A Novel Approach to High Fidelity Observation of Stress in Intensive Care Nursing through Application of Technology

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Abstract
This report explores the data collection efforts to support an ethnographic observation of intensive care nurses during an individual nurse's standard working shift with the goal of observing physiological symptoms of stress, fatigue, and burnout as it relates to their work. The design of the data collection detailed within is intended to be low impact, minimally invasive and achieve high fidelity and insight into nursing work activities in a high demand environment. All research activities outlined in this paper were developed and pilot tested before implementation for a full 12 hour shift. Upon activation it was rapidly recognized that technological and personnel limitations would require adaptation. The participant pool demographics, and lessons learned are detailed within this paper. The adaptations are detailed for future study focused on ethnographic study in situations where placing a direct observer is impractical.

Introduction

Burnout is the physiological and psychological condition an individual can experience when they are exposed to repeated stressors without appropriate means for recovery (Maslach, Jackson, & Leiter, 2015). Burnout is known to manifest as physical and emotional exhaustion, cause reduced feelings of personal accomplishment and even depersonalization (Maslach, Schaufeli, & Leiter, 2001). Recent studies have become particularly interested in issues of burnout as they impact healthcare providers. The symptoms of exhaustion and depersonalization are particularly concerning when the individuals suffering burnout are responsible for the medical care of others. A recent study found that 44% of professional nurse participants reported symptoms of burnout (Emanuel, Ferris, Von Gunten, & Von Roenn, 2005).

Hospital nurses are known to suffer from high stress, fatigue, and burnout (Maslach et al., 2001; McHugh, Kutney-Lee, Cimiotti, Sloane, & Aiken, 2011; Steege & Dykstra, 2016). The accrual of stress, and fatigue leading to burnout can impair mental performance, and has the potential to increase the risk of medical errors (Shanafelt et al., 2010). Medical errors are currently estimated to be the third ranked cause of death in the United States (Makary & Daniel, 2016). For nurses, the issue of depersonalization is also a concern as they are the most frequently encountered direct care provider most patients will encounter. Nurses are often expected to be the face of a patient's care team to both the patient and any family or guests present, maintaining their own composure while also expressing empathy (Mauno, Ruokolainen, Kinnunen, & Bloom, 2016). When nurses are experiencing the impacts of depersonalization they can lose the ability to view their patients as people, and instead perceive them as objects requiring work to be performed. Depersonalization likely has an ability to impact patient perceptions of quality of care.

To date, most of the research conducted focused on clinician burnout has been based on the administration of surveys (Gardner et al., 2019; Khamali et al., 2018; Schwartz et al., 2019). The Maslach Burnout Inventory is particularly popular as a commonly used and reliable burnout survey (Maslach et al., 2015). The primary issue with survey-based burnout identification is that it relies on the respondent to accurately recall and portray their experiences relative to the survey elements. In order to avoid any potential misrepresentation of stress, fatigue, and burnout, an understanding of the physiological symptoms of these constructs is necessary.

Ethnographic or naturalistic study of work behaviors itself has been a common approach used in healthcare. These studies benefit from the direct observation of healthcare related activities in the actual care environment rather considering them in the abstract (Bjerknes & Bjørk, 2012; Liu, Manias, & Gerdtz, 2012; Taxis & Barber, 2003). These studies however, are challenging to execute in a healthcare environment where space is limited and an observer obstructing the healthcare workers can be problematic. With the implementation and continual development of electronic health records and their supporting computer systems (Henry, Pylypchuk, Searcy, & Patel, 2016), many of the studies that would have required a physical observer can now be facilitated by review of computer activity records (Chung et al., 2012; Poissant, Pereira, Tamblyn, & Kawasumi, 2005; Ratwani et al., 2018).

The major shortcoming is that review of computer records as an analog for ethnographic study only support surveillance of activities that occur on the computer. In order to fully assess stress, fatigue and burnout, we elected to adopt a non-invasive wearable technology-based approach. By utilizing the wearable technology in the form of a mobile eye tracker, we have been able to conduct a more traditional ethnographic study of the stress and fatigue triggers intensive care nurses experience during their work shift.

Physiological measures of stress, fatigue and burnout have been of interest to researchers and investigated in numerous ways. Various technologies exist that enable the measurement of physiological response to triggers and can be as minimally invasive as a wrist worn device or be captured by a full array of electrical leads and respiratory monitoring. Researchers have established that there are pronounced variations in heart rate, skin temperature, galvanic skin response and pupil diameter that manifest in response to emotional triggers (Ali et al., 2018, 2018; de Looff, Didden, Embregts, & Nijman, 2019; Greene, Thapliyal, & Caban-Holt, 2016; Li, Xie, & Wang, 2019; Ollander, Godin, Campagne, & Charbonnier, 2016; Wijsman, Grundlehner, Liu, Hermens, & Penders, 2011). While studies have focused on some subset of these and other measures, there is little consensus in which combination of response metrics is optimal. We have elected to remain as minimally invasive to participants, both in terms of physically attaching the measurement devices but also in the time commitment to do so.

Study of nursing activities within the intensive care units poses unique challenges. An intensive care unit is a busy and complex environment, space is often at a premium, and the entire area is designed to facilitate the care and movement of patients. Placing researchers anywhere within the unit to observe can pose unnecessary risks to the observers, participants, and patients. In response to these risks and concerns, we have elected to employ a novel approach, long duration mobile eye tracking. By equipping the participant with a mobile eye tracker ("Tobii Pro Glasses 2 wearable eye tracker," 2015) we have achieved the ability to conduct a naturalistic observation of daily nursing work through the entire working shift.

In support of the identification of stress, fatigue and burnout, we also equipped participants with an Empatica e4 wristband ("Real-time physiological signals | E4 EDA/GSR sensor," n.d.). The E4 device captures a galvanic skin response, skin temperature, and heart rate data via photo plethysmography sensors from the participant throughout their shift. Through analysis of the collected physiological data, periods of potential emotional arousal, including stress, can be identified. These moments can be correlated back to specific instances within the eye tracking recording to determine the exact triggers of the emotional arousal and contextual clues related to the circumstance.

We sought to study the issues of stress, fatigue and burnout in critical care nursing. While previous studies of clinicians and even specifically nurses have shown that burnout is present (McHugh et al., 2011; Meltzer & Huckabay, 2004), we elected to employ a novel approach utilizing wearable technology for an ethnographic study capturing the stress, fatigue and ultimately burnout present in critical care nurses. Through the combination of the mobile eye tracker device and wearable physiological monitor, we will be able to not only assess the stress, fatigue and ultimately burnout present in our participants, but also identify the common trigger events shared by all participants.

Materials and Methods

Study Design and Specific Aims

Study Aims

The primary aim of this study is to identify potential triggers to stress in critical care nurses, specifically those within the technological domain. The secondary aims are to conduct a thorough ethnographic evaluation of stress, fatigue and burnout experienced by critical care nurses. Finally, these analyses will be employed to assist in the development of workplace interventions which may reduce the stress and burnout experienced by critical care nurses.

Study Design

The study is formatted as an ethnographic data collection of an opportunistic sample of critical care nurses. We set a minimum threshold of ten participants with no upper limit on participation, based on volunteers amongst the cardiovascular intensive care unit nursing staff. All participants engaged in all aspects of the study which consisted of an initial survey, a physiological body composition measurement, a single shift wearing a mobile eye tracking device (Tobii Pro Glasses 2), and three shifts wearing a wrist based physiological measurement device (Empatica E4).

Recruitment

The inclusion criteria were critical care nurses working in the cardiovascular intensive care unit (CVICU) at Houston Methodist Hospital in Houston, TX. Both day and night shift participants were recruited, by outreach sessions conducted by the study staff to introduce the study and research team to the unit. The only exclusion criteria were participants who required corrective lenses and did not have contact lenses available due to limitations of the eye tracker.

Ethics and Consent

The Houston Methodist Office of Research Protections, and Texas A&M Institutional Review Boards reviewed and approved the study. Nurse participants provided written informed consent at the time of their first day participating in the study. All data collection, and management procedures were conducted in accordance with national, state, local, and institutional policies and regulations.

We acknowledge there are significant ethical and privacy concerns in placing a mobile eye tracker on a health care provider while they are actively caring for patients. These concerns are encapsulated in their own forthcoming publication derived from a survey of the relevant ethics literature and contributions from the authors and the directors at the Houston Methodist Office of Research Protections.

Data Collection and Management

On the first day of participation, participants were provided with the study survey, provided body composition measurements, and wore the Tobii eye tracker and Empatica E4 physiological recording device on the first day of their typical work week. At the end of their work week, participants wore the Empatica E4 again. After their weekend period, participants wore the Empatica E4 a third time, concluding their participation in the study.

All data collection efforts were scripted for the research team to maintain fidelity. In addition, the Institutional Review Boards approved informational materials to be distributed to employees and hospital guests further clarifying the purpose and nature of the study and data collected.

<u>Measurements</u>

Maslach Burnout Inventory

The Maslach Burnout Inventory was administered to all participants at the start of their participation in the study. The survey provides a baseline knowledge for the research team on the condition of the participants at the onset of data collection. The inventory itself is well validated and has been thoroughly employed in related research (Maslach et al., 2015; Maslach & Leiter, 2008; Shanafelt et al., 2010, 2015). Consisting of 15 questions answered on a Likert scale and scored following the established manual. The burnout inventory provides a measure of burnout markers across three categories, Emotional Exhaustion, Depersonalization, and Personal Accomplishment. Emotional Exhaustion represents the fatigue that is often encountered by nurses as they are required to present a calm and collected face to patients and their families, while dealing with high stress and emotionally taxing situations. Depersonalization captures the degree to which the nurses stop viewing their patients as people and begin viewing them as work items to be processed. Finally, personal accomplishment is a positive measure which represents the rewarding nature of nursing work when the participant is able to assist a patient in recovery and ultimately return to home or a less critical area of the hospital.

Empatica E4

<u>Electrodermal Activity</u>

Electrodermal Activity (EDA), also known as Galvanic Skin Response (GSR), is the autonomic response of the body's nervous system triggering sweat production and are tracked by changes in skin conductance (Benedek & Kaernbach, 2010; Braithwaite, Watson, Jones, & Rowe, 2013). EDA signals can be classified as Tonic and Phasic (Benedek & Kaernbach, 2010).Tonic responses present as longer-term smooth changes in skin conductance, and may be often a result of the body maintaining homeostasis with the environment (Benedek & Kaernbach, 2010). Phasic responses are those which present as rapid changes and are typically considered to be triggered by short-term stimuli from the environment, such as those causing stress (Benedek & Kaernbach, 2010).

<u>Photo Plethysmography</u>

Photo plethysmography (PPG) measures blood flow that passes under the sensor by observing variations in light response through the skin. The E4 processes the raw blood volume pulse data from the PPG sensor into an inter beat interval (IBI) and a heart rate measure. While the PPG measure is subject to motion artifacts, the E4 performs some artifact reduction in processing the raw blood volume pulse data into IBI and heart rate.

<u>Skin Temperature</u>

Skin temperature is the raw measure of the area of skin directly under the E4 device. Some stress events may impact the measured skin temperature as the body undergoes various physiological changes in response to a trigger event.

Tobii Pro Glasses 2

<u>Pupillary Response</u>

As part of the autonomic nervous system, pupillary diameter varies with environmental and mental triggers. Much of pupil diameter is influenced by environmental light levels, however there are definite and autonomic changes that occur in response to emotional triggers as well.

<u>Eye Movements</u>

The nature and quality of eye movements can vary depending on fatigue level of the individual. The Tobii Glasses attempt to also classify the nature of such movement which can provide insight into the level of fatigue or stress a participant may be experiencing.

<u>Observed Interactions</u>

As part of the ethnographic data collection, the individual interactions that take place may trigger physiological responses. These activities are captured by the A/V recording performed by the Tobii Glasses may include specific technological interactions such as viewing a new medication order within the electronic health record, untangling a patient’s intravenous lines,

<u>Approximate Cognitive Load</u>

While the Tobii Glasses do not directly document and identify blink activities, it is possible to discern blink events from the pupil diameter data. By establishing a range of acceptable blink duration, the periods where data is missing and attributable to a blink event can facilitate the measurement of approximate blink rate. By analyzing the blink events similar to that of a heart rate rhythm, in conjunction with other eye movement metrics, trends and can be established. In some literature, blink rate, eye movement and pupillary response have been shown to be linked to cognitive load (Duchowski et al., 2018; Hershman, Henik, & Cohen, 2018; Marshall, 2002). While typically conducted under controlled environment settings, an approximation for the cognitive load a nurse functions under throughout the working day can be calculated by observing the variations in blink rate over time.

Environment Specific Triggers

In addition to the ethnographic collection of data, it is suspected that certain environmental triggers such as overhead alarms may cause stress reactions in participants. In particular we theorize that the overhead announcement of a code-blue event which requires an all-available response to assist should trigger some measurable response in all participants. We are comparing the times that a code-blue event occurred within the CVICU and anywhere that CVICU staff may have a responsibility to respond to with data collected from active participants at that time for potential responses.

Longitudinal Stress and Fatigue Aggregation and Recovery

By capturing the first and last days of the work week and the first day of the following work week, an approximate comparison of the overall stress and fatigue may be possible. We hypothesize that the first and third days of participation should be near equivalent in observable stress and fatigue markers, however the second day, representing the end of the work week, should show higher stress and fatigue indicators.

Results

Of the potential participant pool of CVICU nurses, 28 full participants were recruited. Of the recruited participants, eight were from the night shift, and the remaining 20 worked on day shift. We recruited six male nurses, representing a higher male to female ratio than the industry standard at approximately nine percent (nursing ref).

Male	Female
6	22

American Indian or Alaska Native	1
Asian	5
Black or African American	2
Hispanic or Latino	2
Native Hawaiian or Other Pacific Islander	4
Other	4
White	16

Single, Never Married	Married or Domestic Partnership	Widowed	Divorced	Separated
11	16	0	1	0

No Children	One	Two	Three	Four or more
16	4	7	1	0

	Average	Standard Dev.	Min	Max
Age	34.64	8.09	25	56
BMI	26.99	5.73	18.2	42.6
Body Fat %	28.75	7.80	9.4	45.2
Years in ICU Nursing	7.23	6.30	0.33	23
Years in ICU at HMH	4.95	6.06	0.33	23
Years at HMH	4.81	6.06	0.33	23

Total nursing experience	8.00	6.06	0.33	23

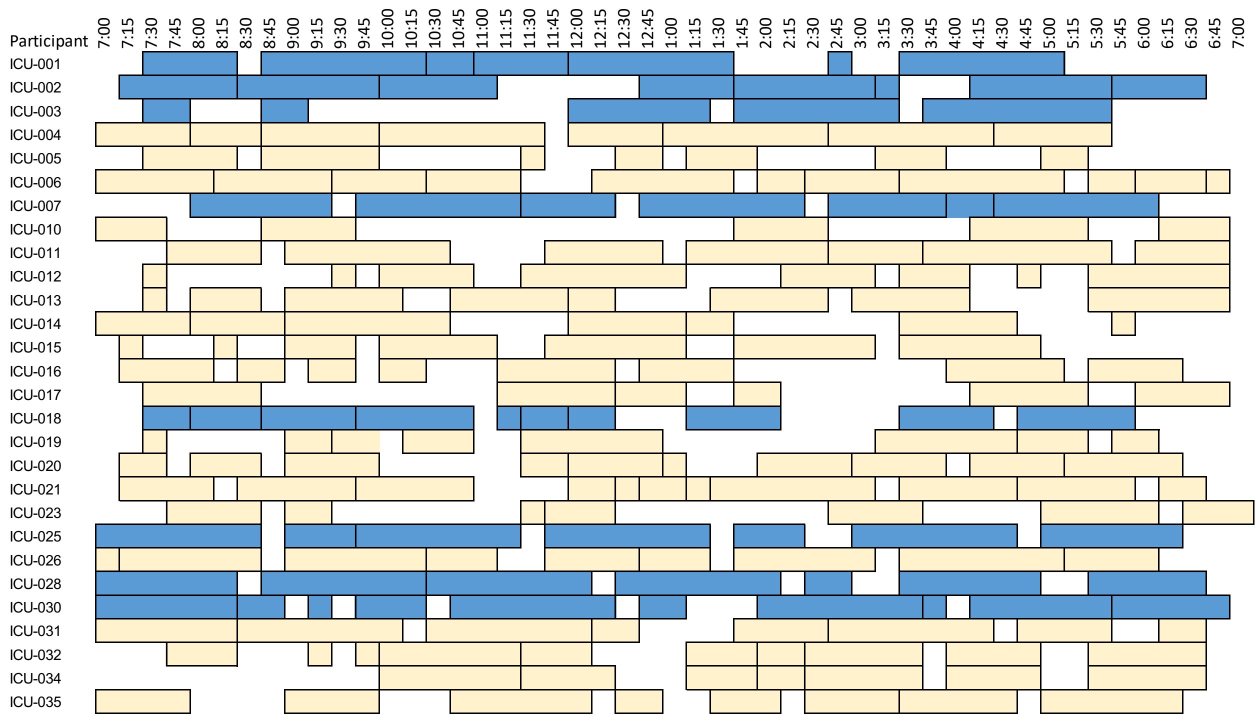
Habits	Yes	No
Tobacco Use	1	27
Alcohol Use	18	10
Caffeine Use	23	5
Exercise Regularly	21	7
Work Extra Shifts	10	16

Survey responses show that the early stages of burnout, emotional exhaustion are beginning to manifest, however they are not escalating into depersonalization. This may be related to the high levels of personal accomplishment also reported by the nursing participants.

	Emotional Exhaustion	Depersonalization	Personal Accomplishment
ICU-001	8	3	9
ICU-002	7	2	17
ICU-003	8	3	13
ICU-004	8	2	16
ICU-005	5	2	13
ICU-006	14	5	14
ICU-007	8	4	10
ICU-010	15	8	13
ICU-011	11	8	16
ICU-012	8	0	12
ICU-013	11	2	17
ICU-014	2	0	11
ICU-015	10	0	16
ICU-016	7	4	13
ICU-017	7	5	11
ICU-018	15	6	15
ICU-019	4	1	13
ICU-020	10	13	11
ICU-021	11	4	14
ICU-022	11	2	13
ICU-023	10	3	15
ICU-025	18	11	9
ICU-026	15	5	6
ICU-028	3	3	13
ICU-030	5	0	18
ICU-031	9	3	14
ICU-032	2	7	18

ICU-034	6	0	12
ICU-035	15	17	16

Combined data collection mechanisms successfully collected combined Tobii Glasses and Empatica E4 based initial days for all participants. Twenty participants were able to successfully participate in the follow-on days, follow on days were missed due to equipment failures and changes in participant schedules.



The data collection efforts with the eye tracker encountered several technical issues in pushing the equipment to this degree. However, despite the limitations of the hardware encountered, it was possible to achieve approximately 78% coverage of the 12 hour shift with eye tracking video.

Discussion

At this time, primary data collection has concluded, and in-depth analysis has just begun. This paper is focused on presenting the initial findings of the survey elements and lessons learned in conducting a study of this nature in a clinical environment which presents several unique complications.

The staff of the ICU nearly all responded in moderate to high categories for the emotional exhaustion measures of burnout from the Maslach Burnout Inventory. However they also nearly all scored as not experiencing symptoms of depersonalization. When high scores of emotional exhaustion and depersonalization are present, the feelings of personal accomplishment can begin to suffer as burnout sets in. A possible theory for this situation is that while the work of an ICU nurse is significantly emotionally draining, there are also rewards in the work itself that offset. The balance enables these nurses to exist with moderate to high emotional exhaustion without progressing into depersonalization.

Eye tracking recordings were able to be completed for approximately 78% of the twelve hour shifts. Given that the eye tracker was not designed for sustained operation of such duration, achieving this level of success is significant. Throughout a mostly successful day the eye tracker would heat up and require occasional "breaks" during which it became necessary to retrieve from the participant and allow it to cool. Due to battery capacity limitations, recordings could operate for one to two hours. The regular interactions with the nurses for battery changes were limited by all patient care activities took priority. By this we mean that if the nurse was due for a battery change, that activity was deferred until they were at a point where they informed the research team that they could be interrupted. This prioritization of patient care does mean that some brief battery change intervals extend significantly longer.

While overall successful, we encountered several issues in employing the Tobii Glasses for this study. Primarily the limitation of battery capacity. Due to the original design being meant for shorter duration studies, the battery life for a Tobii Glasses ranged between one and two hours. This limitation required regular, almost hourly interaction with the participant, around their clinical responsibilities to perform a battery change. In many cases, this battery change needed to occur while the participant was engaged in care activities. Waiting for the participant to be available for the battery change resulted in some of the gaps in recording.

In addition, though designed as a mobile and wearable unit, it was found that the Tobii Glasses did not respond as well to some of the disruptions caused when worn by a nurse for an entire shift. Though many clips were offered and used, and where possible wires run under jackets, the headset was periodically unplugged from the recording pack. The unit was also found to be particularly vulnerable to excess movement, particularly some nurses were caring for patients in a level of isolation requiring an isolation gown to be worn. The process of putting on the gown almost always caused the recording to fail due to an intermittent connection disruption between the headset and recording pack.

The data collection effort with the E4 had its own issues as well. The original data collection design intended for the E4 data to be captured by a mobile device as part of a live stream. When operated in the streaming mode, the E4 can operate for an entire working shift without issue, however it was discovered that there was a significant limitation of the Bluetooth wireless radio range, and if the E4 and mobile device lost their connection for too long the E4 would shutdown. This issue presented itself during pilot sessions and resulted in a shift to the alternate E4 operating mode where data is recorded directly to the device memory, this ensured complete recording for the entire shift however, there is no option for monitoring the data stream during collection.

Being a wrist worn device as opposed to the more accurate array of electrodes, the E4 is recognized to have some vulnerability to motion artifacts. We intend to employ the recommended software for analysis, Kubios (ref?) which is expected to be able to adapt with the motion artifacts. It was also noted on the EDA sensors that when the nurses used the foam hand sanitizer or washed their hands with water, the sensor would spike if splashed. The behavior was noted by the team and is not expected to negatively impact the data analysis given the multiple physiological data sources being utilized.

Practical Application

Through this novel approach to study of an intensive care unit we expect to be able to assemble a more complete picture of the work activities and their impacts on critical care nurses throughout the working shift. We will also be developing an analysis approach specific to our combination of metrics collected and utilizing them to ensure meaningful change targeting stress, fatigue, and burnout is made in the CVICU for the nurses. The tools and methods employed to support this

Conclusion

Minimally invasive and high-resolution study of nursing activities for long duration are possible, however they are restricted by the limits of the technology used. Our data collection efforts have been successful despite several setbacks. Keeping the entire unit engaged in the research also facilitated greater positive response towards the project and research team. Mobile eye tracking hard ware may not be designed to be as truly tolerant of the degree of movement that a busy nurse may experience, though we do feel that our data collected is still sufficiently representative of the working activities of the participants.

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