Effect of simulation on cognitive load in health care professionals and students: protocol for a systematic review and meta-analysis

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Review title

Effect of simulation on cognitive load in health care professionals and students: protocol for a systematic review and meta-analysis

Abstract

Objective: The objective of this review is to assess the effect of simulation activities and their design features on cognitive load in health care professionals and students.

Introduction: Simulation activities are now widely implemented in health care professionals' education. However, the mechanisms by which simulations and their design features lead to health care professionals' and students' learning remains unclear. Still, because of their high interactivity and complexity, simulation activities have the potential to impact the cognitive load of learners. Synthesizing evidence regarding this phenomenon could help simulation educators identify the design features that affect learners' cognitive load, and explain why some simulation activities are more effective than others.

Inclusion criteria: This review will consider experimental and quasi-experimental studies in which the effect of a simulation activity on cognitive load in health care professionals or students from any discipline or level of practice is evaluated. All academic and health settings will be included.

Methods: Following the guidelines of the JBI methods for systematic reviews of effectiveness, CINAHL, Embase, ERIC, MEDLINE, PsycINFO, and Web of Science will be searched for studies published in English or French, without a date limit. Retrieved studies will be independently screened for inclusion, then critically appraised for methodological quality by two reviewers using standardized JBI tools. Data extraction will be done independently using adapted tools from JBI. Where possible, data will be pooled using meta-analytical methods.

Systematic review registration number: PROSPERO CRD42020187723

Keywords: health care education; mental effort; mental load; meta-analysis; simulation

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Introduction <level 1 heading>

Simulation is a technique that allows health care professionals and students to experience and interact with representations of real clinical events, without compromising patient safety.[1] Now widely implemented in diverse health care contexts, simulation activities are generally composed of three phases: preparation, simulated scenario, and debriefing.[2] Preparation can involve two components: i) presimulation preparation, which refers to any course-related activities that the participant is asked to undertake before the simulated scenario, and ii) prebriefing, which refers to an interaction between a facilitator and participants prior to the start of a simulated scenario for information purposes.[2] The scenario phase refers to the simulated experience where participants interact with a patient (mannequin or actor) in order to meet the learning objectives.[1] Finally, debriefing usually follows the scenario and is meant for participants to reflect on their learning experience and receive feedback on their simulation performance.[1] All these phases have been shown to be important components of a simulation activity because they have positive effects on health care professionals' and students' satisfaction and learning outcomes, such as knowledge acquisition and skill development.[3, 4]

Although current evidence supports the benefits of simulations for health care professionals' and students' learning, the relative merit of one simulation activity over another is difficult to ascertain considering variations in their design features.[5] For example, in the preparation phase, educators can choose to add an educational activity to the baseline simulation scenario (eg, lecture, discussion). In the scenario phase, they can choose between different elements such as simulation modalities (eg, a task trainer, a simulated patient) or various instructional features (eg, repetitive practice, feedback). In the debriefing phase, educators can determine the intensity of the facilitation and the debriefing method that will be used. Therefore, the design features of simulation activities are highly heterogeneous, making them potentially more or less effective depending on the learning objectives and the educational context.[5] This is further complicated by the number of conceptualizations used to categorize simulation design features that have been proposed in the past few years. The National League for Nursing Jeffries Simulation Theory suggests considering features such as objectives, fidelity, problem-solving, student support, and debriefing.[6] To these, the International Nursing Association for Clinical Simulation and Learning Standards of Best Practice add the following: needs assessment, simulation modality, clinical scenarios, facilitator approach, preparation activity, prebriefing, evaluation process, and pilot test.[7] From an empirical standpoint, Cook et al.[5] have systematically reviewed design features that have been compared in prior studies of simulation-based learning and could potentially influence the learning outcomes of simulations for health care professionals and students. They grouped these features into the following categories: simulation modalities, instructional design features, group composition, facilitators, added modality, and sensory augmentation.

By their nature, simulation activities are highly interactive and complex, and place considerable demands on learners' cognitive resources. Thus, simulation activities have the potential to impact the cognitive load of learners.[8] Cognitive load is the burden that a learning task places on a learner's

working memory.[9] According to the cognitive load theory (CLT), learning is limited by the capacity of an individual's working memory, which can only process a few pieces of information for a few seconds at a time.[9] During a simulation activity, if the quantity and complexity of information to process lie within the capacity of the learner's working memory, learning is facilitated.[8] Inversely, if the quantity and complexity of information exceed the learner's working memory capacity, overload occurs and learning is impeded.[8] Cognitive load wois the sum of three types of load: i) intrinsic load is associated with the demands directly imposed by the learning task (ie, the amount of information and interactivity between each element); ii) germane load refers to the mental resources of the learner directly devoted to learning; and iii) extraneous load is occupied by elements that have the potential to distract the learner from the learning task (eg, noise, information not related to the task).[10] Cognitive load therory posits that characteristics of each individual, such as prior knowledge, age, and expertise level, can also influence their cognitive load and consequently their learning process during an educational activity.[9, 11]

To date, several systematic reviews have demonstrated the effectiveness of simulations on learning outcomes,[12, 13] but the mechanisms that affect learning, such as the cognitive load of learners, have received less attention. A recent scoping review on cognitive load in the context of workplace training identified 76 studies that focused on simulation activities among health care professionals and students, 73 of which used quantitative designs to measure various simulation activity or design features on cognitive load.[14] Thus, there is a number of primary studies that could be synthesized to assess the impact of simulation activities on health care professionals' and students' cognitive load. This could help identify design features that optimize or overload learners' working memory capacity, and potentially explain why some simulation activities are more effective than others for learning. This could improve the training of health care professionals and students, as well as potentially reduce the costs associated with these activities in academic and clinical settings, as unnecessary or potentially harmful features to the learning process could be avoided.

Therefore, the purpose of this review is to assess the effect of simulation activities and their design features on cognitive load in health care professionals and students. According to a search in PROSPERO, MEDLINE, the Cochrane Database of Systematic Reviews, and the *JBI Database of Systematic Reviews and Implementation Reports*, no review has explored this topic, and no systematic review is underway.

Review questions <level 1 heading>

i) What is the effect of simulation activities on cognitive load in health care professionals and students?

ii) What is the effect of simulation design features on cognitive load in health care professionals and students?

Inclusion criteria <level 1 heading>

Participants <level 2 heading>

This review will consider studies with health care professionals or students from any discipline (eg, medicine, nursing, paramedic, pharmacy) and any level of practice (ie, pre- and post-registration, undergraduate, and postgraduate). All academic and clinical settings will be considered. We will only consider studies in which participants actively take part in simulation activities in their own professional role.

Intervention <level 2 heading>

This review will focus on simulation activities, which are defined as the entire set of actions and events from the beginning to the end of a simulated event for educational purpose. All simulation modalities will be considered, including procedural simulation (ie, task trainer), simulated patients (ie, standardized patients), simulated clinical immersion (with low- to high-fidelity patient), and hybrid simulation (ie, a simulation that combines two or more simulation modalities).[15] To be included in this review, simulation activities must include an interaction with a mannequin (partial or full) or a simulated patient. Digital simulations (eg, virtual simulation) will be excluded to reduce clinical heterogeneity, as the cognitive load of learners in a digital environment may be affected by factors specific to it (eg, computer literacy levels).

Comparator <level 2 heading>

Whenever possible, this review will consider studies in which the comparator is another educational intervention or another simulation activity. Studies without an active comparator (ie, passive control group or no control group) will also be included.

Outcome <level 2 heading>

The outcome of interest will be participants' cognitive load during the simulation activities, which refers to the burden that a learning activity, a simulation in this case, imposes on learners' working memory system.[10] Concepts often associated with CLT such as mental effort and mental workload will also be considered.

Learners' self-reported cognitive load will be considered as the critical outcome for this review, as it is the most commonly used method to measure cognitive load in the health care simulation literature,[16] possibly because of its feasibility in terms of operationalization. Thus, instruments such as the NASA Task Load Index,[17] the Paas Scale,[18] and scales that measure cognitive load sources (ie, intrinsic load, germane load, and extraneous load) will be considered.[19]

Other quantitative measures of cognitive load, as reported by Naismith and Cavalcanti,[16] will also be considered including i) changes in a secondary task performance, which are assumed to reflect variations in the learner's cognitive load (eg, reaction time to perform a secondary task, memory task); ii) physiological indices, such as heart, eye, or brain activity that can be monitored with

electrocardiogram or heart rate monitor, eye-tracking devices, and electroencephalogram or functional magnetic resonance imaging; and iii) observer ratings (eg, behaviors indicative of cognitive load such as changes in speech). Outcomes will be considered only if measured during or right after the simulation activity.

It should be noted that at this point in time, no cognitive load measure has clearly demonstrated its superiority in terms of validity or reliability.[16] This limitation will be acknowledged in the discussion of the review's report.

Types of studies <level 2 heading>

We will consider experimental and quasi-experimental studies (ie, randomized controlled trials, non-randomized controlled trials, before and after studies, and interrupted time-series studies), published in English or French, with no time limitation. Conference proceedings, opinion papers, knowledge syntheses, dissertations, and theses will be excluded.

Methods <level 1 heading>

This review will follow JBI methodology for systematic reviews of effectiveness.[20] This protocol has been registered in PROSPERO: CRD42020187723.

Search strategy <level 2 heading>

An initial limited search of MEDLINE (Ovid SP) was undertaken in April 2020 and identified 336 potentially relevant articles. The search strategy was based on a combination of three concepts: i) health care professionals and health care students (population); ii) simulation activities (intervention); and iii) cognitive load (outcome). Terms from the titles and abstracts of relevant articles and index terms were used to develop a full search strategy for MEDLINE (Appendix I), which will be adapted for other databases.

The following databases will be searched without time restriction: CINAHL (EBSCOhost), Embase (Ovid SP), ERIC (Ovid SP), MEDLINE (Ovid SP), PsycINFO (APA PsycNet), and Web of Science (Clarivate Analytics). The reference lists of all included studies will be screened for additional studies. Gray literature will not be included because we want to know the extent of the empirical, peer-reviewed literature only, which we judge to be mature enough to identify a considerable number of eligible studies.

Study selection <level 2 heading>

Records will be uploaded into the Covidence (Veritas Health Innovation, Melbourne, Australia), and duplicates will be removed. Titles and abstracts will be screened against the predetermined inclusion criteria by two independent reviewers (BV, GF, MAMC, SB). Potentially relevant studies will be retrieved and their citation details imported into the JBI System for the Unified Management, Assessment and Review of Information (JBI SUMARI; JBI, Adelaide, Australia).[21] Full text of selected records will be assessed for inclusion by two independent reviewers (BV, GF, MAMC, SB). Reasons for the exclusion of full-text studies will be recorded and reported. Any disagreements between reviewers at each stage

of the selection process will be resolved through discussion or with the involvement of a third reviewer (AL). The results of the search will be reported in full in the final report and presented in a Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram.[22]

Assessment of methodological quality <level 2 heading>

Selected studies will be assessed by two independent reviewers (BV, GF, MAMC, SB) using standardized critical appraisal instruments from JBI for randomized controlled trials (13 questions) and quasi-experimental studies (9 questions).[20] When required, we will contact authors to request missing or additional data for clarification. Disagreements will be solved by consensus among the two reviewers or with the involvement of a third reviewer (AL).

Based on Roberts et al.[23] interpretation of quality appraisal, our review team decided on what we would consider high-, moderate- or low-quality scores. For randomized controlled trials, scores of 10 or more will be considered as high quality, scores of 7 to 9 as moderate quality, and anything lower than 7 as low quality. For quasi-experimental studies, scores of 8 or 9 will be considered as high quality, 6 or 7 as moderate quality, and any scores lower than 6 as low quality.

Studies with low methodological quality will not be excluded from data synthesis. However, results of quality assessment will be reported in a narrative form and in a table, and considered through subgroup analyses if meta-analytical methods are used.

Data extraction <level 2 heading>

A data extraction form based on the standardized JBI tool was developed and pilot tested by the review team. Using this extraction form, two reviewers will independently extract specific details about study identification, methods, population, interventions/comparators, and outcomes of significance to the review questions (Appendix II). Any disagreements that arise between reviewers, at any stage of the data extraction, will be resolved through discussion or with a third reviewer.

In order to conduct meta-analyses, simulation activities and their design features will be categorized based on Cook et al.[5] design features. We decided to use this framework because it comes from the empirical literature and we judged it to be the most comprehensive framework to date on the subject. This categorization includes simulation modalities (e.g., procedural simulation, immersive simulation), instructional design features (e.g., repetitive practice, feedback), group composition (e.g., interdisciplinary, single-discipline) , instructor (e.g., training, experience) , added modality (e.g., lecture, discussion), and sensory augmentation (e.g., tactile, visual). For the categorization, two reviewers will independently code the description of the simulation activities. Additional features that do not fit with those categories will be discussed between reviewers and added if relevant. Although participants' characteristics are not explicitly mentioned in Cook's design features categorization, information about this aspect of the studies will be extracted as well. This aspect is further supported by the fact that the CLT posits that the specific characteristics of each individual are very important. More specifically, we will extract study participants' age, discipline, and level of expertise, which are individual characteristics known to affect cognitive load during educational activities.[9, 11] Based on the clinical experience of the

review team, participants' level of expertise will be determined based on their years of experience (students, novice [new graduates <1 year], beginners/competent [1-5 years], and experts [>5 years]).

Data synthesis <level 2 heading>

Regarding the first research question, we will use meta-analytical methods to evaluate the magnitude of the difference in health care professionals' and students' cognitive load when participating in simulation activities compared to no or any other educational intervention. Using JBI SUMARI, we will include in meta-analyses all randomized and non-randomized studies for which there are enough data to compute a mean difference between study groups.

At least two studies will need to contribute to a meta-analysis for it to be conducted. To minimize clinical diversity, we will favor the pooling of studies in which simulation modalities (eg, procedural simulation, simulated patient, immersive simulation, hybrid simulation), comparators, and assessments of cognitive load are similar. The comparators will be categorized as lectures, readings, demonstrations, or e-learning interventions. Cognitive load assessment will be categorized as either self-report questionnaires, secondary task analysis, physiological indicators (subcategorized based on the specific indicator, such as heart rate pupilar diameter), or observer ratings.

All meta-analyses will be performed using an inverse variance approach with random effects models.[24] Results of all meta-analyses will be expressed with 95% confidence intervals and presented as either raw or standardized mean differences, depending on whether study authors use identical assessment tools. We will define a statistically significant result by a two-sided alpha of 0.05. When using standardized mean differences, the magnitude of the difference between groups will be interpreted using Cohen's classification. As we do not expect study authors to report cognitive load measure as categorical variables (eg, odd or risk ratios), the potential pooling of such data with mean differences will be judged on a case-to-case basis.

Statistical heterogeneity will be assessed using the I^2 statistic. An I^2 value superior to 50% will be considered as a high level of heterogeneity. Subgroup analyses will be conducted to investigate statistical heterogeneity if at least two studies can contribute to each subgroup. We will perform subgroup analyses to explore sources of methodological diversity that could have contributed to statistical heterogeneity. We will evaluate if the pooled effect estimate differs based on our risk of bias assessment (ie, high vs. moderate vs. low quality) of included studies and the randomization of participants (ie, randomized vs. nonrandomized trials).

We will assess the risk of reporting biases for each meta-analysis that include at least 10 studies through the construction of a funnel plot. This figure will be generated with RevManv5.4 (Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration).

Regarding the second research question, we will explore clinical diversity regarding the simulation design features and the population characteristics. First, we will focus on pooling effect estimates of similar within-study comparators of simulation design features (ie, studies that focus on assessing the

impact of the same design features on cognitive load, which are studies that present head-to-head comparisons of the impact of different simulation activities on cognitive load). Second, we will perform subgroup analyses in the previously described meta-analyses (research question 1) to evaluate if there are observational differences in pooled effect estimates of studies based on the simulation design features proposed by Cook et al.[5] (Appendix III). Third, we will explore the diversity of the population characteristics by pooling effect estimates of similar within-study comparators of health care professionals' and students' characteristics (ie, studies that focus on the same individual characteristics). In addition, we will perform subgroup analyses in the previously described meta-analyses (research question 1) to evaluate if there are observational differences in pooled effect estimates of studies based on the health care professionals' and students' characteristics (ie, age, discipline, level of expertise).

Assessing certainty in the findings <level 2 heading>

A Summary of Findings will be created in GRADEpro ((McMaster University, ON, Canada) for the main intervention comparison(s) and include the primary outcome (ie, cognitive load) to draw conclusions about the certainty of the quantitative evidence for the critical outcome (self-reported) and then for the other types of outcomes (secondary task analysis, physiological indicators, observer ratings). The quality of the evidence will be assessed independently according to the five domains: risk of bias, inconsistency, indirectness, imprecision, publication bias established by the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) guidelines.[25]

Conflicts of interest

The authors declare no conflict of interest.

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Appendix I: Search strategy

Search in MEDLINE (Ovid SP) conducted April 8th, 2020

Concept	#	Research strategy
A	1	(Anesthet* or Audiolog* or Cardiolog* or Chiropract* or Clinic* or Dent* or Dietitian* or Dermatolog* or Doctor$1 or Emergentolog* or Endocorinologist* or Ergotherap* or Gastroenterolog* or Gynecolog* or 'Health personnel' or 'Health care personnel*' or 'Healthcare personnel*' 'Health profession*' or 'Health care profession*' or 'Healthcare worker*' or 'Health care worker*' or Medic* or Midwi#e* or Neurolog* or Nurs* or Nutrition* or 'Occupation* therap*' or Optometr* or Patholog* or Paramedic* or P?ediatric* or Pharmac* or Phlebotomist* or 'Physical therap*' or Physician* or Podiatr* or Psychiatr* or Psychotherap* or Psycholog* or Radiolog* or Radiotherap* or Surge*). ab,hw,kf,ti.
A	2	exp Health Personnel/ or exp Students, Health Occupations/ or exp Clinical clerkship/ or exp Education, Dental/ or exp Education, Medical/ or exp Education, Nursing/ or exp Education, Pharmacy/ or exp Education, Public Health Professional/
A	3	((Anesthet* or Audiolog* or Cardiolog* or Chiropract* or Clinic* or Dent* or Dietitian* or Dermatolog* or Doctor$1 or Emergentolog* or Endocorinologist* or Ergotherap* or Gastroenterolog* or Gynecolog* or 'Health' or Medic* or Midwi#e* or Neurolog* or Nurs* or Nutrition* or 'Occupation* therap*' or Optometr* or Patholog* or Paramedic* or P?ediatric* or Pharmac* or Phlebotomist* or Physician* or Podiatr* or Psychiatr* or Psychotherap* or Psycholog* or Radiolog* or Radiotherap* or Surge*). adj2 (Student* or Trainee* or Intern* or Residen* or 'clinical clerkship*')).ab,hw,kf,ti.
A	4	1 or 2 or 3
B	5	Simulat*.ab,hw,kf,ti.
B	6	exp Simulation Training/
B	7	5 or 6
C	8	((cognitive or mental) adj1 (load or workload or burden or effort)) or 'Human channel capacity'.ab,hw,kf,ti.
	9	4 and 7 and 8
No time limit, French or English		
Total retrieved : 336		

Appendix II: Data extraction form

1. Study identification

First author's name	
Year of study	
Country	
Journal	

2. Method

Study aim, research questions		
Study design		
Total number of participants		
Time points measured		
Name of the instruments used		
Assessors	☐ Self-reported	☐ Observed Number of observer(s): Inter-reliability measures:
Outcome assessed		

3. Population

Academic/clinical setting		
Eligibility criteria		
Number of withdrawals and exclusions		
Individual characteristics	☐ Students Year of study program: Level of expertise : Age: Health care discipline:	☐ Professionals Number of years of experience: Level of expertise : Age: Health care discipline:

4. Intervention

Description of the simulation activity	Prebriefing:	Scenario:	Debriefing:
Design features	Based on the categorization of simulation design features of Cook et al.[5]		
Comparator intervention	☐ Lecture ☐ Reading material ☐ Demonstration ☐ E-learning ☐ Another simulation activity		

5. Results

Outcome name		
Outcome type, reported as	☐ Continuous Reported as:	☐ Dichotomous Reported as:
Range and unit of measurement		
Direction (higher is better, lower is better)		
Data value (change from baseline, end point)		

Appendix III: Categorization of simulation design features

Category	Category definition	Subcategory examples
Simulation modalities	Compare two technology-enhanced simulation modalities	Procedural simulation
		Simulated patient
		Immersive simulation
		Hybrid simulation
Instructional design features	Compare different instructional design features to enhance effectiveness	Multiple learning strategies
		Duration
		Sequence
		Repetitive practice
		Distributed practice
		Clinical scenario
		Feedback
		Range of task difficulty
		Group practice
		Hands on practice
		Timing
		Instructions
		Stress
		Mastery
		Blending simulation
		Testing effect
		Curricular integration
		Individualized learning
		Interactivity
		Cognitive or mental imagery techniques
		Add reminder
Group composition	Compare different approaches to grouping learners	Interdisciplinary group
		Single-discipline group
Instructor	Compare different levels of instructor training or presence	Self-instruction
		Instructor intensity
		Instructor training/experience
		Distance supervision
Added modality	Evaluate the addition of one or more other modalities (eg, lecture) to	Discussion add or compare
		Lecture, add or compare
		Patient/standardized patient experience, add

	baseline simulation training	Computer-assisted instruction, add
		External support, add
		Team training, add
		Tutor, add
		Robot assistance, add
Sensory augmentation	Evaluate the addition of a feature or effect to enhance sensory experience	Tactile
		Visual
		Olfactory
		Auditory

Adapted from Cook et al.[5]