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Cognitive Load, Anxiety, and Performance During a Simulated Subarachnoid Block

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Abstract
Background: Numerous simulation-based studies have concluded that cognitive load is negatively related to performance. However, this relationship has not been studied in nurse anesthesia students. Furthermore, few studies have assessed the relationship between emotions and cognitive load.
Methods: This observational study grouped 41 nurse anesthesia students according to past experience with subarachnoid block placement. During subarachnoid block simulation, perceived overall cognitive load (POCL), state anxiety, and performance were measured using the Paas Scale, State-Trait Anxiety Inventory, and a procedural checklist, respectively.
Results: Performance and POCL were negatively correlated ($\rho = -0.48$, $p = .001$). A positive correlation was found between POCL and state anxiety ($\rho = 0.7$, $p = .000$). There were significant experience-based, intergroup differences in POCL and performance.
Conclusion: Experiential background, POCL, and state anxiety should be considered when assessing nurse anesthesia student performance during subarachnoid block simulation.

During simulation-based training, the limits of human cognitive architecture—which describes the organization of, and relationships between, the functional units involved in cognition (Sweller & Sweller, 2006)—are often exposed. Novices rely heavily on a specific component of cognitive architecture, the working memory, to consciously process the novel information encountered during simulation (Paas, Renkl, & Sweller, 2003). However, the working memory is limited in its capacity to store and manage data (Baddely, 2010; Miller, 1956). If the amount or complexity of the information associated with a simulation exceeds working memory capacity, the quality of a learner's performance is likely to decline (Young, van Merrienboer, Durling, & Cate, 2014). Therefore, the demand placed on the working memory, known as cognitive load (Paas et al., 2003), has been cited as an important educational variable in health care simulation (Fraser, Ayres, & Sweller, 2015; Leppink & van den Heuvel, 2015; Van Merrienboer & Sweller, 2010).

Several studies suggest that cognitive load may influence simulation-based learning and performance (Aldekhyl, Cavalcanti, & Naismith, 2017; Bharathan et al., 2013; Fraser et al., 2012, 2014; Haji, Rojas, Childs, de Ribaupierre, & Dubrowski, 2015; Yurko, Scerbo, Prabhu, Acker, & Stefanidis, 2010). Reductions in cognitive demand have been associated with improved clinical skill performance, such as surgical knot-tying (Haji et al., 2015), whereas excessive cognitive demand has demonstrated the potential to increase fatigue and facilitate errors in novice surgeons (Yurko et al., 2010). In addition, cognitive load has been shown to predict the quality of performance during tasks such as simulated ultrasound image acquisition (Aldekhyl et al., 2017).

> **Key Points**
> - A moderate negative correlation was found between perceived overall cognitive load and nurse anesthesia student performance during a simulated subarachnoid block.
> - A strong positive correlation was found between state anxiety and perceived overall cognitive load in the absence of a significant relationship between state anxiety and the quality of subarachnoid block performance.
> - Significant intergroup differences in perceived overall cognitive load and performance were found when comparing nurse anesthesia students based on their degree of experience with subarachnoid block placement.

Cognitive Load and Schemata

The degree of cognitive load placed on the working memory is tied to past experience through the use of complex cognitive frameworks, known as schemata. Schemata are cognitive constructs that integrate large amounts of information into a single unit (Paas et al., 2003). Experience is vital to schemata formation as this process takes place over time and requires the integration and reorganization of information (Kirschner, 2002; Sweller & Sweller, 2006). These cognitive frameworks are stored in a portion of human cognitive architecture known as the long-term memory. When needed, the working memory can access a schema from the long-term memory and process the schema as a single unit. The processing of a single schema reduces cognitive load because there is no need to hold numerous distinct information elements in the limited working memory (Kirscher, 2002; Paas et al., 2003). Therefore, during a given task, the cognitive load experienced by an expert should be less than that of a novice. Several studies support this proposition (Szulewski, Gegenfurtner, Howes, Sivilotti, & Van Merrienboer, 2017; Szulewski, Roth, & Howes, 2015) and

highlight the role that domain-specific experience plays in determining cognitive load (Gegenfurtner, Lehtinen, & Saljo, 2011; Kalyuga, Chandler, & Sweller, 2001).

Cognitive Load and Emotions

In addition to experiential background, the emotional state of an individual has been posited as a factor that may contribute to cognitive load during simulation-based training (Fraser et al., 2015; Leppink & van den Heuvel, 2015). An emotion of particular interest, which occurs frequently within the realm of simulation, is anxiety (Nielsen & Harder, 2013), specifically, state anxiety, which is a transient condition characterized by feelings such as tension and apprehension coupled with activation of the autonomic nervous system (Spielberger, 1985). The potential impact of state anxiety should be considered in simulation-based education, as it may compromise cognitive resources and negatively impact the ability to process task-relevant information (Eysenck, Derakshan, Santos, & Calvo, 2007).

Knowledge Gap

Evaluation of the relationship between cognitive workload and performance has occurred in numerous populations of health care trainees and practitioners (Bharathan et al., 2013; Davis, Oliver, & Byrne, 2009; Fraser et al., 2012, 2014; Haji et al., 2015; Schlairet, Schlairet, Sauls, & Bellflowers, 2015; Yurko et al., 2010). However, researchers have yet to assess the conceptual relationship in student registered nurse anesthetists (SRNAs). These novices are frequently expected to perform cognitively demanding procedures, such as the subarachnoid block (SAB), under stressful operating room conditions. Administration of a SAB requires the cognitive processing of numerous information elements pertaining to anatomy, sterility, local anesthetic dosing, and the sequential nature of the task. This procedure is associated with complications such as bleeding, infection, neurological damage, and local anesthetic toxicity, which are more likely in the presence of poor procedural execution.

Given the cognitive demands and potential complications, SRNAs are provided with simulated and real-life opportunities for SAB placement throughout the nurse anesthesia curriculum. However, no studies have compared cognitive load or performance among SRNAs at varying points in their training. Moreover, no research has evaluated the relationships between student performance and important cognitive variables—such as perceived cognitive load and state anxiety—in the SRNA population. To address these knowledge gaps, SRNAs with varying degrees of SAB experience participated in a simulated SAB scenario. Standardized self-report measures were used to assess perceived overall cognitive load (POCL) and state anxiety. Performance was evaluated using a procedural checklist.

This study was designed to address two primary research questions. First, what are the relationships between POCL, state anxiety, and performance during simulated SAB placement by SRNAs? Second, do POCL, POCL, state anxiety, and performance differ between SRNAs at varying stages of SAB placement training?

Theoretical Framework

Cognitive Load Theory

Cognitive load theory originated from the work of Sweller (1988) and focuses on the interactions between information elements and human cognitive architecture—specifically the working and long-term memories. The theory serves to guide educators in appropriately matching a learner's experiential background with key aspects of simulation, such as task fidelity, task complexity, and instructional support (Leppink & van den Heuvel, 2015; Reedy, 2015). As the fidelity, complexity, and content difficulty of a simulated scenario increase, there is an increase in the number of information elements that the working memory must process. Cognitive load is additive in that the aforementioned factors, as well as the method in which information is presented, place an overall cognitive load on the limited working memory (Paas et al., 2003). The availability of relevant schemata stored in the long-term memory may serve reduce this overall cognitive load (Kirscher, 2002, Paas et al., 2003). However, the quality of a learner's performance is likely to decline if overall cognitive load exceeds working memory capacity (Young et al., 2004).

Processing Efficiency and Attentional Control Theories

In the simulation setting, emotional factors, such as anxiety, are also thought to play a role in determining cognitive load (Fraser et al., 2015; Leppink & van den Heuvel, 2015). The exact mechanism through which anxiety interacts with the working memory is unclear; however, it is generally accepted that anxiety negatively impacts the working memory (Moran, 2016). Processing efficiency theory suggests that anxiety induces task-irrelevant processing, such as worry, which reduces the working memory's capacity to store and process task-relevant information (Eysenck & Calvo, 1992). Alternatively, attentional control theory posits that anxiety may impair the ability to inhibit irrelevant stimuli, thereby increasing the impact of distractions on the working memory (Eysenck et al., 2007). Regardless of the mechanism, it is reasonable to assume that an anxious individual is more likely to experience high cognitive load. And, while not assessing anxiety specifically, Fraser et al. (2014) reported increased cognitive load in medical students experiencing negative emotions associated with a simulated patient death.

Methods

Sample

After internal review board approval, a total of 41 SRNAs were enrolled in this cross-sectional, observational study. Only students in good academic standing who had attended all standard didactic neuraxial anesthesia lectures and SAB simulation sessions were eligible to participate. In total, 41 students from two eligible cohorts met the inclusion criteria, with all 41 students agreeing to participate in the study. During informed consent, participants received a description of the study aims and were informed they would complete an anesthesia-related procedure in the simulation lab.

Participants were allocated to one of three groups according to their experience with real-life clinical SAB placement at the time of data collection. Those in the first group (n = 18) were in their final semester of didactic education before entering the clinical phase of the program. Participants in the second group (n = 12) had completed 10 months of clinical rotations with limited exposure to SAB placement. The third group (n = 11) was also composed of participants with 10 months of clinical experience; however, they had completed clinical rotations offering numerous opportunities to place a SAB. All participants had placed at least one simulated SAB before study enrollment.

Data Collection

Participants received a one-on-one standardized prebriefing before placing the simulated SAB. Two nurse anesthesia faculty conducted the prebriefings, during which all components of the spinal anesthesia kits were reviewed. In addition, use of the Epimed Genesis epidural-spinal injection simulator was reviewed in detail. The Genesis task trainer contains elements simulating the anatomical structures found in the lumbar back and allows for critical procedural cues. The task trainer also allows for the free flow of simulated cerebral spinal fluid on needle entry into the subarachnoid space.

All participants used identical equipment including sterile gloves and standard spinal anesthesia trays. The simulator was placed in the sitting position and participants were instructed to administer a SAB, from the beginning to end, with the intention of providing anesthesia to the T4 dermatome. Participants were also instructed to verbalize their actions as the block was performed and state when the process was complete. Faculty coordinating the simulation sessions informed all participants that they would not answer questions regarding any procedural aspects of the SAB.

Immediately before SAB placement, participants reported state anxiety using the State-Trait Anxiety Inventory (STAI) (Form Y-1) (Spielberger, Gorsuch, Lushene, Vagg,

& Jacobs, 1983). During the simulation, all faculty remained outside the participant's line of sight. After successful placement of the SAB, participants were instructed to report their POCL using the Paas Scale (Paas, 1992). Participants were notified that the simulations would be video and audio recorded. Efforts were made to place the recording device outside the participant's line of sight. The recordings were later viewed by two scorers recruited from the nurse anesthesia faculty, neither of whom participated in the data collection process. All research was conducted in a simulation facility of over 1,000 square feet containing spaces devoted to the simulation of a high-fidelity operating room and intensive care unit.

Outcome Measures

Paas Scale
POCL was measured using the Paas Scale, which requires participants to quantify their overall cognitive load using a single, self-report item (Paas, 1992). The instrument uses an ordinal scale ranging from one to nine, with one corresponding to, "very, very low mental effort" and nine indicating, "very, very high mental effort." In the case of the Paas Scale, "mental effort" is equivalent to POCL. Evidence of criterion-related validity with both biometric measures of cognitive load and learning outcomes has been established for the instrument (Fraser et al., 2012, 2014; Szulewski, Gegenfurtner Howes, Sivilotti, & Van Merrienboer, 2017). A test-retest method was used to assess for evidence of Paas Scale reliability. The first and second cognitive load measurements were separated by 28 days with a Spearman's correlation of 0.81.

State-Trait Anxiety Inventory
State anxiety was operationalized using the STAI (Form Y-1) (Spielberger et al., 1983). Participants taking the STAI used a 4-point Likert scale to report their level of agreement with twenty descriptive statements at the time of testing. Examples of these descriptive statements include, "I feel at ease" and "I feel upset." Spielberger (1989) established evidence of concurrent and construct validity for the STAI. Evidence of reliability was evaluated in the study sample and was acceptable with a Cronbach's alpha of 0.94.

Procedural Checklist
Performance was measured using a procedural checklist for SAB placement (Udani, Macario, Nandagopal, Tanaka, & Tanaka, 2014). This dichotomous ("satisfactory" or "unsatisfactory") 16-item checklist was developed using a modified Delphi-approach to enhance content and face validity. A score of one point was given to checklist items that were completed in a "satisfactory" manner, whereas a score of zero was given to items that were not completed or completed in an "unsatisfactory" manner. Each scorer received one-on-one training regarding use of the performance checklist as well as written instructions. Inter-rater reliability between the scorers evaluating the SAB performance videos was acceptable with a weighted $\kappa = 0.75$, $p = .000$, 95% CI (0.61, 0.88).

Data Analyses

All outcome data were initially evaluated for normality, and statistical significance was set at 0.05. Subsequently, the Kruskal-Wallis H test was used to compare groups with regard to sample characteristics such as age and past clinical and simulation experience. Performance scores used in data analyses were derived using the mean of the two scores assigned by the faculty evaluating the simulation recordings. The relationships between POCL, state anxiety, and performance were evaluated using Spearman's Rho. One-way analysis of variance was used to assess for intergroup differences in POCL and performance. Post hoc analyses of analysis of variance results were performed using the Tukey test.

Results

Sample characteristics including age and gender, as well as data regarding participation in previous simulations, and years of intensive care unit experience are available in Table (group 1 = no clinical experience, group 2 = clinical experience with limited SAB placement, group 3 = clinical experience with substantial SAB placement). No significant differences were identified between the groups with regard to age, $p = .201$, years of clinical experience, $p = .858$, number of simulations before program enrollment, $p = .432$, or the number of simulated SABs placed, $p = .071$.

Correlational analyses revealed a strong positive relationship between state anxiety and POCL, $\rho = 0.70$, $p = .000$, and a moderate negative relationship between POCL and performance, $\rho = -0.48$, $p = .001$. The correlation between state anxiety and performance was insignificant, $\rho = -0.27$, $p = .095$, and no intergroup differences

Table Sample Characteristics			
Characteristic	Group 1 (n = 18) *M*	Group 2 (n = 12) *M*	Group 3 (n = 11) *M*
Age	31.3	33.7	30.7
Females	13	8	7
Clinical experience*	4.2	3.8	3.8
Prior simulations†	3.9	5.3	4.2
Simulated subarachnoid blocks	1.2	1.7	1.7
Clinical subarachnoid blocks	0	1.7	14.5

* Years of clinical experience in the intensive care unit before enrollment in the nurse anesthesia program.
† Number of simulation experiences before entering the nurse anesthesia program and excluding advanced cardiac life support and pediatric advanced cardiac life support.

in state anxiety were identified $F(2,38) = 2.4$, $p = .105$. POCL differed significantly between the groups $F(2,38) = 4.32$, $p = .020$, with group 1 reporting higher POCL ($M = 6.94$, $SD = 1.35$) than group 3 ($M = 5.55$, $SD = 1.13$), $p = .022$. There was no significant difference in POCL between groups 1 and 2 ($M = 6.83$, $SD = 1.40$), $p = .972$, or groups 2 and 3, $p = .061$.

Performance scores varied significantly between the groups $F(2,38) = 3.89$, $p = .029$. Lower performance scores were observed in group 1 ($M = 11.39$, $SD = 1.59$) as compared with group 3 ($M = 13.23$, $SD = 0.96$), $p = .023$. There was no statistically significant difference in performance between groups 1 and 2 ($M = 11.92$, $SD = 2.37$), $p = .694$. In addition, the difference in performance between groups 2 and 3 was insignificant, $p = .179$.

Discussion

Cognitive Load and Performance

Concerns have been expressed regarding the inconsistent nature of the relationship between cognitive load and performance (Naismith & Cavalcanti, 2015). However, in this research, a moderate negative correlation was found between POCL and performance, which is congruent with the underpinnings of cognitive load theory. Several simulation researchers have come to a similar conclusion when assessing cognitive load and performance in health care providers (Aldekhyl et al., 2017; Fraser et al., 2012, 2014). With regard to the strength of the bivariate relationship, Yurko et al. (2010) found a comparable regression coefficient, $r = -0.5$, $p < .001$, when assessing mental workload and laparoscopic surgical performance in a sample of medical students. In addition, Ruiz-Rabelo et al. (2015) found similar correlations between surgeon mental workload and indicators of performance, such as operative time, $r = 0.50$, $p = < .001$. However, it is notable that Yurko et al. (2010) and Ruiz-Rabelo et al. (2015) used the NASA Task Load Index (Hart & Staveland, 1988) to operationalize mental demand, rather than the Paas Scale, making cross-study comparisons difficult.

State Anxiety, Cognitive Load, and Performance

Although participants with elevated levels of state anxiety displayed higher mental processing demands, as evidenced by the strong correlation between state anxiety and POCL, higher degrees of state anxiety did not translate to poor performance. Although cause and effect were not evaluated in this study, this correlation finding is consistent with the proposition that anxiety may impair cognitive processing to a greater degree than performance (Eysenck et al., 2007). From a mechanistic standpoint, Eysenck et al. (2007) suggest that anxious individuals work to mitigate the negative effects of anxiety on performance through the use of compensatory mechanisms, such as an increase in effort or adjustment in cognitive processing.

The strong positive relationship between state anxiety and POCL coupled with the insignificant correlation between POCL and performance highlights the importance of considering the learner's processing effectiveness, which is defined by efficiency—or quality of performance—divided by effort. It is notable that processing effectiveness is inherently lower in anxious learners as they must put forth additional effort in an attempt to mitigate the cognitive implications of anxiety (Eysenck, 1979; Eysenck et al., 2007). This phenomenon is often overlooked in simulation, as educators generally focus on performance outcomes. If the goal is to prepare providers with the capability to multitask in complex clinical environment, the amount of cognitive effort invested to obtain quality performance should be considered. When most of the working memory capacity is devoted to completing a single task, there is little cognitive reserve available to address concomitant duties such as communication and patient monitoring. Depending on the assumed level of proficiency, it is reasonable to propose that additional educational interventions may be indicated for the learner expending excessive cognitive effort to achieve the most basic performance goals.

Experience, Cognitive Load, and Performance

Theoretically, domain-specific experience enables schemata formation leading to a reduction in working memory demand, which in turn facilitates performance. The results of this study support the aforementioned theoretical assertion as participants with greater domain-specific experience reported significantly lower POCL and achieved higher performance scores. Additional support for the importance of domain-specific experience arises from the observation that time spent delivering anesthesia in the clinical setting, without the placement of SABs, failed to significantly reduce POCL or improve performance during the simulation. Surprisingly, when the experienced participants in group 3 were compared with those with minimal domain-specific experience in group 2, no significant differences in POCL or performance between groups were found. This finding amounts to a theoretical discrepancy; however, study limitations—such as the relatively small sample size—must be considered in its interpretation.

From a practical standpoint, these results highlight the importance of striving for congruency between the cognitive demands of simulation and the learner's degree of domain-specific experience. Simulation characteristics that determine the learner's cognitive demands—such as fidelity, task complexity, and level of instructional support—should be tailored to the learner as they gain domain-specific experience (Leppink & van den Heuvel, 2015). Placing a learner with limited domain-specific experience in a complex, high-fidelity scenario with minimal instructional support is likely to result in excessive cognitive load, leading to

impaired learning and poor performance. It is preferable that learners commit errors in the simulation lab, where they can be addressed and corrected rather than in the clinical setting where patient harm may result. Therefore, educators should continue to use simulation as a sheltered environment for learners to obtain the experience needed to establish vital domain-specific schemata.

In addition, educators and researchers should explore the effectiveness of technologies that could serve as ''presimulation'' instructional methods to prime schemata formation in learners before hands-on simulation experience. Possible approaches include the use of technologies such as virtual reality and first-person—based demonstrations, which a student can experience on their own time, with limited faculty and facility resources. Similar instructional methods are currently used in the didactic environment with the ''flipped classroom.'' However, additional research is needed to assess the efficacy of this approach in the realm of simulation-based education.

Study Limitations

This study was limited by the relatively small sample as well as the presence of video recording and academic faculty during the simulations, which may have elevated POCL and state anxiety. In addition, because randomization was not used, it is possible that uncontrolled confounding variables may have influenced the results. Further limitations include the correlational nature of several findings, as well as the use of self-report measures.

Conclusions

To date, this is the first study to evaluate the relationships between POCL, state anxiety, and performance in SRNAs. The results contribute to a body of simulation-based evidence supporting the negative nature of the relationship between cognitive load and performance (Naismith & Cavalcanti, 2015). The results also highlight the complicated nature of the relationships between state anxiety, POCL, and performance. In an effort to optimize training, educators should consider POCL, state anxiety, and domain-specific experiential background when using simulation to train SRNAs in the skill of SAB placement. Future research should focus on exploring the generalizability of the study findings and investigating possible interventions aimed at priming schemata formation before hands-on simulation.

Acknowledgment

References

Aldekhyl, S., Cavalcanti, R., & Naismith, L. (2018). Cognitive load predicts point-of-care ultrasound simulator performance. *Perspectives in Medical Education*, *7*(1), 23-32. https://doi.org/10.1007/s40037-017-0392-7.

Baddely, A. (2010). Working memory. *Current Biology*, *20*(4), R136-R140. https://doi.org/10.1016/j.cub.2009.12.014.

Bharathan, R., Vali, S., Setchell, T., Miskry, T., Darzi, A., & Aggarwal, R. (2013). Psychomotor skills and cognitive load training on a virtual reality laparoscopic simulator for tubal surgery is effective. *European Journal of Obstetrics and Gynecologic Reproductive Biology*, *169*(2), 347-352. https://doi.org/10.1016/j.ejogrb.2013.03.017.

Davis, D. H., Oliver, M., & Byrne, A. J. (2009). A novel method of measuring the mental workload of anaesthetists during simulated practice. *British Journal of Anaesthesia*, *103*(5), 665-669. https://doi.org/10.1093/bja/aep268.

Eysenck, M. W. (1979). Anxiety, learning, and memory: A reconceptualization. *Journal of Research in Personality*, *13*(4), 363-385. https://doi.org/10.1016/0092-6566(79)90001-1.

Eysenck, M. W., & Calvo, M. G. (1992). Anxiety and performance: The processing efficiency theory. *Cognition and Emotion*, *6*, 409-434. https://doi.org/10.1080/02699939208409696.

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion*, *7*(2), 336-353. https://doi.org/10.1037/1528-3542.7.2.336.

Fraser, K., Ayres, P., & Sweller, J. (2015). Cognitive load theory for the design of medical simulations. *Simulation in Healthcare*, *10*(5), 295-307. https://doi.org/10.1097/SIH.0000000000000097.

Fraser, K., Huffman, J., Ma, I., Sobczak, M., McIlwrick, J., Wright, B., & McLaughlin, K. (2014). The emotional and cognitive impact of unexpected simulated patient death: A randomized controlled trial. *Chest*, *145*(5), 958-963.

Fraser, K., Ma, I., Teteris, E., Baxter, H., Wright, B., & McLaughlin, K. (2012). Emotion, cognitive load and learning outcomes during simulation training. *Medical Education*, *46*(11), 1055-1062. https://doi.org/10.1111/j.1365-2923.2012.04355.x.

Gegenfurtner, A., Lehtinen, E., & Saljo, R. (2011). Expertise differences in the comprehension of visualization: A meta-analysis of eye-tracking research in professional domains. *Educational Psychology Review*, *23*(4), 523-552. https://doi.org/10.1007/s10648-011-9174-7.

Haji, F. A., Rojas, D., Childs, R., de Ribaupierre, S., & Dubrowski, A. (2015). Measuring cognitive load: Performance, mental effort and simulation task complexity. *Medical Education*, *49*(8), 815-827. https://doi.org/10.1111/medu.12773.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (task load Index): Results of empirical and theoretical research. In Hancock, P. A., & Meshkati, N. (Eds.), *Human mental workload*. Amsterdam: North Holland Press.

Kalyuga, S., Chandler, P., & Sweller, J. (2001). Learner experience and efficiency of instructional guidance. *Educational Psychology*, *21*(1), 5-23. https://doi.org/10.1080/01443410124681.

Kirschner, P. A. (2002). Cognitive load theory: Implications of cognitive load theory on the design of learning. *Learning and Instruction*, *12*(2002), 1-10. https://doi.org/10.1016/S0959-4752(01)00014-7.

Leppink, J., & van den Heuvel, A. (2015). The evolution of cognitive load theory and its application to medical education. *Perspectives on Medical Education*, *4*(3), 119-127. https://doi.org/10.1007/s40037-015-0192-x.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, *63*(2), 81-97.

Moran, T. P. (2016). Anxiety and working memory capacity: A meta-analysis and narrative review. *Psychological Bulletin*, *124*(8), 831-864. https://doi.org/10.1037/bul0000051.

Naismith, L. M., & Cavalcanti, R. B. (2015). Validity of cognitive load measures in simulation-based training: A systematic review. *Academic Medicine*, *90*(11), S24-S35. https://doi.org/10.1097/ACM.0000000000000893.

Nielsen, B., & Harder, N. (2013). Causes of student anxiety during simulation: What the literature says. *Clinical Simulation in Nursing*, *9*(11), e507-e512. https://doi.org/10.1016/j.ecns.2013.03.003.

Paas, F. (1992). Training strategies for attaining transfer of problem-solving skills in statistics: A cognitive load approach. *Journal of Educational Psychology, 84*(4), 429-434.

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist*, *38*(1), 1-4. https://doi.org/10.1207/S15326985EP3801_1.

Reedy, G. B. (2015). Using cognitive load theory to inform simulation design and practice. *Clinical Simulation in Nursing*, *11*(8), 355-360. https://doi.org/10.1016/j.ecns.2015.05.004.

Ruiz-Rabelo, J. F., Francisco, J., Navarro-Rodriguez, E., Di-Stasi, L. L., Diaz-Jimenez, N., Cabrera-Bermon, J., & Briceno-Delgado, J. (2015). Validation of the NASA-TLX score in ongoing assessment of mental workload during a laparoscopic learning curve in bariatric surgery. *Obesity Surgery*, *25*(12), 2451-2456. https://doi.org/10.1007/s11695-015-1922-1.

Schlairet, M. C., Schlairet, T. J., James, T., Sauls, D., & Bellflowers, L. (2015). Cognitive load, emotion, and performance in high-fidelity simulation among beginning nursing students: A pilot study. *Journal of Nursing Education*, *54*(3), 5-11. https://doi.org/10.3928/0150218-10.

Spielberger, C. D. (1985). Assessment of state and trait anxiety: Conceptual and methodological issues. *Southern Psychologist*, *2*(4), 6-16.

Spielberger, C. D. (1989). *State-Trait Anxiety Inventory: Bibliography* (2nd ed.). Palo Alto, CA: Consulting Psychologists Press.

Spielberger, C. D., Gorsuch, R. L., Lushene, R., Vagg, P. R., & Jacobs, G. A. (1983). *Manual for the State-Trait Anxiety Inventory.* Palo Alto, CA: Consulting Psychologists Press.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, *12*, 257-288. https://doi.org/10.1016/0364-0213(88)90023-7.

Sweller, J., & Sweller, S. (2006). Natural information processing systems. *Evolutionary Psychology*, *4*, 434-458. https://doi.org/10.1177/147470490600400135.

Szulewski, A., Gegenfurtner, A., Howes, D. W., Sivilotti, M., & Van Merrienboer, J. (2017). Measuring physician cognitive load: Validity evidence for a physiologic and a psychometric tool. *Advanced in Health Sciences Education*, *22*(4), 951-968. https://doi.org/10.1007/s10459-016-9725-2.

Szulewski, A., Roth, N., & Howes, D. (2015). The use of task-evoked pupillary response as an objective measure of cognitive load in novices and trained physicians: A new tool for the assessment of expertise. *Academic Medicine*, *90*(7), 981-987. https://doi.org/10.1097/ACM.0000000000000677.

Udani, A. D., Macario, A., Nandagopal, K., Tanaka, M. A., & Tanaka, P. P. (2014). Simulation-based mastery learning with deliberate practice improves clinical performance in spinal anesthesia. *Anesthesiology Research and Practice*, *2014*, 659160. https://doi.org/10.1155/2014/659160.

Van Merrienboer, J. J., & Sweller, J. (2010). Cognitive load theory in health professional education: Design principles and strategies. *Medical Education*, *44*(1), 85-93. https://doi.org/10.1111/j.1365-2923.2009.03498.x.

Young, J. Q., Van Merrienboer, J., Durning, S., & Cate, O. T. (2014). Cognitive load theory: Implications for medical education: AMEE guide No. 86. *Medical Teacher*, *36*(5), 371-384. https://doi.org/10.3109/0142159X.2014.889290.

Yurko, Y. Y., Scerbo, M. W., Prabhu, A. S., Acker, C. E., & Stefanidis, D. (2010). Higher mental workload is associated with poorer laparoscopic performance as measured by the NASA-TLX tool. *Simulation in Healthcare*, *5*(5), 267-271. https://doi.org/10.1097/SIH.0b013e3181e3f329.