide users with visual feedback that a gesture is about to be performed.

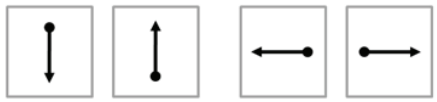

Figure 5. Browser Finger Gestures

7. USABILITY TEST

The usability test was conducted in the UTS' *m-Health computer laboratory*. The goal was to find design flaws, obstacles in the workflow in qualitative way, and to provide recommendations for the next prototype release.

The participants were members of the m-Health laboratory and have worked in the mobile health research field in Europe and Australia; they include 3 males, aged from 19 - 42 years, and 4 females from the age 20 to 46 years. This group should help to indentify the major design flaws (Nielsen 2000).

Tasks performed by the participants were designed according to the UML use cases for the prototype system, thus every use case had a corresponding usability test task. For example one use case defined that nurses need live vital signs for their diagnosis, hence one test task was to identify vital signs on the application and to magnify the current minimum of one on the chart. Some tasks were not related to use cases but had the purpose to inspect other application related aspects such as the finger gestures. Each task had a defined goal that had to be reached in order to be seen as accomplished. If they felt stuck, participants were given the opportunity to get help from the experimenter sitting next to them, to achieve the task's goal. To obtain additional information about the problems the participants were facing they were asked to speak aloud during the test session (Nielsen 1993).

The PMMC application was tested in a realistic scenario as this can reveal more usability problems (Heinsen & Vogt 2003). A DELL Latitude XT Tablet PC with the application running in full screen mode and its touch screen as the only interaction device served as the test platform. Each test session was recorded with a webcam mounted on a helmet the participants had to wear during the session for later analysis (see Fig. 6). The webcam also gave insight of how differently users dealt with the entire application including hardware and activated buttons for instance.

Figure 6. Helmet with mounted webcam and Dell Latitude XT tablet PC

8. DISCUSSION

The general perception of testers of the PMMC application was that it is "*easy to use*" and information was arranged in a logic way as "*it didn't seem too hard use [...] it is pretty clear and easy*".

Gestures have to be highlighted was the users made use of them extensively as one user states "y*ou can touch everything and make everything happen just by touching*". This means that gestures seem to be a practicable interaction approach for a touch screen browser. Some test participants apply them quite frequently and anywhere, even on screens which were not gesture enabled at all. Some users had problems deciding whether gestures could be applied on the screen they were shown. A *gesture suggestion feature* that provides additional information about gestures could help solve this problem. It could provide visual clues if users touch the screen longer than a specified time threshold.

One problem with the back and forward browsing gesture was that users reversed them. Instead of moving the finger to the left-hand side to activate back browsing they dragged it to the right and vice versa for browsing forward. It appeared that users, as they could touch the screen with their fingers had the impression that they would handle a tangible object. Therefore their mental model was a webpage that was lined up on a timeline of visited page from the left to right; new page added on the right hand-side. Consequently users move the timeline/page with their fingers to right to browse back, instead to the left as the gestures would suggest (see Fig. 5). These findings reflect the idea of the 'drag to move object' gesture pattern as this represents the natural way how human expect physical things to react (Saffer 2008; Valli 2008).

In order to support this timeline paradigm the back and forward browsing should be done in a consistent motion. A visual transition and sliding effect from one website to the other could support the spatial orientation and would make the website change more obvious to users. This could also minimize the cognitive load because the page load does not happen in a leap but rather in smooth way the use can visual observe (Valli 2008).

The website created for the casualty's medical data was very effective in providing the necessary information. One participant commented that an application like this "*is great [... and ...] appealing [...] you want to use the application*". A problem was the readability and the activation of some textual hyperlinks as fingers were sometime too big to hit the clickable target precisely. The recommendation is to re-design website in a way that users can read the content even from a short distance and to increase all touch target to minimum size.

A few participants did not understand the automatic switch to the vital sign screen if they were on a different screen in case of a vital sign threshold breach. The switch was accompanied with auditory warning signal and with a flashing background behind the affected vital sign, which was understood by users: "*it is flashing it wants me to do something*". To make this more meaningful it should be accompanied by a visual cue. For example a sliding screen effect making it obvious that a switch was performed and also why this is happened.

Other usability issues found with the hardware setup was that one participant complained about fatigue arms and pain in her wrist as she was holding the tablet PC tilted during the test session. The reason why the user held the PC in this position was that she was trying to avoid reflections on the matt display. This matter should be taken into account when choosing touch screens – anti glare screens would be essential in the outside area if an elderly patient fell over outside. The suggested improvements shall be solved in the next prototype version.

9. CONCLUSION

PMMC is an application built on top of the existing *ReMoteCare* framework with multiple deployment possibilities. Apart from similar applications and projects with some matching ideas and technologies, no other application has been designed especially for elderly emergency response situations in a nursing home so far. PMMC reduces the reaction time from the occurance of an emergency to the notification of carers with permanent monitoring of elderly via a wireless sensor network. Detected emergencies result in an alarm and caregivers will be provided with essential casualty, location, and video information. At the point-of-treatment, next to the casualty, carers are able access medical data, which they had to formerly memorise, and receive the casualty's live vital sign data on the PMMC screen, giving them a clear picture of the patient's health condition. The concept of a wireless sensor network allows nursing homes to monitor multiple people simultaneously, which increases the number of elderly who can be looked after. A issue that has to be addressed in a real life application is that the sensive medical data must be protected by robust security measures to prevent evesdropping or manipulation by non-authorised third parties. With this system nursing homes may work more efficiently, because they can look after more people with the same amount of people. At the same time, elderly people will benefit from such a system as the quality of care increases as incidents are detected instantly and longterm medical data is available for analysis and prediction of future health issues.

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