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Development of a test setup for validating a cognitive assessment platform within ICU's

Muriel De Boeck*[a], Philippe Jorens[b], Guido De Bruyne[a], Kristof Vaes[a]

[a]University of Antwerp, Faculty of Design Sciences, Department of Product Development
[b]Antwerp University Hospital, Department of Critical Care Medicine
*muriel.deboeck@uantwerpen.be

Abstract | Medical care is one of the most important and urgent areas to obtain insights and better understanding of the workflow of the caregivers using a human-centred approach, particularly in departments where caregivers' activities are crucial to human lives, such as the intensive care unit (ICU). Within this paper, we used a combination of quantitative and qualitative approaches to investigate role stress on ICU-caregivers. The aim of this preliminary study is to develop a test setup as preparation towards the development and validation of an instrument to monitor cognitive states, namely a Cognitive Assessment Platform (CAP). This resulted in (1) a task analysis, which we translated into an app for easy task registration, (2) a selection of sensors to measure cognitive states at caregivers of an ICU and (3) a questionnaire based on the Stress Questionnaire for Health Professional (SQHP).

KEYWORDS | COGNITIVE STATE, PHYSIOLOGICAL MEASUREMENTS, WEARABLE SENSORS

1. Introduction

The basic principle of human-centred design is that products and services result from a thorough understanding of the physical, cognitive and emotional needs of users. This approach enhances effectiveness and efficiency, and improves human well-being (ISO, 2010). To understand human functioning in highly stressful and complex environments, a human-centred approach can provide a better comprehension of the needs of the different kinds of people who interact with each other in such an environment. Moreover, it counteracts possible adverse effects in human health, safety and performance (Van Zyl and De La Harpe, 2014).

Safety critical environments, such as medicine and healthcare, are very important and urgent areas to obtain insights and better understanding of the workflow of the staff using a human-centred approach. Particularly in departments where performed activities are crucial to human lives, such as the intensive care unit (ICU) (Ohmura et al., 2006). Adverse events, defined as injuries or complications that are provoked by a medical human error rather than the patient's underlying disease, occur in about one-third of cases in adult ICU patients and the risk of error is cumulative (Baker et al., 2004; Orgeas et al., 2008; Seynaeve et al., 2011; Molina et al., 2018). The risk factors of adverse events include high nursing workload, caregivers' sleep deprivation or fatigue, communication failure, a high patient-to-nurse ratio and poor management (Valentin et al., 2006; Bucknall and Tracey, 2010; Ksouri et al., 2010; Pagnamenta et al., 2012; Steyrer et al., 2013; Faisy et al., 2016). Cognitive limitations such as fatigue, mental workload, arousal or stress, may result in errors during task intensive activities and deteriorated performance.

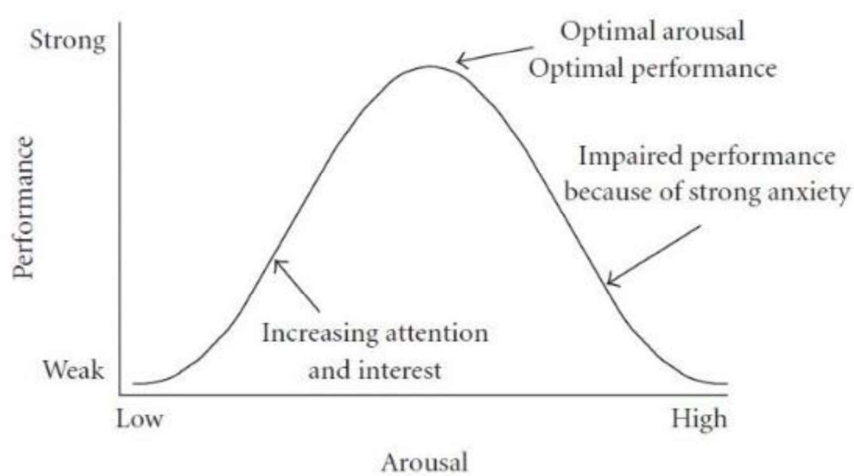

Figure 1. Illustration of the Yerkes-Dodson law (Dodson and Yerkes, 1908)

The principle which states that performance and the mental state of arousal or stress are directly related, was proposed by psychologists Yerkes and Dodson (Dodson and Yerkes, 1908). They indicated that behavioural performance increases with physiological or mental arousal, but only up to a certain point. This means that if the arousal-level is too high, people not only experience psychological discomfort such as stress and/or anxiety, but can no longer function optimally due to a reduced level of attention, memory and cognitive processes. In conclusion, the Yerkes-Dodson law (see Figure 1) is a well-cited century-old principle, which shows that the relationship between arousal and behavioural performance can be linear or curvilinear, depending on the difficulty of the task.

Physiological parameters allow monitoring of cognitive states such as stress or arousal by quantifying responses from the brain and nervous system, cardiovascular system and visual system. For example, heart rate variability (RR-interval) allow gaining insight in stress levels (McDonald and Soussou, 2011), while EEG's allow quantifying arousal levels through analysis of brain waves, see figure 2 (Berka *et al.*, 2007; Stikic *et al.*, 2014; Liu *et al.*, 2016; Webster *et al.*, 2017). Through wearable computing it is possible to monitor these physiological parameters in real-time. Additionally, wearable computing is rapidly becoming a major research direction due to new developments in smart technologies, which may hold promises for enhancing product intelligence. In conclusion, workload intensive tasks, smart technologies and interpersonal variations in cognitive capacities induce a need to better understand human cognition and adjust care products and interfaces accordingly.

Several review papers regarding wearable sensor-based system (Pantelopoulos and Bourbakis, 2010; Banaee, Ahmed and Loutfi, 2013; Lakudzode and Rajbhoj, 2016) provide inventories of the most commonly used physiological parameters for health monitoring in literature and are summarised in Table 1.

Table 1. Summarisation of the most commonly used biosensors used for health monitoring according to current literature.

Type of signal	**Type of sensor**	**Description of measured data**
Electrocardiogram (ECG)	Chest electrodes	Electrical activity of the heart
Blood pressure - systolic and diastolic (BP)	Arm cuff-based monitor	Refers to the force exerted by circulating blood on the walls of blood vessels
Body (skin) temperature	Temperature probe or skin patch	A measure of the body's ability to generate and get rid of heat
Respiration rate (RR)	Piezoelectric sensor band around chest	Number of movement indicative of inspiration and expiration per minute
Oxygen saturation (SpO_2)	Pulse oximeter on finger	Indicates the amount of oxygen that is being transported in the blood
Heart rate (HR)	Pulse oximeter on finger or skin electrodes	Frequency of the cardiac cycle

Photoplethysmogram - Skin conductivity (PPG)	Galvanic skin response sensor	Electrical conductance of the skin (activity of the sweat glands)
Blood glucose (BG)	Strip-based glucose meter	Measurement of the amount of glucose in blood
Electromyogram (EMG)	Skin electrodes	Electrical activity of the skeletal muscles
Electroencephalogram (EEG)	Scalp-placed electrodes	Measurement of brain activity
Body movements	Accelerometer	Measurement of acceleration in 3D spaces

The aim of this preliminary study is to develop a test setup as preparation towards the validation of an instrument, namely a Cognitive Assessment Platform (CAP), which consists of a set of sensors that allow synchronous data acquisition of the different physiological measurements. The caregivers will also be questioned to verify whether the subjective results match the objective measurements. In a follow-up study, the CAP will also enable identifying stressful situations that require excessive workload or may degrade performance, and allow a synchronisation between the physiological data of its wearer and specific care tasks. Ultimately, this research shall contribute to the development of a full operational CAP to gain fundamental insights in and a better understanding of the workflow of the caregivers, which in turn could provide rich opportunities for further examination and discovery. For this research, we closely cooperate with the ICU department at the Antwerp University Hospital (UZA). This precursory study is an initial exploration regarding different aspects of the follow-up study and consists following research activities:

1. A task analysis based on therapeutic intervention scoring system (TISS-28) and observations. We translated this task analysis into an app for easy task registration, which will enable linking the performed task with the physiological data of the caregiver;
2. A selection of sensors to measure cognitive states – fatigue, workload and stress – at caregivers of the ICU of UZA. This based on literature reviews and on observations on their current working conditions (required for ethical approval);
3. Lastly, a questionnaire, which will provide a general qualitative overview of stress and fatigue levels specifically within the ICU of UZA (required for ethical approval).

2. Method

2.1 Task analysis and app development

Within this study, we performed a task analysis to analyse main cognitive activities of the ICU-caregivers at UZA and to set up a task inventory, which was crucial for the development of the app. In a later study, the caregivers will use the app as a system to register the tasks that they are performing at that moment. This way, we can synchronize the monitored physiological data with the performed tasks and explore possible continuities.

We conducted the task analysis based on observations within the ICU of UZA and on the Therapeutic Intervention Scoring System-28 (TISS-28). TISS-28 is a tool used to assign scores to patients according to severity of illness and is used as an indicator of nursing workload in ICU TISS-28 (Miranda, de Rijk and Schaufeli, 1996).

2.2 Selection of wearable sensors

A selection of wearable sensors to measure cognitive states at caregivers within the ICU of UZA was made based on current state-of-the art according to the literature (see table 1) and on observations regarding the conditions within the environment of the ICU. This selection of sensors will be used in a later follow-up study.

2.3 Questionnaire

The questionnaire was set up in consultation with head nurse and confirmed by head of the ICU at UZA and the ICU team. The aim of this questionnaire is to obtain qualitative insights in the stress and fatigue levels of caregivers and to capture the professional experiences of nurses in aspects related to occupational stress. Therefore, we used the six sources of occupational stress according to the Stress Questionnaire for Health Professionals (SQHP) (Gomes and Teixeira, 2016). These six sources that we took into account consider aspects related to work and family affairs (managing clients, relationships at work and home-work interface), aspects related to specific nursing tasks and the time available to achieve them (leading training activities and work overload) and also aspects related to career progression and salary. The questionnaire was set up using Qualtrics software since it provides an extensive variety of types of questions (other than multiple choice or open questions), and since it is possible to combine it with SPSS software for analysing the data.

3. Results

3.1 Task analysis and app development

The task analysis resulted in a task inventory of all key activities within the ICU of UZA. Additionally, all key activities were classified in thirteen main categories to make task registration easier for caregivers, which are shown in Table 2.

Table 2. Task inventory based on TISS-28 and on observations.

1. Register parameters o General registration (every two hours) o Record an ECG	2. Hygienic care o Body care (hair, brushing teeth, shaving, etc.) o Change bed o Corpse care	3. Medication o Prepare medication

	○ Intimate toilet ○ Ostomy care ○ Offer bed pan ○ Offer kidney dish ○ Wound care	○ Via Intravenous infusion ○ Via syringe ○ Orally
4. Respiratory care ○ Oral care ○ Clean endotracheal tube ○ Aspiration ○ Intubation ○ Install non-invasive ventilation	5. Administrative task ○ Receive briefing ○ Write patient report ○ Prescribe medication ○ Order material ○ Fill out the Electronic Patient Dossier (EPD) ○ Fill out score form ○ Meeting	6. Nutrition ○ Offer food ○ Offer a drink ○ Feed the patient
7. Communication and support ○ With patient ○ With visitors ○ With doctor ○ With external staff	8. Mobility patient ○ Install patient ○ Transport patient ○ Turn and position patient in bed ○ Move patient to another bed	9. Acute care ○ CPR ○ Intubation
10. Logistics ○ Collect medication ○ Collect equipment ○ Call technical service ○ Unload medication ○ Order material ○ Refill carts ○ Refill boxes ○ Clean devices	11. Technical skills ○ Insert probe ○ Assist doctor (place catheter, bronchoscopy, …) ○ Place Intravenous infusion ○ Take blood ○ Take samples ○ Continuous veno-venous hemofiltration (CVVH)	12. Breaks ○ Short break (toilet, coffee) ○ Dinner break
13. Other ○ Supervise student ○ Educate a colleague ○ Other: …		

Further, we translated the results of the task analysis into an app, which will enable easy task registration for the ICU-caregivers. The main interface of the app is shown in Figure 2.

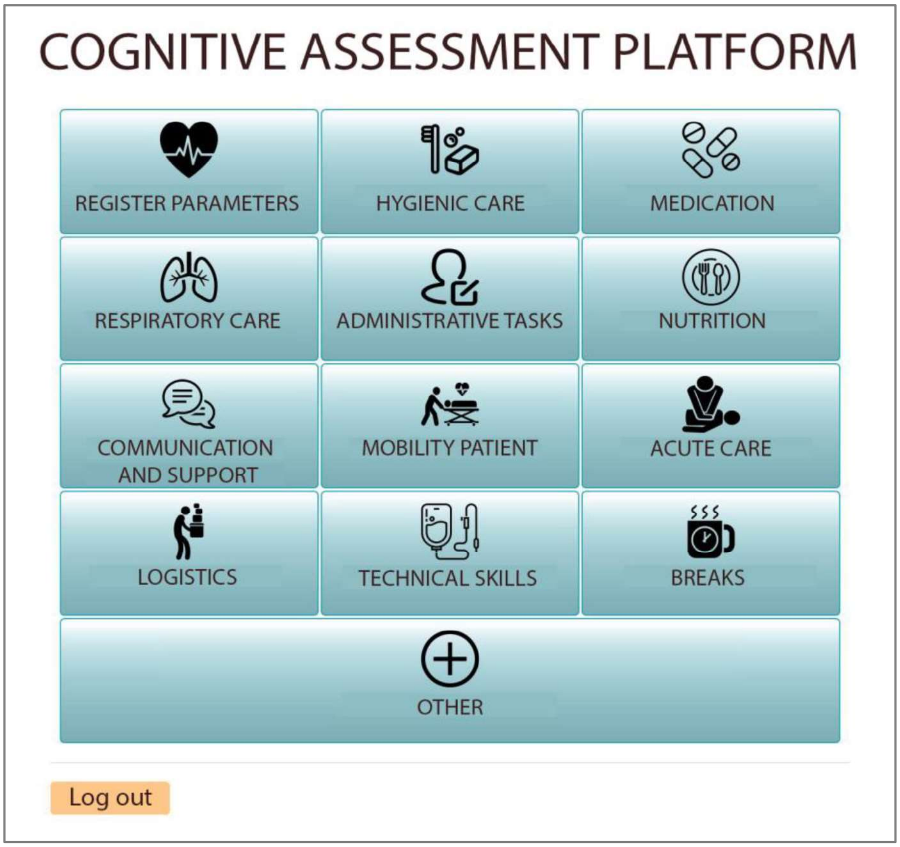

Figure 2. Illustration of the interface of the app, showing the thirteen categories of the tasks.

Every category has a list of tasks (see Figure 3a) that can be selected by the caregiver. By selecting a task, a timer starts recording the time (see Figure 3b) such that the monitored physiological data can be synchronised with the performed tasks and possible continuities can be explored (e.g. how does recovery occur, what is the importance of breaks, which tasks are most demanding, do the results correlate with the results of the questionnaire, etc.). Anytime, the user can go back to the previous page.

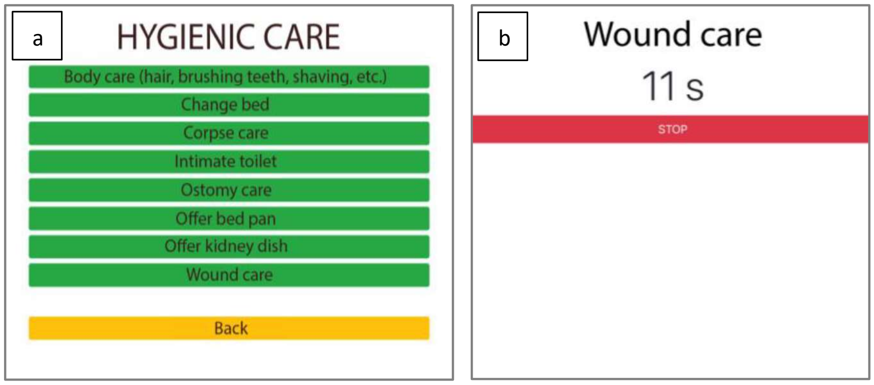

Figure 3. (a) Illustration of the interface after selecting a random category and (b) after selecting a specific task (in this case: "wound care").

3.2 Selection of wearable sensors

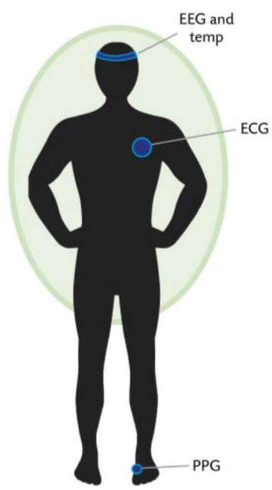

Figure 4. Placement of the selected sensors.

Based on field research, we encountered that the ICU-caregivers need to keep their hands and forearms sterile during their work, which means that we cannot place any sensors on these locations. Consequently, BP, HR and SpO2 could not be measured within this research (see Table 1). Further, body movements and EMG would not provide significant results within this context because of the caregivers' constant movement. BG would be too difficult to measure and RR would be too intrusive for the caregivers. Finally, these wearable sensors and cables were attached unobtrusively to the body so that they would not interfere with the tasks of the caregiver. Considering the different sensors to measure cognitive state according to current literature, we selected ECG, skin temperature, PPG and EEG as shown in Figure 3. PPG is typically recorded non-invasively from the surface of the palms and fingers. However, the caregivers need to keep their wrists sterile. Therefore, we opted to perform measurements at the foot location. From a physiological point of view, the feet are known to serve as a suitable measurement location for GSR (Healey, 2011; Govoni, 2012; Gravenhorst et al., 2013; Phitayakorn et al., 2015). Further, we placed the ECG on the left side of the chest because the closer the pads are to the heart, the better the measurement (Babu Prasad, 2018). Since a cap would be too intrusive, only a limited number of channels were used to record electrical activity of the brain.

3.3 Questionnaire

Based on the different sources of occupational stress according to the SQHP – namely aspects related to work and family affairs, aspects related to specific nursing tasks and work overload and aspects related to career progression and salary – a questionnaire was set up. The head of the ICU at UZA and his ICU team then reviewed the survey. Within our questionnaire, we evaluate seven different dimensions of stress factors that ICU-caregivers face in their activities: (1) socio-demographical questions, (2) personal questions, (3) questions regarding working conditions, (4) stress-related questions, (5) fatigue-related questions, (6) questions concerning home-work interface and finally, (7) questions about career and salary.

Different types of question formulations (such as multiple choice, matrix table, slider or rank order) were used to prevent monotonous questions. This preparation of the questionnaire is required for ethical approval.

4. Discussion

The aim of this preliminary study was to construct a test setup as preparation towards the development and validation of a Cognitive Assessment Platform (CAP) for monitoring cognitive state. Ultimately, the CAP will enable identifying stressful situations that require excessive workload or degrade performance, and allow a synchronisation between the physiological data of its wearer and specific tasks.

This preliminary study applied a user-centred design approach, providing a better understanding of the needs of individuals working in a highly stressful and complex environment such as an ICU, with the aim to enhance teamwork and work efficiency. Therefore, we developed a test setup that will enable us to gain an explicit insight in the ICU staff, their tasks, and environment. The results of this study - which were required for ethical approval of our follow-up study - consisted of (1) a task analysis, which we translated into an app for easy task registration, (2) a selection of sensors to measure cognitive states at caregivers of an ICU and (3) a questionnaire based on the Stress Questionnaire for Health Professional (SQHP).

The herein presented test setup will be applied in our follow-up study to develop and validate the unobtrusive, user-friendly CAP. The sensors that we have selected within this study will be used to design a CAP prototype. To validate the CAP prototype, experiments will be performed on twelve caregivers within the ICU of the Antwerp University Hospital (UZA). During the experiments, the caregivers will need to use the developed app to register the tasks they are performing, enabling us to link the performed task with the physiological data of the caregiver. They will then be asked to fill in the questionnaire to obtain a general qualitative overview of stress and fatigue such that we can verify whether the subjective results match the objective measurements.

To conclude, this preliminary study was essential to create a test setup, which we will use in our future study to gain insights in the ICU caregivers, their tasks, and environment. Based on these observed healthcare insights, our future design prospects are to develop and validate the innovative CAP, purposed to be a user-friendly wearable tool to enhance ICU workflow and work efficiency.

References

Babu Prasad, M. (2018) ‘Android based health care monitoring system’, *International Journal of Innovative Technology and Exploring Engineering*, 8(2 Special Issue 2), pp. 253–255.

Baker, G. R. *et al.* (2004) ‘The Canadian Adverse Events Study: the incidence of adverse events among hospital patients in Canada.’, *CMAJ : Canadian Medical Association journal = journal de l’Association medicale canadienne*, 170(11), pp. 1678–86. doi: 10.1503/cmaj.1040498.

Banaee, H., Ahmed, M. U. and Loutfi, A. (2013) ‘Data mining for wearable sensors in health monitoring systems: A review of recent trends and challenges’, *Sensors (Switzerland)*, 13(12), pp. 17472–17500.

Berka, C. *et al.* (2007) ‘EEG Correlates of Task Engagement and Mental\nWorkload in Vigilance, Learning, and Memory Tasks’, *Aviation, Space, and Environmental Medicine*, 78(5), pp. B231–B244.

Bucknall, R. and Tracey, K. (2010) ‘Medical error and decision making: Learning from the past and present in intensive care’, *Australian Critical Care*. Australian College of Critical Care Nurses Ltd, 23(3), pp. 150–156.

Dodson, J. D. and Yerkes, R. M. (1908) ‘The relation of strength of stimulus to rapidity of habit-formation’, *Journal of Comparative Neurology and Psychology*, 18(5), pp. 459–482.

Faisy, C. *et al.* (2016) ‘Nurse workload and inexperienced medical staff members are associated with seasonal peaks in severe adverse events in the adult medical intensive care unit: A seven-year prospective study’, *International Journal of Nursing Studies*, 62, pp. 60–70.

Gomes, A. R. and Teixeira, P. M. (2016) 'Stress, Cognitive Appraisal and Psychological Health: Testing Instruments for Health Professionals', *Stress and Health*, 32, pp. 167–172.

Govoni, N. A. (2012) 'Galvanic Skin Response', *Dictionary of Marketing Communications*.

Gravenhorst, F. *et al.* (2013) 'Towards a mobile galvanic skin response measurement system for mentally disordered patients', *BODYNETS 2013 - 8th International Conference on Body Area Networks*, 1, pp. 432–435.

Healey, J. (2011) 'GSR sock: A new e-textile sensor prototype', *Proceedings - International Symposium on Wearable Computers, ISWC*, pp. 113–114.

ISO (2010) *Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems*, *Geneva, Switzerland*. Available at: https://www.iso.org/obp/ui/#iso:std:52075:en (Accessed: 12 December 2017).

Krigolson, O. E. *et al.* (2017) 'Choosing MUSE: Validation of a Low-Cost, Portable EEG System for ERP Research', 11(March), pp. 1–10.

Ksouri, H. *et al.* (2010) 'Impact of morbidity and mortality conferences on analysis of mortality and critical events in intensive care practice', *American Journal of Critical Care*, 19(2), pp. 135–145.

Lakudzode, S. and Rajbhoj, M. (2016) 'Review on human stress monitoring system using wearable sensors', *International Research Journal of Engineering and Technology*, pp. 2395–56. Available at: https://irjet.net/archives/V3/i4/IRJET-V3I4145.pdf.

Liu, J. *et al.* (2016) 'Cognitive pilot-aircraft interface for single-pilot operations', *Knowledge-Based Systems*.

McDonald, N. J. and Soussou, W. (2011) 'QUASAR's QStates cognitive gauge performance in the cognitive state assessment competition 2011', *Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS*, pp. 6542–6546.

Miranda, D. R., de Rijk, A. and Schaufeli, W. (1996) 'Simplified Therapeutic Intervention Scoring System: the TISS-28 items-results from a multicenter study', *Critical Care Medicine*, 24(1), pp. 64–73.

Molina, F. J. *et al.* (2018) 'Adverse events in critical care: Search and active detection through the Trigger Tool', *World Journal of Critical Care Medicine*, 7(1), pp. 9–15.

Ohmura, R. *et al.* (2006) 'B-Pack: a Bluetooth-based wearable sensing device for nursing activity recognition', *2006 1st International Symposium on Wireless Pervasive Computing*, p. 6 pp.

Orgeas, M. G. *et al.* (2008) 'Impact of adverse events on outcomes in intensive care unit patients', *Critical Care Medicine*, 36(7), pp. 2041–2047.

Pagnamenta, A. *et al.* (2012) 'Adverse event reporting in adult intensive care units and the impact of a multifaceted intervention on drug-related adverse events', pp. 1–10.

Pantelopoulos, A. and Bourbakis, N. G. (2010) 'A survey on wearable sensor-based systems for health monitoring and prognosis', *IEEE Transactions on Systems, Man and Cybernetics Part C: Applications and Reviews*, 40(1), pp. 1–12.

Phitayakorn, R. *et al.* (2015) 'Practicality of using galvanic skin response to measure intraoperative physiologic autonomic activation in operating room team members', *Surgery (United States)*. Elsevier Inc., 158(5), pp. 1415–1420.

Seynaeve, S. *et al.* (2011) 'Adverse drug events in intensive care units: A cross-sectional study of prevalence and risk factors', *American Journal of Critical Care*, 20(6).

Steyrer, J. *et al.* (2013) 'Attitude is everything?: The impact of workload, safety climate, and safety tools on medical errors: A study of intensive care units', *Health Care Management Review*, 38(4), pp. 306–316.

Stikic, M. *et al.* (2014) 'Modeling temporal sequences of cognitive state changes based on a combination of EEG-engagement, EEG-workload, and heart rate metrics', *Frontiers in Neuroscience*, 8(OCT), pp. 1–14.

Valentin, A. *et al.* (2006) 'Patient safety in intensive care: Results from the multinational Sentinel Events Evaluation (SEE) study', *Intensive Care Medicine*, 32(10), pp. 1591–1598.

Webster, E. *et al.* (2017) 'Predicting cognitive states from wearable recordings of autonomic function', *IBM J. Res. Dev.*, 61(2/3), pp. 2:1--2:11.

Van Zyl, I. and De La Harpe, R. (2014) 'Mobile application design for health intermediaries: Considerations for information access and use', *HEALTHINF 2014 - 7th International Conference on Health Informatics, Proceedings; Part of 7th International Joint Conference on Biomedical Engineering Systems and Technologies, BIOSTEC 2014*, pp. 323–328.

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