Clinical Simulation in Nursing (2019) 31, 21-27

Clinical Simulation in Nursing

www.elsevier.com/locate/ecsn

Featured Article

Task-Evoked Pupillary Responses in Nursing Simulation as an Indicator of Stress and Cognitive Load

Cristina Cabrera-Mino, BS[a], Mary Ann Shinnick, PhD, ACNP, CCNS, CHSE[b,*], Stefanie Moye, BS[c]

[a]*Staff Research Associate, UCLA School of Nursing, Los Angeles, CA*
[b]*Associate Adjunct Professor, Director of Simulation, UCLA School of Nursing, Los Angeles, CA*
[c]*Research Assistant, UCLA School of Nursing, Los Angeles, CA*

KEYWORDS
cognitive load;
stress;
simulation;
nursing;
pupillometry;
eye tracking;
task-evoked;
prelicensure

Abstract
Background: There are no studies identifying specific tasks in a simulation that increase stress and cognitive workload.
Methods: This was a two-group comparative study of Novice and Expert Nurses participating in simulation using pupillometry to measure stress and cognitive load associated with specific tasks.
Results: Significantly higher stress was found in the Novices for four of the six expected tasks, specifically interventional tasks requiring clinical judgment.
Conclusions: The Novices had greater stress on interventional type tasks. Simulations with more emphasis on interventional tasks in which the nursing student is the sole decider of interventions may decrease stress and enhance performance.

Cite this article:
Cabrera-Mino, C., Shinnick, M. A., & Moye, S. (2019, June). Task-evoked pupillary responses in nursing simulation as an indicator of stress and cognitive load. *Clinical Simulation in Nursing, 31*(C), 21-27. https://doi.org/10.1016/j.ecns.2019.03.009.

Nurse educators are tasked with training prelicensure nursing students in the development of strong clinical judgment skills such as accurate interpretation of clinical assessments and appropriate interventions based on that assessment. To promote these abilities in students, nursing programs use simulation-based education (SBE) as preparation for the registered nurse (RN) role. Simulation, the recreation of a clinical event, is known to reproduce the stress of patient assessment and intervention (Bong, Fraser, & Oriot, 2016), but specific causes of stress during SBE are unclear. Based on seminal articles on stress, it is defined here as the uncontrollable physical, biological, and/or psychological responses of a person encountering strain beyond their capacity to adapt/remain at ‘‘homeostasis’’ and displaying increased arousal in the aforementioned

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.
* Corresponding author: mshinnic@sonnet.ucla.edu (M. A. Shinnick).

1876-1399/$ - see front matter
https://doi.org/10.1016/j.ecns.2019.03.009

domains (Gaillard & Wientjes, 1994; Hobfoll, 1988; Selye, 1956). Some stress is beneficial as it can improve performance but, depending on how a stressful situation is assessed, it can impair performance (Ignacio et al., 2015). Moderate levels of stress have been found to stimulate performance in technical skills (Leblanc, Woodrow, Sidhu, & Dubrowski, 2008) while excessive stress has been shown to impair performance (Arora et al., 2010) and impair learning and working memory capacity (Al-Ghareeb, Cooper, & McKenna, 2017; Bong et al., 2016). Nursing students who exhibited high stress levels in SBE were found to be less accurate in their skill performance (Mills, Carter, Rudd, Claxton, & O'Brien, 2016), but to date, it is unclear which activities within the simulation elicit stress and if this effect is seen in experienced nurses.

Key Points

- Nursing students experience stress in simulation associated with tasks requiring intervention and clinical judgment.
- Some stress is good but too much or too little can impair performance.
- Increased simulation experiences with more emphasis on interventional tasks may decrease subsequent stress in similar clinical situations.

Researchers have studied the overall impact of SBE on learner stress using a variety of techniques such as participant self-report and physiological changes in heart rate, blood pressure, and cortisol levels (Ignacio et al., 2015; McKay, Buen, Bohan, & Maye, 2010). These physiological changes of the autonomous nervous system have been associated with the cognitive load (the mental effort associated with decision making) expended in relation to the level of task difficulty (Causse, Senard, Demonet, & Pastor, 2010). Although these physiological stress measures have merit, the equipment sensors used to collect them can be cumbersome, can be expensive, and do not all provide data in real time. In addition, they do not capture immediate task-evoked responses to changes in stress and cognitive load. One technique without these disadvantages is pupillometry, which uses eye tracking glasses (ETGs) to continuously track pupillary responses (i.e., dilation/constriction, point-of-focus) as a means of determining stress and cognitive load during tasks without interfering in subject performance. Video-captured pupil diameter changes have been positively associated with cognitive load levels in increasingly difficult arithmetic tasks (Chen & Epps, 2014). Along with percentage of change in pupil diameter, level of cognitive load induced by arithmetic tasks has also been assessed with an eye tracker using visual field analysis (Gavas, Chatterjee, & Sinha, 2017). In a study evaluating task-evoked pupillary responses during a memory recall task, participants who had lower-span working memory (i.e., recalled fewer items) had larger changes from baseline in pupil diameter, as compared to those with higher-span working memory (Heitz, Schrock, Payne, & Engle, 2008).

Pupillometry has the ability to identify the task-evoked pupillary responses of participants in SBE. This information could assist in informing faculty on specific clinical activities that elicit stress and greater cognitive load in the Novice versus the Expert nurse. Reliably identifying these differences may illuminate the paradigm needed to successfully advance novice nurse competency and decrease stress in SBE. Therefore, for this study, we used pupillometry, obtained by ETGs, on both Novice and Expert nurses in a simulated clinical event to identify differences in stress and cognitive load as detected by pupil dilations associated with specific tasks.

Theoretical Framework

The Theoretical Framework used for this study is the cognitive load theory (Paas, Van Merrienboer, & Adam, 1994; Sweller, van Merrienboer, & Paas, 1998), which describes the effect of performing a task on a person's cognitive processing ability. Excessive strain, such as that contributed by stress, on a subject's cognitive load can impair performance by disrupting working memory (Bong et al., 2016). Working memory is the process of organizing incoming information to learn a skill and make decisions (Moreno & Park, 2010). Impaired working memory impacts both decision-making and skill performance (Beddoe & Murphy, 2004) traits required of a competent nurse. SBE is known to create stress in learners at all levels (Bong et al., 2016) with higher levels of stress linked to extraneous factors. Therefore, the design of this study's simulation was done such that extraneous stressors such as observers, family members, clinical alarms, and nonfamiliar electronic systems were removed (i.e., electronic health record replaced by a paper record; medications on a table instead of in an unfamiliar electronic system). Thus, the cognitive load of the study simulation was deliberately designed to reduce the effect of disparity in experience between Experts and Novices.

Methods

Sample

This study used a prospective, correlational-comparative design with two groups: Novice nurses (senior prelicensure nursing students nearing graduation; $n = 13$) and Expert nurses (adult ICU or Emergency Department nurses with >5 years of clinical experience; $n = 15$). Each subject participated individually in a high-fidelity manikin-based simulation of a patient with decompensated heart failure (HF). The Novice nurses were recruited from a single Baccalaureate School of Nursing. The Expert nurses were recruited from a large tertiary hospital and a smaller community hospital. The study team recruited students to the study in a class not taught by the researchers, and nurses were recruited by blanket e-mail to nursing staff in several ICUs. There was no grade impact or extra credit given for participation in this study and all research activity was done outside of work and school time. For their study participation, each participant received a $25 gift card to a popular store.

Inclusion criteria for the Novice nurses consisted of status as a senior prelicensure nursing student who had successfully completed coursework in the care of the decompensated HF patient. Inclusion criteria for the Expert nurses were employment of five or more years as an ICU or Emergency Department (ED) nurse. Exclusion criteria included any subject in which the ETG could not be calibrated or of which satisfactory pupillometry data could not be quantified.

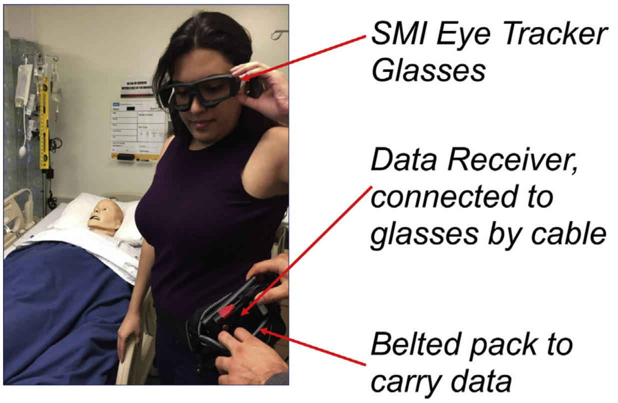

Figure 1 Eye tracking glasses with pupillometry feature as worn in simulation.

Instruments

Simulation Design

Simulation of patients with HF is important as HF is the most common hospital discharge diagnosis in the United States in patients aged 65 years and older (Pfuntner, Wier, & Stocks, 2013) and this is a common patient situation that all levels of nurses are likely to encounter. The study simulation depicts an adult male patient complaining of new onset dyspnea. During the simulation, the patient (SimMan® 3G, Laerdal, NY) complains of increasing dyspnea with pulmonary crackles (fluid overload) on physical examination. Expected clinical actions of the subjects included: (a) Elevated the Head of the Bed (HOB); (b) Applied the Pulse Oximeter; (c) Applied Oxygen to the ‘‘Patient’s’’ Face; (d) Connected Oxygen to the Flowmeter; (e) Listened to the Lungs; (f) Reviewed Orders/Chose Furosemide (Lasix®). The patient’s symptoms do not improve until both oxygen and furosemide have been given (scenario end point—appropriate treatment for decompensated HF). Content validation of the simulation was done by HF nursing experts and a cardiologist at the Ahmanson/UCLA Cardiomyopathy Center. It is a basic nursing simulation, not intended to be difficult or add any cognitive burden beyond what would be experienced in the clinical setting and has been used in another large study of over 160 nursing students (Shinnick, Woo, Horwich, & Steadman, 2011). Each simulation was facilitated by a trained and certified health care simulation educator. Debriefing was not included as it was not part of the study objectives.

Video Capture

Video of each subject’s simulation was achieved wearing ETGs (SensoMotoric Instruments [SMI, Teltow, Germany]), software version 2.7. The ETGs have excellent audio and video capture (24 Hz audio; 1280 × 960 video resolution) and are able to collect large amounts of data including a continuous measurement of pupil diameter of both eyes (pupillometry) (Figure 1). Pupillometry data are captured second by second and are linked to video actions. The resulting video is from the view of the subject so subjects cannot be seen or identified. Following all the simulations, the researcher reviewed each coded, anonymous video and annotated for the time of clinical task initiation to be linked to any pupil changes.

Stress/Cognitive Load Detection (Pupillometry)

Right and left pupil diameters were captured by the ETG at a sampling rate of 60 Hz (60 gaze points per second). As each participant had a unique pupil dilation value at the start of the simulation, the researchers noted the mean pupil dilation at the simulation start time (Baseline) and the subsequent pupil changes associated with the tasks were recorded as ‘‘Change from Baseline’’ (dilated [positive change] or constricted [negative change]). ‘‘Change from Baseline’’ pupil diameter of each subject was then matched to the task annotations of the six clinical tasks: (a) Elevated the Head of the Bed (HOB); (b) Applied the Pulse Oximeter; (c) Applied Oxygen to the ‘‘Patient’s’’ Face; (d) Connected Oxygen to the Flowmeter; (e) Listened to the Lungs; (f) Reviewed Orders/Chose Furosemide (Lasix®).

Room lighting was held constant throughout the data collection period. There were no subjects wearing corrective lenses, and all subjects included in this study had full pupillometry data.

Demographic Questionnaire

A demographic questionnaire was completed after the simulation so the topic of the simulation would not be divulged. It included history of personal or family experience with HF, the participant’s status (Novice or Expert), age, gender, and prior simulation exposure.

Data Collection Protocol

This study was IRB approved. Following an explanation of the study and signed informed consent and confidentiality

Table 1 Completion of Expected Tasks Between Groups

Variable	Novice (n = 13)	Expert (n = 15)
Elevated the Head of Bed	92%	93%
Applied Pulse Oximeter	92%	100%
Applied Oxygen to Patient	92%	100%
Connected Oxygen to Flowmeter	85%	93%
Listened to Lungs	77%	80%
Reviewed Orders/Choose Furosemide	92%	100%
Checked K+ level	15%	0.07%

agreements, each subject was individually fitted with the ETG and their eyes calibrated to the software (Bojko, 2013). They were individually oriented to the simulation room, manikin features, and available supplies such as medication area and medical record (prebrief). Each subject then participated solo in a 10-minute HF simulation scenario initiated by a patient history (not revealing a diagnosis of HF or HF exacerbation) followed by the patient manikin (SimMan® by Laerdal) complaining of new onset dyspnea. The complaints and symptoms of the simulated patient do not improve until oxygen and furosemide (Lasix®) are administered, as ordered by the provider in the medical record. Six basic nursing tasks, as detailed previously, were expected to be completed. There was no debriefing as the objective and focus of this study was to identify task-evoked stress and cognitive workload differences between the groups in a simulated clinical experience.

Statistical Analysis

Descriptive statistics were used for the demographic data. Pupillary Change from Baseline for the six aforementioned tasks was analyzed using nonparametric tests (Mann–Whitney *U* test) as the data were not normally distributed. Statistical significance was prospectively set at $p < .05$.

Results

None of the subjects had a personal or family experience with HF. Statistical significance was found between the groups for age (Novices 25.38 ± 6.15; Experts 38.9 ± 10.07; $p = <.01$), but there was no statistical difference between the groups for the number of simulations they had participated in previously (Novices 4.69 ± 1.4; Experts 4.20 ± 2.3; $p = .71$) or gender ($p = .06$).

Of the 28 participants (Experts [n = 15]; Novices [n = 13]; males = 2 [Novices]), only 57% completed all the expected tasks (Novices 46%; Experts 67%). Within the remaining subjects that skipped an expected task, 75% of them only missed one task (e.g., did not auscultate the lungs) (Table 1).

Using Mann–Whitney *U* test, "Change from Baseline" pupil diameter was computed for the six expected tasks. As

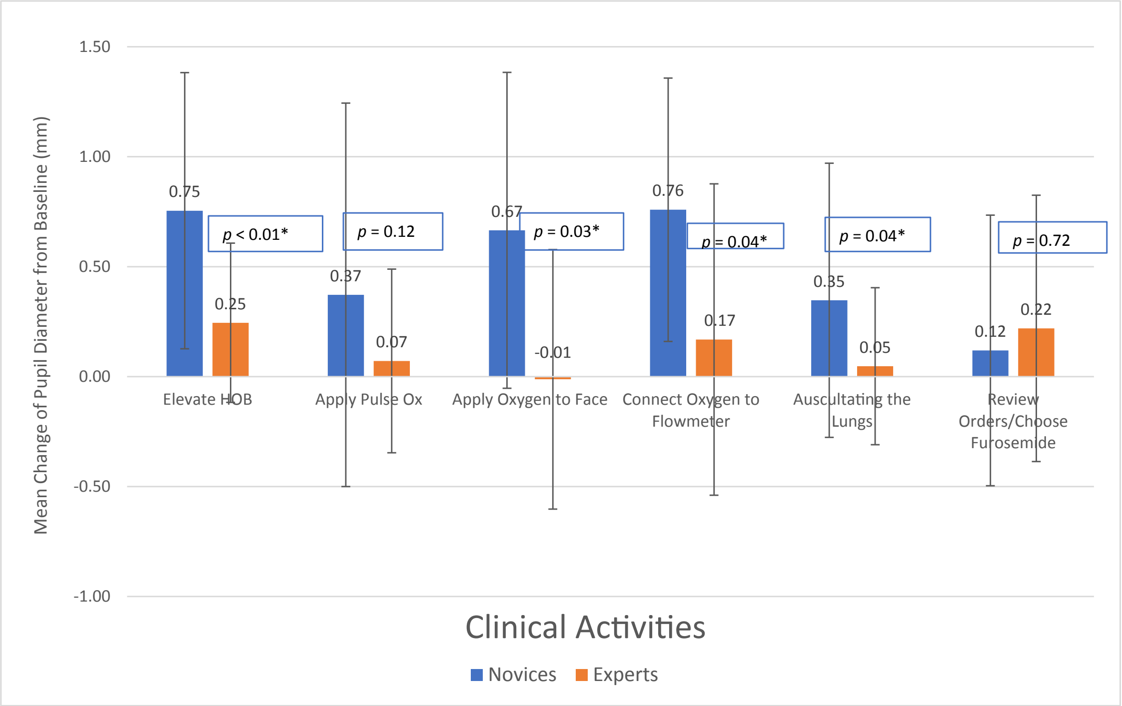

Figure 2 Total mean pupil diameter change from baseline between Novices and Experts during clinical activities.

not all participants completed all tasks, a test-by-test elimination was done to adjust for incomplete data. Statistical significance in pupil dilation between the groups was found for four of the six tasks: (a) Elevated the HOB ($p = <.01$); (b) Applied Oxygen to the Patient's Face ($p = .03$); (c) Connected Oxygen to the Flowmeter ($p = .04$); and (d) Listened to Lungs ($p = .04$). While the Novices had pupil dilation in each of these tasks, the Experts had pupil constriction in one of the three tasks (Applied Oxygen to the Patient's Face) (Figure 2).

Discussion

Using pupillometry is a novel approach to determine task-evoked pupillary responses due to stress and cognitive load differences between Novice and Expert nurses in a common simulated clinical event. Pupil changes revealed a higher stress response in the Novice group during the tasks of Elevated the HOB, Applied Oxygen, Connected Oxygen to the Flowmeter, and Listened to the Lungs. The first three of these tasks could be characterized as interventional type tasks. These are tasks which Expert nurses commonly perform in the clinical setting for all types of dyspneic patients. However, while performed by most of the Novices in the study, they were associated with higher stress and cognitive load levels. This may be due to the fact that nursing students would perform these tasks by themselves in the clinical setting less often than an experienced RN. In the clinical setting, when a patient becomes dyspneic, the RN would typically "take over" the patient care. In contrast to other tasks, Expert nurses showed pupillary constriction while applying oxygen to the patient, the only task in the simulation to produce such a response. We speculate that this may indicate that the Experts were more relaxed during this task, as pupil constriction is connected to the parasympathetic nervous system. Constriction is also caused by the accommodation reflex, which occurs when a person focuses from a faraway object to one closer; it may be that the Experts were more comfortable moving closer to the patient than the Novices (McDougal & Gamlin, 2015). The fourth task, Listened to the Lungs, while more likely characterized as an assessment task, also caused stress in the Novices in this study. This may be due to the uncertainty of accurately identifying the correct lung sounds (i.e., crackles vs. wheezing in which the interventions are different) and the subsequent decision making needed based on the lung assessment. Making an accurate assessment is particularly stressful to the Novice with limited experience as it directly relates to the outcome of the patient.

Interestingly, two of the tasks (i.e., Applied Pulse Oximeter, Reviewed Orders/Chose Furosemide [Lasix®]) did not indicate increased stress or cognitive load in the Novice. A possible explanation for why the Novice showed significantly less stress during tasks that could be characterized as assessment tasks could be the Novice was simply performing a low difficulty level skill such as attaching the oximeter and following provider orders. The Novice generally gains experience in performing these tasks in a skills laboratory and in the clinical setting but the tasks themselves do not require any decision making or clinical judgment. Novices heavily rely on provider orders, which is essentially "following directions," a task the Novice does not see requiring any clinical judgment. However, listening to the lungs, elevating the HOB (i.e., how high to elevate), applying oxygen to the patient (i.e., choosing a delivery device and liter flow level), and connecting the oxygen to the flowmeter (i.e., how much liter flow) are interventions that require clinical judgment and appear to create stress in the Novice. Based on the cognitive load theory, the Novices had impaired working memory that impacted skill performance.

Pupillometry is valuable as it provides an indirect measure of sympathetic arousal and activity of the locus coeruleus, an area of the brain associated with performance and attention (Aston-Jones & Cohen, 2005). Mean changes in pupil size have also been tracked to the level cognitive load involved in memory tasks, arithmetic, visual search tasks (Attar, Schneps, & Pomplun, 2016; Goldinger & Papesh, 2012). Studies using simulation (Reiner & Gelfeld, 2014; Zheng, Jiang, & Atkins, 2015) show that when presented with increasingly complex tasks, there is a positive relationship between pupil diameter and perceived task difficulty. During the simulation in this study, the significantly different pupillary responses of the Novices from the Experts helped identify what specific tasks induce stress in the Novices. The Novices, with less clinical experience and practice "being the nurse," had significantly more stress and cognitive load than the Experts. Improving Novice nurse clinical judgment skills and experience in interventional type tasks that require decision making can be accomplished by more well-designed simulations and added practice in the role of "being a nurse," thus improving working memory.

Of note is the significant difference in age between the Novices and Experts. The average age of the Novice was approximately 25, and according to neuropsychological studies, frontal lobe maturation continues in the 23 to 30 age range (Sowell, Thompson, Holmes, Jernigan, & Toga, 1999b). In the post adolescence period, the frontal cortex is one of the most prominent sites of brain maturation, such as by increased myelination, which may improve executive decision-making processing (Sowell, Thompson, Holmes, Batth et al., 1999a). Novice nurses tend to be younger than Expert nurses and thus more likely to have a less developed frontal lobe. While nurse educators cannot accelerate the aging process, they should be cognizant of the effects of brain maturation in younger nurses and how it affects differences in clinical judgment.

Aside from maturation effects on the frontal lobe, the decision-making process is vulnerable to changes due to stress. When under stress, the body quickly responds through the sympathetic adrenomedullary pathway "fight-or-flight" mechanism, resulting in the release of catecholamines that stimulate the locus coeruleus by way of the vagus nerve, projecting into structures such as the amygdala, hippocampus, and prefrontal cortex (Chrousos & Gold, 1992) (Joels & Baram, 2009). The locus coeruleus is responsible for the pupillary responses captured by the eye tracker used in this study. Neuroimaging studies have shown that these areas of the brain, which involve the regulation of emotions, memory, and decision making, show metabolic changes leading to altered behavior during stressful events (Pruessner et al., 2010). Although this provides the neurological basis for impaired decision making under stress as seen in Novice nurses, it should be noted that individual differences such as genetic factors, age, medication use, and personality variables (i.e., low self-esteem) also alter the reactivity of the stress response (Pruessner et al., 2005). However, repeat exposure to the same stressor is known to decrease the effect of stress on the sympathetic adrenomedullary pathway system, thus reducing impairment on decision-making areas of the brain (Schommer, Hellhammer, & Kirschbaum, 2003). Therefore, for subsequent clinical simulations, it may be of benefit to the Novices to repeat the clinical activities that were most stressful to them so as to ease their stress response in future similar situations. Acting in multiple simulations ''as a nurse'' has been found to enhance the synthesis of knowledge as well as improve clinical judgment features such as noticing and interpreting patient conditions (Lawrence, Messias, & Cason, 2018). In addition, Shin and colleagues (2015) found repeating clinical simulations improved student's critical thinking scores (2015), an ability necessary for clinical judgment.

As there was no statistical significance in simulation experience between the Novices and Experts, it is unlikely that any of the differences in stress could be attributed to simulation experience. However, Expert nurses have more actual clinical experience and have likely encountered these same tasks on multiple occasions whereas the Novices may only be able to perform these tasks in a simulated clinical event or under the direction of an RN.

SBE with some associated stress is valuable as it represents the reality of the actual clinical setting (Bong et al., 2016). With the insights gained by pupillometry, SBEs should be designed to emphasize the interventional tasks that elicit some stress to the Novice participant as a means to develop clinical judgment ability while in a safe environment. However, according to the Cognitive Load Theory, SBEs with excessive stress will impair performance by increasing cognitive load on the Novice, which may lead to poorer learning outcomes (Bong et al., 2016). SBE activities must be tailored to the level of the learner and be appropriate for the simulated situation.

Based on these study findings, simulation experiences with more emphasis on interventional tasks in which the nursing student is the sole decider of clinical interventions may enhance performance in SBE and subsequently the clinical setting (Lawrence et al., 2018). This targeted approach to simulated clinical activities could possibly decrease both the practice gap and some of the stress and cognitive load of nursing interventions for the Novice.

Limitations

Limitations that should be considered in this study are the effects of any substance or possible undisclosed condition that may affect pupillary responses of the participating nurses. These include, but are not limited to, the simulating effects of caffeine, anti-anxiety medications, and conditions such as a general anxiety disorder. However, by using each individual's ''Change from Baseline'' pupil measurements, we hoped to alleviate the effects of these individual differences. Another limitation is the number of prior simulations among the participants. This study was performed at a time when the participant schools and institutions did not offer a large number of simulated activities so replication on a sample with more simulation experience should be done to confirm findings. Finally, use of a valid and reliable subjective assessment tool of stress and cognitive load at the end of the simulation (recall to simulated tasks) would be valuable to determine any correlation of subjective findings of stress and cognitive load and those determined by pupillary differences.

Conclusion

In this study, clinical actions requiring a decision or an intervention increased stress and cognitive load in senior nursing students (Novices) despite multiple skills laboratory sessions, simulations of similar clinical events, and over 300 hours of clinical experience with RN supervision. Possible interventions to decrease stress and cognitive load in Novices could include increased simulation experiences requiring the Novice to make the decisions ''as the nurse'' and repeat simulations with tasks that caused stress. More robust clinical experiences that emphasize opportunities for the Novice to be empowered to make clinical decisions are also needed.

Acknowledgment

The authors would like to acknowledge Christian Cannady, BS, Simulation Technician UCLA School of Nursing, for his enormous contributions in the technical aspects of the study simulations and the eye tracking/pupillometry components.

References

Al-Ghareeb, A. Z., Cooper, S. J., & McKenna, L. G. (2017). Anxiety and clinical performance in simulated setting in undergraduate health professionals education: An integrative review. *Clinical Simulation in Nursing*, *13*(10), 478-491. https://doi.org/10.1016/j.ecns.2017.05.015.

Arora, S., Sevdalis, N., Nestel, D., Woloshynowych, M., Darzi, A., & Kneebone, R. (2010). The impact of stress on surgical performance: A systematic review of the literature. *Surgery*, *147*(3), 318-330. https://doi.org/10.1016/j.surg.2009.10.007, 330.e1-e6.

Aston-Jones, G., & Cohen, J. D. (2005). An integrative theory of locus coeruleus-norepinephrine function: Adaptive gain and optimal performance. *Annual Review of Neuroscience*, *28*, 403-450. https://doi.org/10.1146/annurev.neuro.28.061604.135709.

Attar, N., Schneps, M. H., & Pomplun, M. (2016). Working memory load predicts visual search efficiency: Evidence from a novel pupillary response paradigm. *Memory & Cognition*, *44*(7), 1038-1049. https://doi.org/10.3758/s13421-016-0617-8.

Beddoe, A. E., & Murphy, S. O. (2004). Does mindfulness decrease stress and foster empathy among nursing students? *The Journal of Nursing Education*, *43*(7), 305-312.

Bojko, A. (2013). InJustak, M (Ed.). (2013). *Eye tracking the user experience: A practical guide to research*, *vol. 1*. Brooklyn, NY: Rosenfeld Media, LLC.

Bong, C. L., Fraser, K., & Oriot, D. (2016). Cognitive load and stress in simulation. InGrant, V J., & Cheng, A. (Eds.). (2016). *Comprehensive Healthcare Simulation: Pediatrics*, *vol. 1*. Switzerland: Springer International. (pp. 3-17).

Causse, M., Senard, J. M., Demonet, J. F., & Pastor, J. (2010). Monitoring cognitive and emotional processes through pupil and cardiac response during dynamic versus logical task. *Applied Psychophysiology and Biofeedback*, *35*(2), 115-123. https://doi.org/10.1007/s10484-009-9115-0.

Chen, S., & Epps, J. (2014). Efficient and robust pupil size and blink estimation from near-field video sequences for human-machine interaction. *IEEE Transactions on Cybernetics*, *44*(12), 2356-2367. https://doi.org/10.1109/TCYB.2014.2306916.

Chrousos, G. P., & Gold, P. W. (1992). The concepts of stress and stress system disorders. Overview of physical and behavioral homeostasis. *JAMA*, *267*(9), 1244-1252.

Gaillard, A., & Wientjes, C. (1994). Mental load and work stress as two types of energy mobilization. *Work & Stress*, *8*(2), 141-152. https://doi.org/10.1080/02678379408259986.

Gavas, R., Chatterjee, D., & Sinha, A. (2017). *Estimation of Cognitive Load Based on the Pupil Size Dilation*. Paper Presented at the 2017 IEEE International Conference on Systems, Man, and Cybernetics (SMC).

Goldinger, S. D., & Papesh, M. H. (2012). Pupil dilation reflects the creation and retrieval of memories. *Current Directions in Psychological Science*, *21*(2), 90-95. https://doi.org/10.1177/0963721412436811.

Heitz, R. P., Schrock, J. C., Payne, T. W., & Engle, R. W. (2008). Effects of incentive on working memory capacity: Behavioral and pupillometric data. *Psychophysiology*, *45*(1), 119-129. https://doi.org/10.1111/j.1469-8986.2007.00605.x.

Hobfoll, S. E. (1988). *The Ecology of Stress*. Washington, DC: Hemisphere Publishing Corp.

Ignacio, J., Dolmans, D., Scherpbier, A., Rethans, J. J., Chan, S., & Liaw, S. Y. (2015). Comparison of standardized patients with high-fidelity simulators for managing stress and improving performance in clinical deterioration: A mixed methods study. *Nurse Education Today*, *35*(12), 1161-1168. https://doi.org/10.1016/j.nedt.2015.05.009.

Joels, M., & Baram, T. Z. (2009). The neuro-symphony of stress. *Nature Reviews Neuroscience*, *10*(6), 459-466. https://doi.org/10.1038/nrn2632.

Lawrence, K., Messias, D. K. H., & Cason, M. L. (2018). The influence of simulation experiences on new nurses' clinical judgment. *Clinical Simulation in Nursing*, *25*, 22-27. https://doi.org/10.1016/j.ecns.2018.10.008.

Leblanc, V., Woodrow, S., Sidhu, R., & Dubrowski, A. (2008). Moderate examination stress leads to improvements on fundamental trechnical skills in surgical residents. *The American Journal of Surgery*, *196*, 114-119.

McDougal, D. H., & Gamlin, P. D. (2015). Autonomic control of the eye. *Comprehensive Physiology*, *5*(1), 439-473. https://doi.org/10.1002/cphy.c140014.

McKay, K. A., Buen, J. E., Bohan, K. J., & Maye, J. P. (2010). Determining the relationship of acute stress, anxiety, and salivary alpha-amylase level with performance of student nurse anesthetists during human-based anesthesia simulator training. *AANA Journal*, *78*(4), 301-309.

Mills, B., Carter, O., Rudd, C., Claxton, L., & O'Brien, R. (2016). An experimental investigation into the extent social evaluation anxiety impairs performance in simulation-based learning environments amongst final-year undergraduate nursing students. *Nurse Education Today*, *45*, 9-15. https://doi.org/10.1016/j.nedt.2016.06.006.

Moreno, R., & Park, B. (2010). Cognitive load theory: Historical development and relation to other theories. In Plass, J. L., Brünken, R., & Moreno, R. (Eds.), *Cognitive Load Theory*. Cambridge: Cambridge University Press. (pp. 9-28).

Paas, F. G., Van Merrienboer, J. J., & Adam, J. J. (1994). Measurement of cognitive load in instructional research. *Perceptual and Motor Skills*, *79*(1 Pt 2), 419-430. https://doi.org/10.2466/pms.1994.79.1.419.

Pfuntner, A., Wier, L. M., & Stocks, C. (2013). *Most Frequent Conditions in U.S. Hospitals, 2010: Statistical Brief #148*. Rockville, MD. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/23534077.

Pruessner, J. C., Baldwin, M. W., Dedovic, K., Renwick, R., Mahani, N. K., Lord, C., & Lupien, S. (2005). Self-esteem, locus of control, hippocampal volume, and cortisol regulation in young and old adulthood. *Neuroimage*, *28*(4), 815-826. https://doi.org/10.1016/j.neuroimage.2005.06.014.

Pruessner, J. C., Dedovic, K., Pruessner, M., Lord, C., Buss, C., Collins, L., & Lupien, S. J. (2010). Stress regulation in the central nervous system: Evidence from structural and functional neuroimaging studies in human populations - 2008 Curt Richter award Winner. *Psychoneuroendocrinology*, *35*(1), 179-191. https://doi.org/10.1016/j.psyneuen.2009.02.016.

Reiner, M., & Gelfeld, T. M. (2014). Estimating mental workload through event-related fluctuations of pupil area during a task in a virtual world. *International Journal of Psychophysiology*, *93*(1), 38-44. https://doi.org/10.1016/j.ijpsycho.2013.11.002.

Schommer, N. C., Hellhammer, D. H., & Kirschbaum, C. (2003). Dissociation between reactivity of the hypothalamus-pituitary-adrenal axis and the sympathetic-adrenal-medullary system to repeated psychosocial stress. *Psychosomatic Medicine*, *65*(3), 450-460.

Selye, H. (1956). *The Stress of Life*. New York, NY: McGraw-Hill.

Shinnick, M., Woo, M., Horwich, T., & Steadman, R. (2011). Debriefing: The most important component in simulation? *Clinical Simulation in Nursing*, *7*(3), e105-e111.

Shin, H., Ma, H., Park, J., Ji, E. S., & Kim, D. H. (2015). The effect of simulation courseware on critical thinking in undergraduate nursing students: Multi-site pre-post study. *Nurse Education Today*, *35*(4), 537-542. https://doi.org/10.1016/j.nedt.2014.12.004.

Sowell, E. R., Thompson, P. M., Holmes, C. J., Batth, R., Jernigan, T. L., & Toga, A. W. (1999a). Localizing age-related changes in brain structure between childhood and adolescence using statistical parametric mapping. *Neuroimage*, *9*(6 Pt 1), 587-597. https://doi.org/10.1006/nimg.1999.0436.

Sowell, E. R., Thompson, P. M., Holmes, C. J., Jernigan, T. L., & Toga, A. W. (1999b). In vivo evidence for post-adolescent brain maturation in frontal and striatal regions. *Nature Neuroscience*, *2*(10), 859-861. https://doi.org/10.1038/13154.

Sweller, J., van Merrienboer, J. J. G., & Paas, F. G. W. C. (1998). Cognitive architecture and instructional design. *Educational Psychology Review*, *10*(3), 251-296. https://doi.org/10.1023/A:1022193728205.

Zheng, B., Jiang, X., & Atkins, M. S. (2015). Detection of changes in surgical difficulty: Evidence from pupil responses. *Surgical Innovation*, *22*(6), 629-635. https://doi.org/10.1177/1553350615573582.