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Cognitive load in clinical training: a scoping review of factors and strategies linked to well-being, retention, and performance

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Research Article

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Abstract

Background: Cognitive load is the mental effort required to perform a task due to demands on working memory storage and information processing. In clinical training, the cognitive load can be high due to the task complexity. Applying cognitive load management strategies may help educators support trainees' well-being, retention, and performance. Limited research exists on the translating cognitive load management strategies with practical recommendations for enhancing clinical trainees' retention, well-being, and performance.

Objectives: This scoping review aims to identify cognitive load factors and management strategies that can be used to improve trainees' well-being, retention, and performance in clinical training and practice.

Methods: We investigated the impacts of different cognitive load factors and management strategies on trainees' well-being, retention, and performance, through a scoping review with narrative synthesis. No meta-analysis was planned. We followed PRISMA-ScR for search and screening. Databases (Embase, MEDLINE, Web of Science, CINAHL) searched 18-19 February 2025; Google Scholar and hand-searches updated 27 February 2026.

Results: We identified 8,395 records (Embase 110; Medline 124; Web of Science 188; CINAHL 66; Google Scholar and hand searches 7,907). After deduplication, screening and full-text review, 125 studies were included. Cognitive load management strategies were clustered here as (i) optimising intrinsic load via task segmentation and part-task/step-up sequencing; (ii) minimising extraneous load via de-cluttering, supportive environments and clear and concise instructions; (iii) optimising germane load via structured feedback, worked examples, and appropriately staged simulation.

Conclusions: Cognitive load management strategies and institutional support may be important for trainee retention, well-being, and performance in clinical training. By using evidence-based strategies, healthcare systems may help trainees better manage cognitive load and improve learning and performance.

Summary

Healthcare workers face substantial cognitive load, with limited research on practical strategies to manage it and support clinical trainees' retention, well-being, and performance. Across diverse designs, higher perceived workload is often associated with poorer well-being and intent to leave; effects on performance vary by task complexity and expertise. Managing intrinsic, extraneous, and germane load may be associated with better learning efficiency; links to well-being and retention are suggested but heterogeneous across studies. Promising, but heterogeneously evaluated, strategies include deliberate practice, structured instructional supports (worked examples, schemas, mnemonics), situational awareness, reflection, and simulation. Organisational supports (e.g., protected time, leadership support, workload redesign) are associated with well-being and, in turn, support performance.

Introduction

Clinical training requires rapid information processing, multi-tasking, and high-stakes decision-making conditions that can impose substantial cognitive demands on healthcare workers (HCWs). The elevated stakes inherent in healthcare settings are often associated with emotional, cognitive and physical stresses, contributing to elevated burnout[1] and suicide ideation/risk[2,3] in some cohorts. Estimates of burnout vary widely by cohort, instrument, and period; for example, a meta-analysis reports ~ 37% among medical students[4], while other cohorts show substantial heterogeneity (10–77%)[5–8]. Prevalences varies by cohort, instrument, and period; putative contributors include workload, responsibility, and exposure to morbidity and mortality on a regular basis.

HCW training has changed dramatically due to the coronavirus disease (COVID-19) pandemic, which unfortunately leads to even higher risks of physical isolation, burnout, and suicidal thoughts for medical trainees[9]. In a cross-sectional study, personal protective equipment (PPE) availability, staff training pre-redeployment, and provision of mental health support, were significantly associated with mental health in 41 countries[10]. This is likely related to higher risk for HCWs of being infected with respiratory viruses[11,12]. Moreover, a 2022 paper[13] reported that intense increase in burnout (63% in 2021 vs. 38% in 2020, $p < 0.001$) and decrease in satisfaction with work-life balance (46% in 2020 vs. 30% in 2021, $p < 0.001$) occurred in US physicians. In the US[14], 1 in 5 physicians and 2 in 5 nurses who worked in the COVID-19 response intend to leave their practice altogether in 2020. Burnout, fear of exposure, COVID-19-related anxiety/depression, and workload were all independently related to intent to reduce work hours or leave one's practice within 1 year (all $p < 0.01$)[14]. Additionally, redeployment to new roles without adequate training and lack of mental health support may increase the risk of burnout and suicidal ideation in HCWs[10].

Cognitive load refers to the amount of intellectual effort required to process information or stressors due to demands on working memory storage and information processing[15]. Cognitive load theory distinguishing intrinsic (linked to the task itself), extraneous (external to the task or unnecessary for completing the task such as environment) and germane (to facilitate learning) loads[16–19]. New information is processed by bounded working memory capacity and duration, with learning supported by schema formation in long-term memory for future use[17]. Allostatic load is the cumulative burden of chronic stress and life events. Practical stress-management approached are often advocated for normal allostatic response[20–22] (Fig. 1); however, our review focuses on training design and system factors linked to cognitive load. Competence is the inherent state of possessing knowledge and cognitive skills to successfully perform a specific or range of tasks[23]. It is often difficult to determine, and different medical specialities have their specific criteria for evaluation. Certification (or licensing) is the method by which external organisations formally recognise a provider and provide them appropriate authorisation to manage patients, and tasks based the competence of the provider[23].

Cognitive overload occurs when the overall cognitive load surpasses the working memory capacity of trainees[24]. During training, cognitive load of HCWs can be high due to the complexity of the procedures, the amount of information that needs to be processed, and the stress of working in a high-pressure environment. Cognitive overload and low perceived value are associated with poorer well-being and training outcomes, with potential implications for patient safety[13,14,16,25,26]. Cognitive load management is described here as the proactive management of cognitive stressors to facilitate trainees' wellness and performance across the training period. Tokuno et al.[25] implied that cognitive overload is more likely in trainees performing more complex tasks and in high-fidelity environments and is more common among less experienced trainees.

While cognitive load theory offers valuable insights into learning design, existing research has primarily focused on specific educational settings or professions. This review aims to bridge this gap by examining the cognitive load factors and management strategies associated with outcomes in HCW training and practice. By exploring the interplay between cognitive load, well-being, retention, and performance in this under-researched domain, this review contributes to approaches for supporting HCWs. To reduce the likelihood of medical and surgical trainees leaving their profession and enhance their well-being and performance, it is crucial to develop strategies to help these trainees manage their cognitive load more efficiently. This review discusses cognitive overload and explores strategies for cognitive load management during HCW training and practice.

Methods

A comprehensive plan for participant inclusion and exclusion, data screening, and collection was established. This plan, outlined in Table 1, used a population, concept and context (PCC), and population, intervention or exposure, comparison or control, and outcome (PICO) frameworks. Inclusion or exclusion of studies focused on relevant population (HCWs), intervention (cognitive load management strategies) and outcomes such as well-being (e.g., stress, burnout, anxiety), retention (e.g., job satisfaction and likelihood of continued working as a HCW), and performance (e.g., clinical skills, clinical reasoning, diagnostic accuracy, procedural competence, long-term application of learning, patient outcomes and error rates).

Table 1
Eligibility frameworks (PCC and PICO)

Framework	Description
PCC: **P**opulation **C**oncept **C**ontext	Healthcare workers/trainees (students, residents, fellows, nurses, allied health) Cognitive load factors and management strategies strategies) Clinical pedagogy. We included empirical studies (experimental, quasi-experimental, observational, qualitative) and, a priori for scoping breadth, select non-empirical sources (protocols/consensus/tutorials) when they explicitly addressed cognitive load therapy-aligned strategies or measurement. No date or language limits were applied.
PICO: **P**opulation **I** (Intervention/Exposure) **C** (Comparison) **O** (Outcome)	Clinical trainees (e.g., medical students, residents, nursing students, allied health students, intern, fellow, consultant) Cognitive load management strategies Traditional clinical training methods (i.e., clinical training without explicit cognitive load management strategies) Improved clinical skills, reduced errors, enhanced knowledge retention, increased confidence, HCW well-being, decreased stress/burnout, improved patient outcomes, long-term competency and HCW retention (with validated instruments)
Abbreviations:	
PCC population, concept, and context.	
PICO population, intervention or exposure, comparison or control, and outcome.	

Research question: What cognitive load factors and management strategies are associated with improved well-being, retention, and performance among trainees in HCWs clinical training and practice?

Review procedure: We conducted a scoping review guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for scoping reviews (PRISMA-ScR)[27], followed by narrative synthesis. A narrative synthesis was selected to provide a broad overview and explore the conceptual foundations and scope of cognitive load management in clinical training, rather than to produce a narrowly focused, quantifiable estimates.

Rayyan-a web and mobile app for systematic reviews[28] was used for this review. A medical librarian refined the strategy and database selection (Embase, MEDLINE, Web of Science, and Cumulative Index to Nursing and Allied Health, CINAHL). Full strategies for each database are in Additional file 1, including Google Scholar and hand-searches. Two authors independently performed screening and full-text review of the databases, with conflicts resolved by discussion, based on: a) Records published up until 27 February 2026; b) population: clinical trainees or HCWs; c) focus: cognitive load factors or management strategies; d) outcomes: well-being, retention, and/or performance (skills, reasoning, errors, patient outcomes). Three co-authors charted data, corresponding to the columns in Additional file 2, and conflicts were resolved through discussions.

Critical appraisal: No formal risk-of-bias appraisal (and meta-analysis) was performed, consistent with scoping review objectives.

Synthesis: We grouped findings by cognitive load therapy construct (intrinsic/extraneous/germane) and outcome domain, using inductive thematic mapping.

Registration: The scoping review was made pre-registered through the Open Science Framework (https://doi.org/10.17605/OSF.IO/VW9FN) on 26 November 2023, and last update on 27 February 2026. No deviations from the protocol occurred beyond updating Google Scholar and a hand-search on 27 February 2026. Search strings, database additions and dates are in Additional file 1.

Results

The search strategy resulted in 8,395 records. Systematic searches were executed in Embase (n = 110), MEDLINE (n = 124), Web of Science (n = 188), and CINAHL (n = 66), on 18–19 February 2025. These were supplemented by Google Scholar and hand searches (n = 7,907) were completed on 27 February 2026 (Fig. 2). Google Scholar and hand-searches was limited to the first 500 records after deduplication. After deduplication, 813 records underwent title and abstract screening, and 306 records underwent full-text review. A total of 125 articles were included (Additional file 2; references [29–56], [16,57–87], [88–110], [3,13,14,25,111–129], [18,26,130–141], [142–146]). We found studies were predominantly from the USA (45), followed by Canada (18), Australia (17), the UK (10), Germany (9), the Netherlands (7), and Denmark (4) by corresponding author institution. Other countries are represented to a lesser extent (see Additional file 2).

In the subsequent sections, we investigate cognitive overload factors (Fig. 3) and strategies for managing cognitive overload, including chunk-based practice with feedback, metacognition, situation awareness, reflection practices, digital training: simulation and artificial intelligence (AI)-based technologies (Table 2, Fig. 4–5).

Table 2
Cognitive load management strategies in clinical training

Managing intrinsic load	Decreasing extraneous load	Optimizing germane load
Gradually proceed from low- to high- complexity task	Provide learners with worked solutions	Introduce variability across tasks; prompt self-explanations
Proceed from low- to high-fidelity environments	Part-task preparation	Alternate tasks on varying patient presentations
Chunk or part-task training	Goal-free tasks completion	Encourage trainees to self-explain
Reduce task element interactivity by task repetition	Avoid providing redundant and split information	Create links between prior learning with new knowledge
Adapted based upon work by Atkinson, Howie, van Merrienboer, Sweller and others [16–19,147]		

Chunk-based practice and training duration

One important strategy for managing intrinsic load is the use of deliberate practice or repetition with focused feedback[65,103,114,117], which may impact performance[90]. Deliberate practice involves breaking down complex tasks into smaller, manageable chunks and practicing each chunk exclusively (therefore, managing the intrinsic load) before integrating them into the whole task[16–19,147]. For instance, complex medical or surgical procedures can be segmented into discrete steps incorporating simplified task structures, allowing trainees to master each component before progressing to the full operation to enhance skill acquisition and retention[80]. Deliberate practice is a promising training method for procedures such as ultrasound-guided vascular access and thoracentesis[38,39,63]. This approach helps manage cognitive load by allowing trainees to focus on one aspect of the procedure at a time in a flexible manner, rather than trying to process all the information at once. Although exact amount of training needed to hone core skills is still unknown, multiple studies[50,99,110,132,148] have indicated that concise, focused training sessions ranging from several hours to multiple sessions can efficiently train HCWs in hands-on tasks. The gradual incorporation of terminally branching schemes[46] into training programmes (i.e., adopting a step-by-step learning approach) may be associated with enhanced diagnostic accuracy, minimised perceptual errors, and reduced cognitive load; thereby, improving clinical decision-making. Furthermore, Yeo and Romero[140] recommend three processes for acquiring expert sonography skills: extensive training, deliberate practice, and performance evaluation/feedback.

Metacognition

Metacognition is described as “thinking about thinking” and is the ability to be aware of one's own thinking processes and to use this awareness to improve learning[149–151]. It involves monitoring one's understanding of own thought processes, identifying one's strengths and weaknesses, and selecting appropriate strategies for learning[149–151]. Metacognition is an important skill for both trainees and experts, and it can be improved with practice. Metacognition is not directly tied to either self-reflection or a supervised process, although it can be related to both. Self-reflection constitutes a specific form of metacognition, where individuals actively contemplate their own thoughts, feelings, and behaviours. Supervised processes, on the other hand, can involve external guidance in shaping one's thinking. For example, a senior physician might ask questions to help trainee understand their own thought process. While metacognition can be effectively utilised within supervised settings, it is not inherently dependent on them. The cognitive errors can be caused by several factors[33,56], including personal, workplace, and patient-related issues, which may impact trainees' confidence and well-being. The metacognitive processes could be tailored against factors associated with cognitive errors. Employing metacognitive strategies, such as structured learning scaffolds and reflective practice on personal experiences, could potentially promote anxiety management skills within nursing practitioners[89].

Situation awareness

Chen et al. suggested that situational awareness is learnable and measurable task. They developed a surgical adaptation of a validated situational awareness assessment technique[51]. Situational awareness was divided into three domains: understanding (i.e., familiarity of operating room and role of different team members in the operating room), attentional demand (stability, complexity, and demand of operating room) and attentional supply (alertness, concentration, attention, and spare mental capacity). Chen et al. found students/clerks have lower baseline situational awareness scores and higher perceived complexity of a surgical procedure. Trainees' situational awareness was significantly boosted, particularly in the understanding domain, after the clerkship period (up to 18 weeks). However, attentional demand and supply might require longer periods of clerkship training[51].

Reflection practices and leveraging prior knowledge

Morrill et al. studied prevalence and types of operative reflection practices among surgical residents in a US hospital setting[106]. Three primary methods of post-operative reflection were mental, written, and oral. Among these, mental reflection was the most common method including step-by-step mental rehearsal, internal narration, and question series. For example, pre-operative 3D segmentation was reported to enhance the accuracy of surgical planning and reduced the time required while optimising the cognitive load[138,139].

The combination of demographic and cognitive load variables produced more sensitive metrics to predict ultrasound simulator performance in a proof-of-principle study from the University of Toronto[30]. In terms of acquiring ultrasound images, seasoned users fared better than novices. The two groups' interpretations of the ultrasound images were similar. The degree of training, previous ultrasound training, and cognitive load all predicted the performance of ultrasound image capture[30]. A nationwide

Australian cross-sectional survey revealed five key factors that influence pedagogical approaches to teaching ultrasound scanning skills, including limited protected teaching time, perceived skill complexity, learner skill level and credentials, and avoiding overwhelming the learner, and patient well-being and willingness to be scanned[109].

Digital training: simulation

During a simulation-based resuscitation programme[41,78], trainees who used preparatory online courses saw changes in cognitive load that were consistent with cognitive optimisation, which may lead to subsequent superior performance. Preclinical simulation may be associated with student performance, reduced clinical staff burden, and improved patient safety during early ultrasound training[49]. Similarly, one month after ultrasound simulation training[49], students showed a notable transfer of acquired ultrasound skills, attaining an average score of at least 3 out of 5, indicating advanced beginner proficiency in both complex psychomotor and patient-sonographer communication skills.

Access to robotic platforms during training varies across systems. Robotic surgery began in the US[152] in the year 2000 and in Australia in 2003[153]. Surgical trainees in Australia[153] and the UK[154] spend seven years training; exposure can be inconsistent in some public settings. Some studies reported that virtual reality simulation training for mastoidectomy may reduce cognitive load compared to traditional cadaveric dissection for novices, underscoring the need to align modality, task complexity, and learner level[34–36].

AI-based technologies

Bostrom[155] et al. identified several shortcomings in current training methods (a consensus from the US leaders in Orthopaedic training programs). Firstly, training programs are not fully exploiting available technologies and innovations to enhance the learning experience. Secondly, trainees are often using electronic resources inappropriately, either without guidance or in the absence of a structured electronic training program. Examples of potentially inappropriate electronic resources for medical and surgical trainees include unreliable websites, educational websites authored by medical practitioners but lacking peer review, and resources of low quality. Thirdly, training programs often fail to provide individualized instruction to cater to the different learning paces and styles of trainees. Finally, formal electronic learning programs can make better use of trainees' time and resources compared to informal learning methods. In essence, Bostrom[155] et al. advocated for a more modern and effective approach to training that incorporates technological advancements, structured electronic learning programs, and individualized instruction to optimize the learning experience for all trainees. Interestingly, Turkish medical students perceived that while AI-based technologies could assist physicians’ access to information (86%) and reduce errors (71%), many of them (45%) were worried about the possible of unemployment due to AI-based tools[53]. An AI-derived knowledge recommender for radiology education has the capacity to decrease reporting times, enhance diagnostic accuracy, and alleviate overall workload and mental strain for radiology trainees[97]. Ambient AI platforms have also been reported to reduce documentation burdens and self-reported cognitive load among HCWs; trainee-specific effects require further study[144,145].

Workplace environment and demonstrable outcomes

The evidence suggests that feeling valued by one's organisation may be associated with several positive outcomes[13,14,26], including reduced burnout, improved job satisfaction, and increased patient satisfaction. A survey from the US found that feeling valued by one's organisation was associated with lower odds of reducing hours or intending to leave[14].

Discussion

By synthesising cognitive load factors and management strategies, this review provides a framework for enhancing trainee well-being and professional performance. Our findings indicate that elevated cognitive load is implicated in diminished HCW retention and well-being, correlating with heightened stress and burnout, thereby increasing turnover and reducing job satisfaction [1–3,5–8]. The relationship between cognitive load and performance is more complex with a marginal positive association, suggesting optimal cognitive load may enhance performance[30,64,78]; however, it is plausible that cognitive overload can impair performance. Trainees should be informed of the risks due to high allostatic load, taking precautions, and being prepared for the unexpected[3,20]. Existing evidence shows that some groups may face additional competing demands that can contribute to cognitive overload. For example, poorly performing students, who may need personalised and research-led interventions after clinical examination failure[156], or female trainees and physicians who may experience additional competing demands, such as breastfeeding at work and pregnancy related complications[157–159]. Cognitive load theory principles provide a coherent lens to interpret mixed performance finding across modalities and learner levels[17–19,147]. These strategies can help trainees cope with the sudden changes in demands or cognitive load and enhance their learning and performance.

Deliberate practice is characterised by repetition, feedback, and progressive refinement[65,103,114] and enables learners to systematically and efficiently develop both technical and cognitive competencies[59,103]. When combined with the streamlining of procedures from complex to simple, deliberate practice enhances skill retention, may be associated with reduced cognitive overload, and improvement of overall performance in clinical tasks[59,65,103,140]. Our results highlight that deliberate practice, which is goal-oriented, sequential, and tailored to the learner’s level, can help trainees adjust their approach and improve their performance[16–19,50,147]. Knowledge must be set up in your mind in a flexible, accessible manner that is predicated on a sizable and connected body of clinical cases so that HCWs can automatically recognise patterns based upon past experiences and commence strategies to systematically and logically analyse data to solve clinical cases. For example, rash, tiredness, and restless legs may seem unrelated at first until a HCW consider gastrointestinal causes, which may imply coeliac disease with secondary anaemia. Research indicates that learners benefit from a stepwise, scaffolded approach, transitioning from low-fidelity to high-fidelity simulations and gradually increasing task complexity as competency improves[80,89,103]. Streamlining procedures for reduction of extraneous cognitive load include use of goal-free tasks, worked examples, and completion problems[18]. Research has demonstrated that distributed practice results in superior retention of psychomotor skills compared to massed practice (all practices performed in 1 day), as regular reinforcement facilitates the gradual consolidation of both motor and cognitive components[35,36]. Time-distributed practice consistently outperforms massed practice, especially for complex psychomotor skills, as it enables learners to refine their performance over multiple sessions rather than relying on an intensive, single-session approach[35,36].

Effective medical education frequently relies on structured instructional frameworks incorporating mnemonics, case-based learning, and modular, interactive educational designs to enhance skill development and knowledge retention. Interactive educational designs can integrate simulation-based learning, spaced learning, and test-enhanced learning methodologies to optimise long-term retention and cognitive efficiency[31,33,86,141]. Early integration of clinical reasoning instruction in medical school can improve clinical performance by familiarising students with diagnostic frameworks, structured decision-making, and the real-world application of knowledge[33]. This approach not only strengthens clinical interpretation skills but also enhances confidence and preparedness in patient care settings. However, increasing instructional authenticity may not consistently improve clinical reasoning performance across all outcome measures and subject areas[93].

Case-based learning (CBL) is a highly effective instructional method that improves diagnostic accuracy and medical interpretation skills[56,98,126]. Research indicates that the use of CBL in combination with expert-generated schemas significantly enhances clinical interpretation, particularly in complex areas such as ECG rhythm analysis[45]. By engaging with realistic patient scenarios, students can develop a systematic approach to problem-solving, reinforcing both theoretical knowledge and practical application.

Situational awareness is important for managing cognitive load via optimising germane load and honing procedural skills[51,106,160]. Team-based learning, by harnessing situational awareness, can support cognitive load by allowing trainees to share the load of learning new information and skills. Medical and surgical trainees are usually intrinsically motivated and can monitor their cognitive processes in action (e.g., self-reflect for biases or errors in their reasoning to amend them) by optimizing their germane load[16–19,147]. By reviewing the recorded training sessions (self-assessment), HCWs can address procedures/techniques where they may have struggled or made errors to become more proficient in the respective techniques. During reflective training, residents can review their interactions with other team members and identify areas where they can improve their communication and teamwork skills. Prior self-directed and experiential learning (such as surgical observership or volunteering) makes the trainee comfortable with the operating room environment. Prior knowledge is important in enhancing the efficiency of learning, alleviating cognitive load, and optimising performance across diverse domains within medical training[29,49,51,54,65,92,117,126]. Individuals with extensive expertise and prior experience exhibit superior performance in skill-based tasks, such as the acquisition of ultrasound images and the management of airways[29,30,32]. Medical training should be designed to effectively manage cognitive demand in accordance with learners' levels of expertise[50,108]. Novices and experts process information in distinct ways, necessitating tailored instructional strategies to optimise learning, enhance performance, and mitigate cognitive overload. While novices benefit from structured guidance and immediate feedback within controlled environments, experts derive greater value from challenging, error-based learning and opportunities for delayed reflection to refine their decision-making capabilities[49,65,92]. Situational learning is a subjective measure, and triangulation with objective techniques may strengthen inferences.

Simulation training provides a safe environment for trainees to practice history taking, physical examination, surgical procedures and develop the processes and strategies of clinical reasoning without the risk of harming patients. By allowing trainees to practice in a controlled setting, simulation training may reduce the cognitive load associated with patient encounters or when performing surgery for the first few times, which can eventually help them become more confident and competent in their abilities. Despite this, the simulated learning environment presents a complex and cognitively demanding scenario, necessitating careful consideration of the learner's prior experience in managing cognitive load[31,34–36,38,39,41,44,49,54,58,61,62,70]. Simulation and prior clinical observerships may further enhance trainees' performance through harnessing situational awareness, along with deliberate practice and structured micro- or bio-breaks[29,51,119]. The use of simulated patient encounters (or cases) and simulation-based training for procedural skills (e.g., ultrasound[31]) during the pre-clinical years or in early specialist training period[33] may accelerate early skill acquisition before clinical application; effects on training duration are unclear[153]. Simulation can help to manage extraneous cognitive load[16,25]. Pedagogical strategies incorporating time-distributed practice and virtual reality simulation demonstrate potentially fostering the sustained retention and reinforcement of complex psychomotor skills, notably those essential for the performance of mastoidectomy[35,36]. Although more cognitively demanding and time-intensive, students reported gaining a deeper understanding of complex tasks within simulated clinical immersion compared to simpler tasks. These experiences pose additional challenges to clinical reasoning, ultimately offering a more enriching and valuable learning experience from the students' perspective[129]. Moreover, simulation-based deliberate practice in procedures such as airway management and central venous catheterisation may be associated with lower error rates in some procedural settings[32,65]. By integrating simulator-based training with real-time feedback, trainees can likely refine their skills in low-risk environments before applying them in clinical settings[80,140].

Digital training (e.g., online medical courses and surgical simulations) may enhance trainees' situational awareness and optimise germane load[16,25,51,119,133,141]. One important benefit of digital learning is the opportunity to provide students with immediate feedback and/or adapt the learning content to the learning ability of students. For example, some students might get exhausted faster than the others and the same student might also have different learning ability over days. As such customising these learning processes to make it adaptive and personally relevant would make it less cognitively intense. Cognitive load may contribute to simulation-based learning failures[70] and further research is needed to determine how this understanding should inform simulation design. Integrating cognitive load measures into ongoing simulation research could quantify the theory's relevance to our field and provide an additional framework for interpreting emerging findings[70]. AI-based platforms may support physicians and trainees who are struggling with time management due to documentation requirements[53,144,145] via summarising individual electronic health records. However, large language models encoding clinical knowledge could also trigger unwarranted stress of misdiagnoses or unnecessary interventions[161].

External factors such as information retrieval, interruptions, reporting software, and time pressure may contribute to extraneous load especially in cardiology trainees[47]. Shared workspace, access to attendings, and availability of final reports foster germane load[47]. Creating a positive learning environment may support HCW training, as it helps to enhance learning outcomes and improves the overall quality[14,91]. Physicians and medical students are more likely to make mistakes if they are hungry, angry, late, or tired[40]. Another key strategy for mitigating this is implementing safety breaks, which address both physical, cognitive and emotional depletion. Simple strategies such as hydration reminders, structured rest periods, and workplace policies that prioritise staff well-being can likely improve performance and job satisfaction[29,40].

HCWs who experience emotional exhaustion, detachment from work (depersonalisation), and a diminished sense of personal accomplishment, may have higher attrition rates and a potentially decline in the quality of patient care[13,26,55,81]. Workshops and interventions focusing on workload management, mindfulness, and structured breaks are important in creating sustainable learning environments and enhancing resilience among HCWs and students[55]. Addressing these challenges through targeted strategies can potentially mitigate burnout, reduce stress-related errors, and improve overall job satisfaction[104]. It is important to measure baseline values and monitor the state of HCW well-being to identify at risk HCWs, and likely support them with a certified physician assistant, trained peer team and mental health experts[55]. There are several ways to measure HCW well-being. Some common measures include self-reported surveys and biomarkers to assess the physical and psychological effects of stress. These surveys[162] ask HCWs about their levels of stress, anxiety, depression, and other mental health problems. Likewise, it could be useful to measure cognitive load during procedural skill training [163] to better manage cognitive load and stresses in training period. It's important to prioritise evidence-based surveys and technologies tailored to the local training context.

The HCW mental health is complex and requires a comprehensive approach involving stakeholders at all levels of the healthcare system. At the individual level, junior HCWs can learn adaptive coping skills through cognitive behavioural therapy and mindfulness techniques[60,112], and they should be provided with specialised mental health services[81]. Senior HCWs can reinforce adaptive coping skills in their junior colleagues[81]. Retiring HCWs should be given appropriate preparation for retirement and be offered ongoing roles in teaching and training[81]. At the institutional level, medical schools can teach students effective coping skills and normalize help-seeking behaviour[81]. Hospitals and health systems can support administrative burdens, ensure workplace autonomy, and provide job security for HCWs[81], by focusing on interventions such as leadership development, strategic recruitment, and adequate staffing and resources[104]. Professional colleges and external regulators can consider implementing individually focused interventions such as offer personnel selection for supervisory roles, mandatory reporting rules, flexible leave arrangements, and work hours and shifts, where feasible[81]. The consensus statement[91] from New Zealand and Australia recommends that medical schools promote student well-being through peer support, stress management, mental health promotion, physical health promotion, and a safe and health-promoting learning environment. In addition, implementing policies that aim to increase financial rewards, offer opportunities for professional growth, promote flexibility, and build employees' strong ties to the community may help to enhance HCW retention[95].

Institutional interventions can complement individual coping strategies and help HCWs manage stress more effectively[104]. HCWs may benefit from relaxation techniques (such as mindfulness-based practices, yoga, meditation, and acupuncture) and having a positive mindset[55,60,73,112]. Burnout-awareness workshops equip HCWs with the tools to recognise early warning signs and adopt preventive measures, such as maintaining a work-life balance, utilising peer support systems, and adjusting workloads[26,55,104]. High levels of stress in students, arising from uncertainties in medical management, can negatively impact their cognitive processes[76]. However, familiarity with the practice setting, anticipation of challenges, debriefing sessions, the provision of a safe learning environment, and future training opportunities can help students manage stress effectively, thereby transforming simulations into positive learning experiences[51,58,80,124,129,131]. Consequently, by integrating these approaches into professional development programmes, healthcare institutions can prevent burnout and improve workforce retention. Mental rehearsal practice may be associated with improved procedural performance[88], likely reducing stress by enabling individuals to visualise complex procedures or decision-making scenarios. Mindfulness-based interventions have demonstrated efficacy in reducing burnout by enhancing attentional control, emotional regulation, and stress resilience[26,55,60,73,112]. Research indicates that mindfulness training diminishes medical errors, improves decision-making under pressure, and promotes overall well-being[92,112]. These interventions can be seamlessly incorporated into daily routines or delivered through structured formats such as workshops, guided reflection sessions, and stress management programmes, thereby fostering long-term resilience among healthcare professionals. When trainees and medics use their skills and knowledge to make a positive difference in the lives of others, they may find happiness and fulfilling life[55,73].

This review is not without its limitations. The task of interweaving cognitive load, well-being, and performance into a cohesive review proved challenging. We sought to reduce retrieval bias by including four databases and Google Scholar/hand-searches; however, publication bias cannot be excluded. There is a possibility that we may have unintentionally overlooked relevant studies that did not employ specific keywords associated with cognitive load and well-being. This oversight could result in a less comprehensive grasp of the existing evidence, potentially skewing our understanding of the relationship between the factors identified and the success of trainees.

Conclusion

The cognitive load theory inspired strategies may support HCWs to enhance their well-being, learning and performance, by using deliberate practice, instructional frameworks (structured learning, mnemonics, and case-based learning), situation awareness, reflection practices and digital training. Resource levels, staffing models, case-mix, and sociocultural factors likely moderate both cognitive load and intervention effectiveness, although standardised measurement and trainee-centred outcomes (well-being/retention) remain under-studied. To ensure a more global perspective and help reduce avoidable sources of cognitive overload and support well-being, further research on cognitive load factors and management strategies is necessary, particularly from underrepresented regions such as Asia, Africa, South America, parts of Eastern Europe, the Middle East, and Oceania beyond Australia.

Declarations

Author contributions: AB and JS developed the concept of the paper. AB and LL performed literature search using four databases, Google Scholar, hand searching; and screening and full-text review using Rayyan Review Management Platform, shown in the additional file 1. AB, RL and SB extracted the study data shown in the additional file 2. AB wrote the original manuscript and created the figures. AB, RL, LL, SB and NQL provided critical input, revisions, and contributed to the interpretation of the reviewed findings. AB amended the original draft. All authors reviewed and contributed to the work presented.

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References

1. Sletta C, Tyssen R, Lovseth LT (2019) Change in subjective well-being over 20 years at two Norwegian medical schools and factors linked to well-being today: a survey. BMC Med Educ 19:45
2. Vogel L (2019) US doctors call for tracking of suicides among medical trainees. CMAJ 191:E26
3. Stacey A et al (2022) Warning: medical education is hazardous to your mental health. Medical students should make an informed decision to begin and continue training. Can Med Educ J 13:39–44
4. Almutairi H et al (2022) Prevalence of burnout in medical students: A systematic review and meta-analysis. Int J Soc Psychiatry 68:1157–1170
5. Chang E, Eddins-Folensbee F, Coverdale J (2012) Survey of the prevalence of burnout, stress, depression, and the use of supports by medical students at one school. Acad Psychiatry 36:177–182
6. Altannir Y et al (2019) Assessment of burnout in medical undergraduate students in Riyadh, Saudi Arabia. BMC Med Educ 19:34
7. Barbosa ML et al (2018) Burnout Prevalence and Associated Factors Among Brazilian Medical Students. Clin Pract Epidemiol Ment Health 14:188–195
8. Muaddi MA et al (2023) Assessment of Medical Students Burnout during COVID-19 Pandemic. Int J Environ Res Public Health 20
9. de la Vega Sanchez D, Irigoyen-Otinano M, Carballo JJ, Guija JA, Giner L (2023) Suicidal thoughts and burnout among physicians during the first wave of the COVID-19 pandemic in Spain. Psychiatry Res 321:115057
10. Khajuria A et al (2021) Workplace factors associated with mental health of healthcare workers during the COVID-19 pandemic: an international cross-sectional study. BMC Health Serv Res 21:262
11. Trieu MC et al (2021) SARS-CoV-2-Specific Neutralizing Antibody Responses in Norwegian Health Care Workers After the First Wave of COVID-19 Pandemic: A Prospective Cohort Study. J Infect Dis 223:589–599
12. Bansal A et al (2023) Risk assessment and antibody responses to SARS-CoV-2 in healthcare workers. Front Public Health 11
13. Shanafelt TD et al (2022) Changes in Burnout and Satisfaction With Work-Life Integration in Physicians During the First 2 Years of the COVID-19 Pandemic. Mayo Clin Proc 97:2248–2258
14. Sinsky CA, Brown RL, Stillman MJ, Linzer M (2021) COVID-Related Stress and Work Intentions in a Sample of US Health Care Workers. Mayo Clin Proc Innov Qual Outcomes 5:1165–1173
15. Schnotz W, Kurschner C (2007) A reconsideration of cognitive load theory. Educ Psychol Rev 19:469–508

16. Howie EE et al (2023) Cognitive Load Management: An Invaluable Tool for Safe and Effective Surgical Training. J Surg Educ 80:311–322
17. Sweller J, van Merriënboer JJG, Paas F (2019) Cognitive Architecture and Instructional Design: 20 Years Later. Educ Psychol Rev 31:261–292
18. van Merrienboer JJ, Sweller J (2010) Cognitive load theory in health professional education: design principles and strategies. Med Educ 44:85–93
19. Sweller J, van Merrienboer JJG, Paas FG (1998) W.C. Cognitive Architecture and Instructional Design. Educ Psychol Rev 10:251–296
20. McEwen BS (2007) Physiology and neurobiology of stress and adaptation: central role of the brain. Physiol Rev 87:873–904
21. Rahić O, Tucak A, Sirbubalo M, Hindija L, Hadžiabdić J (2021) Antihypertensives' Rock around the Clock. J 4:62–81
22. Tucak-Smajić A (2023) Stress Response and Development of Allostatic Load
23. Soni N, Arntfield R, Kory P (2014) *Point of Care Ultrasound*S aunders
24. Gerjets P, Scheiter K, Cierniak G (2009) The Scientific Value of Cognitive Load Theory: A Research Agenda Based on the Structuralist View of Theories. Educ Psychol Rev 21:43–54
25. Tokuno J, Carver TE, Fried GM (2023) Measurement and Management of Cognitive Load in Surgical Education: A Narrative Review. J Surg Educ 80:208–215
26. West CP, Dyrbye LN, Shanafelt TD (2018) Physician burnout: contributors, consequences and solutions. J Intern Med 283:516–529
27. Tricco AC et al (2018) PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation. Ann Intern Med 169:467–473
28. Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A (2016) Rayyan—a web and mobile app for systematic reviews. Syst Reviews 5:210
29. Aalioui L, Gouzi F, Tricot A (2022) *Reducing cognitive load during video lectures in physiology with eye movement modeling and pauses: a randomized controlled study*
30. Aldekhyl S, Cavalcanti RB, Naismith LM (2018) Cognitive load predicts point-of-care ultrasound simulator performance. Perspect Med Educ 7:23–32
31. Alexander LF et al (2023) Ultrasound Simulation Training for Radiology Residents-Curriculum Design and Implementation. J Ultrasound Med 42:777–790
32. Ambardekar AP, Rosero EB, Bhoja, Ravi, Green J, Rebal BA, Minhajuddin, Abu (2019) … *A Randomized Controlled Trial Comparing Learners' Decision-making, Anxiety, and Task Load During a Simulated Airway Crisis Using Two Difficult Airway Aids*
33. Amey L, Donald KJ, Teodorczuk A (2017) Teaching clinical reasoning to medical students. Br J Hosp Med (Lond) 78:399–401
34. Andersen SA, Mikkelsen PT, Konge L, Caye-Thomasen P, Sorensen MS (2016) Cognitive Load in Mastoidectomy Skills Training: Virtual Reality Simulation and Traditional Dissection Compared. J

Surg Educ 73:45–50

35. Andersen SAW, Konge, Lars C-T (2016) Per, Sorensen, Mads Solvsten. Retent Mastoidectomy Skills After Virtual Real Simul Train
36. Andersen SAW, Mikkelsen P, Trier (2016) Konge, Lars, Cayé-Thomasen, Per, Sørensen. … Cogn load Distrib massed Pract virtual Real mastoidectomy Simul
37. Balslev T, Muijtjens A, de Grave W, Awneh H, van Merrienboer J (2021) How isolation key Inform allowing clarifying questions may improve Inform Qual Diagn accuracy case handover paediatrics
38. Barsuk JH, Ahya SN, Cohen ER, McGaghie WC, Wayne DB (2009) Mastery learning of temporary hemodialysis catheter insertion by nephrology fellows using simulation technology and deliberate practice. Am J Kidney Dis 54:70–76
39. Barsuk JH, McGaghie WC, Cohen ER, O'Leary KJ, Wayne DB (2009) Simulation-based mastery learning reduces complications during central venous catheter insertion in a medical intensive care unit. Crit Care Med 37:2697–2701
40. Baverstock A, Finlay F (2019) Take a break: HALT-are you Hungry, Angry, Late or Tired? Arch Dis Child Educ Pract Ed 104:200
41. Behrens C, Dolmans, Diana HJM, Leppink, Jimmie, Gormley GJ (2018) Driessen, Erik W. *Ward round simulation in final year medical students: Does it promote students learning?*
42. Bellstedt M (2024) Holtrup, Adrian, Otto, Nils, Berndt, Markus, Scherff, Aline Doreen, Papan, C… *Gaze cueing improves pattern recognition of histology learners*
43. Ben Awadh A, Clark J, Clowry G, Keenan ID (2022) *Multimodal Three-Dimensional Visualization Enhances Novice Learner Interpretation of Basic Cross-Sectional Anatomy*
44. Birt J, Moore E, Cowling M (2017) *Improving paramedic distance education through mobile mixed reality simulation*
45. Blissett S, Cavalcanti R, Sibbald M (2015) *ECG rhythm analysis with expert and learner-generated schemas in novice learners*
46. Blissett S, Morrison D, McCarty D, Sibbald M (2017) *Should learners reason one step at a time? A randomised trial of two diagnostic scheme designs*
47. Blissett S, Rodriguez S, Qasim A (2021) O'Sullivan, P. Learning Echocardiography in the Workplace: A Cognitive Load Perspective. Acad Med 96:441–448
48. Bostrom M, Lewis KO, Berger G, Orthopaedic Elect Learning Grad Me (2021). *The Role of Electronic Learning in Orthopaedic Graduate Medical Training: A Consensus From Leaders in Orthopaedic Training Programs*
49. Bowman A, Reid D, Bobby Harreveld R, Lawson C (2021) Evaluation of students' clinical performance post-simulation training. Radiography (Lond) 27:404–413
50. Brzezinski M, Kukreja, Jasleen M (2019) John D. *Time-efficient, goal-directed, and evidence-based teaching in the ICU*

51. Chen JJ, Gompers A, Evenson A, James BC, Royce C (2023) Surgical Adaptation of the Situation Awareness Rating Technique (S-SART): Assessing Situational Awareness Among Medical Students. J Surg Educ 80:216–227
52. Choi-Lundberg DL, Cuellar WA, Williams, Anne-Marie M (2016) *Online dissection audio-visual resources for human anatomy: Undergraduate medical students' usage and learning outcomes*
53. Civaner MM, Uncu Y, Bulut F, Chalil EG, Tatli A (2022) Artificial intelligence in medical education: a cross-sectional needs assessment. BMC Med Educ 22:772
54. Clarke K, Alim A-MA, Nimer L, Hatfield A, Sabharwal E, Syed S (2024) S. *Using Mixed Reality Simulation to Improve Junior Medical Trainees' Preparedness to Manage High-Acuity Trauma*
55. Cohen C, Pignata S, Bezak E, Tie M, Childs J (2023) Workplace interventions to improve well-being and reduce burnout for nurses, physicians and allied healthcare professionals: a systematic review. BMJ Open 13:e071203
56. General Practice Supervisors Australia (GPSA). Teaching clinical reasoning (Teaching guide) (2021)
57. Danboise B, Italiya BS, Richman S (2022) P. *254 Does Video Pre-Briefing Reduce Cognitive Load During a Simulated ACLS Scenario?*
58. Dankbaar, M., Alsma, Jelmer, Jansen, Els, Merrienboer, Jeroen, Saase, Jan, Schuit,Stephanie, D… *An experimental study on the effects of a simulation game on students' clinical cognitive skills and motivation*, (2016)
59. Donato AA, Kaliyadan AG, Wasser T (2014) *Self-Directed Study Using MP3 Players to Improve Auscultation Proficiency of Physicians: A Randomized, Controlled Trial*
60. Dubert CJ (2013) *A mindfulness model of emotion regulation in nursing students: Working memory capacity as a regulatory mechanism*
61. Dubovi I (2018) *Designing for online computer-based clinical simulations: Evaluation of instructional approaches*
62. Dubovi I, Lee VR (2019) *Instructional support for learning with agent-based simulations: A tale of vicarious and guided exploration learning approaches*
63. Duncan DR, Morgenthaler TI, Ryu JH, Daniels CE (2009) Reducing iatrogenic risk in thoracentesis: establishing best practice via experiential training in a zero-risk environment. Chest 135:1315–1320
64. Eickelmann AK, Huwendiek WNJ (2021) S. *Teaching the technical performance of bronchoscopy to residents in a step-wise simulated approach: factors supporting learning and impacts on clinical work - a qualitative analysis*
65. Fernandes R, Malloy-Diniz LF, de Vasconcellos MC, Camargos PAM, Ibiapina C (2021) *Adding guidance to deliberate reflection improves medical student's diagnostic accuracy*
66. Flynn S.G., P.R.S., Jena A.B., Staffa S.J., Kim S.Y., Clarke J.D., Pham I.V., Lukovits K.E., H… *Coaching inexperienced clinicians before a high stakes medical procedure: randomized clinical trial*, (2024)
67. Fontaine G, Cossette S, Dube GM-P, Veronique, Cote J (2020) *Effectiveness of a Theory- and Web-Based Adaptive Implementation Intervention on Nurses' and Nursing Students' Intentions to Provide*

Brief Counseling: Protocol for a Randomized Controlled Trial

68. Fraser, K., Huffman, James, Ma, Irene, Sobczak, Matthew, McIlwrick, Joanne, Wright,Bruce, M… *The emotional and cognitive impact of unexpected simulated patient death: a randomized controlled trial*, (2014)
69. Fraser K, Teteris MI, Baxter E, Wright H, McLaughlin B (2012) K. *Emotion, cognitive load and learning outcomes during simulation training*
70. Fraser KL, Ayres P, Sweller J (2015) Cognitive Load Theory for the Design of Medical Simulations. Simul Healthc 10:295–307
71. Friedman MA, Has TL, Hampton P (2017) B.S. *The impact of a postpartum rounding video module on medical student learning during the obstetrics and gynecology core clerkship*
72. Gao Y, Ceken BD (2022) C., Kow A.W.C. *Mixed reality enhanced laparoscopic living donor liver transplant*
73. Gerrard KM, Shepherd J, Sehdev R, Gangathimmaiah V, Nagle C (2023) Meeting the wellness needs of emergency department clinicians: A scoping review of interventions. Australas Emerg Care 26:169–178
74. Grangeia T, de Jorge B, Franci D, Santos TM, Setubal MSV, Schweller M, de Carvalho MA (2016) *Cognitive Load and Self-Determination Theories Applied to E-Learning: Impact on Students' Participation and Academic Performance*
75. Greville WJ, Dymond, Simon N (2016) Philip M. *The student experience of applied equivalence-based instruction for neuroanatomy teaching*
76. Groot F, Jonker G, Rinia M, ten Cate O, Hoff RG (2020) *Simulation at the Frontier of the Zone of Proximal Development: A Test in Acute Care for Inexperienced Learners*
77. Guluma KZ, Brandl K (2023) *Virtual learning allows for adaptation of study strategies in a cohort of U.S. medical students*
78. Gutierrez G, Lunsky IO, Van Heer S, Szulewski A, Chaplin T (2023) Cognitive load theory in action: e-learning modules improve performance in simulation-based education. A pilot study. CJEM 25:893–901
79. Hackett M, Proctor M (2018) *The effect of autostereoscopic holograms on anatomical knowledge: a randomised trial*
80. Haji, F.A., Cheung, Jeffrey J H, Woods, Nicole, Regehr, Glenn, de Ribaupierre, Sandrine,Dubr… *Thrive or overload? The effect of task complexity on novices' simulation-based learning*, (2016)
81. Harvey SB et al (2021) Mental illness and suicide among physicians. Lancet 398:920–930
82. Hashemi SB, Tan F, K.and, Bain CA (2019) *Addressing Cognitive Load in Training on Electronic Medical Record Systems*ACIS 2019 Proceedings. 56
83. Heer, S.V., Cofie, Nicholas, Gutierrez, Gilmar, Upagupta, Chandak, Szulewski, Adam,Chaplin,… *Shaken and stirred: emotional state, cognitive load, and performance of junior residents in simulated resuscitation*, (2021)

84. Hempel G, Struck HW, Piegeler MF, Rotzoll T (2019) D. *Impact of quantitative feedback via high-fidelity airway management training on success rate in endotracheal intubation in undergraduate medical students-A prospective single-center study*
85. Hill PP, Anderson DDA, Talbert M, Maraj S (2024) C. *Remembering to Resume: A Randomized Trial Comparing Combined Interruption Management Training and Simulation-Based Education to Simulation-Based Education Alone*
86. Hirsch AW, Nagler J (2020) *Spaced Education Through e-Learning for Ongoing Professional Development*
87. Hou M, Liu LY, Luo Y, Xue W, Yuan H, Zhang H (2024) X. *The impact of virtual reality applied in nurse education on students' clinical thinking: A systematic review*
88. Ignacio, J., Dolmans, Diana, Scherpbier, Albert, Rethans, Jan-Joost, Lopez, Violeta,Liaw, … *Development, implementation, and evaluation of a mental rehearsal strategy to improve clinical performance and reduce stress: A mixed methods study*, (2016)
89. Iwama Y, Ikeda M (2024) *Exploring a metacognitive approach for case analysis based learning of anxiety adjustment in nurses: a qualitative study*
90. Jannin L, Ganier F, De Vries P (2019) *Atomized or Delayed Execution? An Alternative Paradigm for the Study of Procedural Learning*
91. Kemp S et al (2019) Medical student wellbeing - a consensus statement from Australia and New Zealand. BMC Med Educ 19:69
92. Klein M, Otto, Barbel, Fischer MR, Stark (2019) Robin. *Fostering medical students' clinical reasoning by learning from errors in clinical case vignettes: effects and conditions of additional prompting procedures to foster self-explanations*
93. La Rochelle JS, Pangaro DSJ, Artino LN, van der Vleuten AR, Schuwirth CP (2011) L. *Authenticity of instruction and student performance: a prospective randomised trial*
94. Lee J, Donkers J, Jarodzka H, Sellenraad G, Faber TJE, van Merriënboer JJG (2024) *The Effects of Reflective Pauses on Performance in Simulation Training*
95. Lin TK, Werner K, Kak M, Herbst CH (2023) Health-care worker retention in post-conflict settings: a systematic literature review. Health Policy Plan 38:109–121
96. Liu, A., Duffy, Melissa, Tse, Sandy, Zucker, Marc, McMillan, Hugh, Weldon, Patrick,Quet, Julie… *Concurrent versus terminal feedback: The effect of feedback delivery on lumbar puncture skills in simulation training*, (2023)
97. Lopez-Rippe J., R.M., Velez-Florez M.C., Amiruddin R., Lerebo W., Gokli A., Francavilla M., R… *RADHawk-an AI-based knowledge recommender to support precision education, improve reporting productivity, and reduce cognitive load*, (2024)
98. Maia D, Andrade R, Afonso J, Costa P, Valente C, Espregueira-Mendes J (2023) *Academic Performance and Perceptions of Undergraduate Medical Students in Case-Based Learning Compared to Other Teaching Strategies: A Systematic Review with Meta-Analysis*

99. Manasia AR et al (2005) Feasibility and potential clinical utility of goal-directed transthoracic echocardiography performed by noncardiologist intensivists using a small hand-carried device (SonoHeart) in critically ill patients. J Cardiothorac Vasc Anesth 19:155–159
100. Manning KD, Spicer JO (2021) Golub, Lucas, Akbashev, Mikhail, Klein, Robin. *The micro revolution: effect of Bite-Sized Teaching (BST) on learner engagement and learning in postgraduate medical education*
101. Marei HF, Donkers J, Al-Eraky MM, Van Merrienboer JJG (2019) Collaborative use virtual patients after lecture enhances Learn minimal Invest Cogn load
102. Margallo, M.C.M., Mariano, Carmela Nicole P., Martinez, Kryssia Nadine Fauve L.,Maria… *Characterizing effective teaching in nursing pharmacology YouTube videos: A mixed methods study*, (2023)
103. McConnaughey S, Freeman, Rosario, Kim S, Sheehan F (2018) *Integrating Scaffolding and Deliberate Practice Into Focused Cardiac Ultrasound Training: A Simulator Curriculum*
104. McCormick E, Devine S, Crilly J, Brough P, Greenslade J (2023) Measuring occupational stress in emergency departments. Emerg Med Australas 35:234–241
105. Modi H, Singh H, Orihuela-Espina F, Athanasiou T, Fiorentino F, Yang GZ, Darzi A, Leff DR (2018) Temporal Stress Operating Room: Brain Engagem Promotes Coping Disengagement Prompts Choking
106. Morrill C, Hardin J, Steiman J (2023) Perioperative Reflection: An Understudied Yet Common Practice Among Surgical Residents. J Surg Educ 80:428–433
107. Narayanan A, Kong NM, Pearson V, Mani L, Fisher K, Khashram JP (2024) M. *Broad Responses and Attitudes to Having Music in Surgery (The BRAHMS Study): An Australia and Aotearoa New Zealand Perspective*
108. Natesan S, Bailitz J, King A, Krzyzaniak SM, Kennedy SK, Kim AJ, Byyny R, Gottlieb M (2020) *Clinical Teaching: An Evidence-based Guide to Best Practices from the Council of Emergency Medicine Residency Directors*
109. Nicholls D, Sweet L, Hyett J, Muller A (2020) Push and pull factors impacting the pedagogical approaches used by sonographers to teach scanning skills. Australas J Ultrasound Med 23:220–226
110. Noble VE et al (2009) Evaluation of a thoracic ultrasound training module for the detection of pneumothorax and pulmonary edema by prehospital physician care providers. BMC Med Educ 9:3
111. Oade S, Storey SK, Timme J (2019) C. *WORK TOGETHER, LEARN TOGETHER: THE BENEFITS OF INITIATING IN-SITU SIMULATION IN AN ACUTE MEDICINE DEPARTMENT*
112. Pandit A, de Gouveia M, Horsfall HL, Reka A, Marcus HJ (2022) *Efficacy of a Mindfulness-Based Intervention in Ameliorating Inattentional Blindness Amongst Young Neurosurgeons: A Prospective, Controlled Pilot Study*
113. Passalacqua C, Malhan LM (2023) N. Reducing Cogn Overload Resusc Room

114. Pusic MV et al (2012) Experience curves as an organizing framework for deliberate practice in emergency medicine learning. Acad Emerg Med 19:1476–1480
115. Rao Bhagavathula V, Bhagavathula, Viswakanth M, Chaudhuri RS, Joydeep Dutta (2022). *The Integration of Prelaboratory Assignments within Neuroanatomy Augment Academic Performance, Increase Engagement, and Enhance Intrinsic Motivation in Students*
116. Richardson KM, Fouquet SD, Kerns, Ellen MC, Russell J (2019) *Impact of Mobile Device-Based Clinical Decision Support Tool on Guideline Adherence and Mental Workload*
117. Ruiz JG, Levinson CD (2009) AJ. *Computer animations in medical education: a critical literature review*
118. Sanderson, B.J., Field, Jeremy D, Kocaballi, Ahmet B, Estcourt, Lise J, Magrabi,Farah, Wood… *Clinical decision support versus a paper-based protocol for massive transfusion: Impact on decision outcomes in a simulation study*, (2023)
119. Schick, K., Reiser, S, Janssen, L, Schacht, L, Pittroff, SID, Dorfler, E, Klein,E, Roenneberg, C,… *Training in medical communication competence through video-based e-learning: How effective are video modeling and video reflection?* (2024)
120. Schlorhaufer C, Behrends M, Diekhaus G, Keberle M, Weidemann J (2012) *Implementation of a web-based, interactive polytrauma tutorial in computed tomography for radiology residents: how we do it*
121. Schmitz F, Schnabel KP, Stricker D, Fischer MR, Guttormsen (2017) S. *Learning communication from erroneous video-based examples: A double-blind randomised controlled trial*
122. Sewell JL, Cate BJ, O'Sullivan OT, Shah P, Boscardin BJ (2019) C. *EXPERIENCED ENDOSCOPY TEACHERS USE TEACHING STRATEGIES THAT ADDRESS LEARNER CHALLENGES AND ALIGN WITH COGNITIVE LOAD THEORY*
123. Sewell JL, Boscardin YJQ, Cate C, O'Sullivan OT (2019) P. *IMPACT OF SPECIFIC TEACHING STRATEGIES ON FELLOW COGNITIVE LOAD DURING COLONOSCOPY TRAINING*
124. Sim, J.J.M., Rusli, Khairul Dzakirin Bin, Seah, Betsy, Levett-Jones, Tracy, Lau,Ying, Li… *Virtual Simulation to Enhance Clinical Reasoning in Nursing: A Systematic Review and Meta-analysis*, (2022)
125. Spiller K, Ossenberg C, Takashima M, Henderson A (2025) *Comparable achievement of workplace performance of student and graduate nurses: A quantitative cohort evaluation*
126. Stark R, Kopp V, Fischer MR (2009) *Facilitating Medical Students' Diagnostic Competence Via Situated, Case-Based Learning With Worked-Out Examples: The Influence of Errors and Feedback*
127. Styn A, Scheiter K, Fischer MR, Shiozawa T, Behrmann F, Steffan A, Kugelmann D, Berndt M (2023) *Effects of tablet-based drawing and paper-based methods on medical students' learning of gross anatomy*
128. Taveira-Gomes T, Prado-Costa R, Severo M, Ferreira MA (2015) *Characterization of medical students recall of factual knowledge using learning objects and repeated testing in a novel e-learning system*

129. Tremblay M-L, Leppink, Jimmie, Leclerc G, Rethans J-J, Dolmans, Diana HJM (2019) *Simulation-based education for novices: complex learning tasks promote reflective practice*
130. Uraiby H, Gordon G-CC, Sereno M, Powell M, McCarthy B (2021) M. *Fostering intrinsic motivation in remote undergraduate histopathology education*
131. Uslu-Sahan F, Ozdemir, Leyla K, Mert M, Yildirim, Sevda, Odabasi O (2025) *Virtual reality and standardized patient simulation programs in chemotherapy education for breast cancer: A comparative analysis of nursing students' knowledge, cognitive load, satisfaction and confidence*
132. Vignon P et al (2007) Focused training for goal-oriented hand-held echocardiography performed by noncardiologist residents in the intensive care unit. Intensive Care Med 33:1795–1799
133. Vydro SA, Drapeau LC, Perez S, Romero A, Norris D, Harmon M, Sewell D (2023) J. Implementation of a 3D-Printed Color-Coded Tracheobronchial Tree for Bronchoscopy Training and Anatomy Learning in a Pulmonary. Crit Care Fellowsh Program
134. Wahyuni S, Cahyati B, Limakrisna P (2020) N. *The Influence of Self Efficacy on Cognitive Load In Online Learning In The Pandemic Covid-19 On Nursing Students*
135. Wang T, Zheng J, Tan CY, Lajoie SP (2023) *Computer-based scaffoldings influence students' metacognitive monitoring and problem-solving efficiency in an intelligent tutoring system*
136. Werner A, Holderried F, Schaffeler N, Weyrich P, Riessen R, Zipfel S, Celebi N (2013) *Communication training for advanced medical students improves information recall of medical laypersons in simulated informed consent talks - a randomized controlled trial*
137. Wolf J, Lohmeyer LD, Farshad Q, Furnstahl M, Meboldt P (2023) M. *How different augmented reality visualizations for drilling affect trajectory deviation, visual attention, and user experience*
138. Yeo C, Ungi MA, Lasso T, Jalink A, Fichtinger D, Nanji G (2017) S. *3D segmentation as a surgical planning tool for residents in liver resection surgery*
139. Yeo, C.T., MacDonald, Andrew, Ungi, Tamas, Lasso, Andras, Jalink, Diederick, Zevin,Boris, F… *Utility of 3D Reconstruction of 2D Liver Computed Tomography/Magnetic Resonance Images as a Surgical Planning Tool for Residents in Liver Resection Surgery*, (2018)
140. Yeo L, Romero R (2022) Optical ultrasound simulation-based training in obstetric sonography. J Matern Fetal Neonatal Med 35:2469–2484
141. Yiin S-J, Chern C-L (2023) *The effects of an active learning mechanism on cognitive load and learning achievement: A new approach for pharmacology teaching to Taiwanese nursing students*
142. McNamara T et al (2025) Short and Sweet: Reducing Extrinsic Cognitive Load When Authoring Self-Study Materials for Medical Students. Med Sci Educ
143. Olson AS et al (2025) Assessment of Emergency Medicine Residents' Situational Awareness and Perception of Patient Safety Culture in the Emergency Department. AEM Educ Train 9:e70060
144. Olson KD et al (2025) Use of Ambient AI Scribes to Reduce Administrative Burden and Professional Burnout. JAMA Netw Open 8:e2534976

145. Hudson TJ et al (2025) Impact of Ambient Artificial Intelligence Documentation on Cognitive Load. Mayo Clin Proc Digit Health 3:100193
146. Tsyrulnik A et al (2026) When SMART Isn't Always Best: An Investigation of Emergency Medicine Resident Goal Setting Practices. AEM Educ Train 10:e70125
147. Ashman G, Kalyuga S, Sweller J (2020) Problem-solving or Explicit Instruction: Which Should Go First When Element Interactivity Is High? Educ Psychol Rev 32:229–247
148. Blaivas M, Lambert MJ, Harwood RA, Wood JP, Konicki J (2000) Lower-extremity Doppler for deep venous thrombosis–can emergency physicians be accurate and fast? Acad Emerg Med 7:120–126
149. Fleur DS, Bredeweg B (2021) Bos, W. Metacognition: ideas and insights from neuro- and educational sciences. NPJ Sci Learn 6:13van den
150. Pintrich PR (2002) The Role of Metacognitive Knowledge in Learning, Teaching, and Assessing. Theory Into Pract 41:219–225
151. Zimmerman BJ (1990) Self-Regulated Learning and Academic Achievement: An Overview. Educational Psychol 25:3–17
152. Shah J, Vyas A, Vyas D (2014) The History of Robotics in Surgical Specialties. Am J Robot Surg 1:12–20
153. Costello Anthony (2023) Junior surgeons must be trained for robotics revolution. MJA Insights
154. Fleming CA et al (2022) Surgical trainee experience and opinion of robotic surgery in surgical training and vision for the future: a snapshot study of pan-specialty surgical trainees. J Robot Surg 16:1073–1082
155. Bostrom MPG, Lewis KO, Berger G (2021) Orthopaedic Electronic Learning Graduate Medical Education Consensus Working, G. The Role of Electronic Learning in Orthopaedic Graduate Medical Training: A Consensus From Leaders in Orthopaedic Training Programs. J Am Acad Orthop Surg 29:317–325
156. Pell G, Fuller R, Homer M, Roberts T (2012) Is short-term remediation after OSCE failure sustained? A retrospective analysis of the longitudinal attainment of underperforming students in OSCE assessments. Med Teach 34:146–150
157. Mills G, Ruzycki SM, Sabourin J, Dance E (2021) Experiences of breastfeeding among women residents in Alberta: a cross-sectional survey. Postgrad Med 133:42–47
158. Stentz NC, Griffith KA, Perkins E, Jones RD, Jagsi R (2016) Fertility and Childbearing Among American Female Physicians. J Womens Health (Larchmt) 25:1059–1065
159. Rangel EL et al (2021) Incidence of Infertility and Pregnancy Complications in US Female Surgeons. JAMA Surg 156:905–915
160. Hashemi SB, Tan F, Kenneth; and, Bain CA (2019) Addressing Cognitive Load in Training on Electronic Medical Record Systems. *ACIS 2019 Proceedings* 56
161. Singhal K et al (2023) Large language models encode clinical knowledge. Nature

162. Aruta J, Almazan JU, Alamri MS, Adolfo CS, Gonzales F (2022) Measuring mental well-being among frontline nurses during the COVID-19 crisis: Evidence from Saudi Arabia. Curr Psychol, 1–11
163. Sewell JL, Boscardin CK, Young JQ, Ten Cate O (2016) O'Sullivan, P.S. Measuring cognitive load during procedural skills training with colonoscopy as an exemplar. Med Educ 50:682–692
164. Bansal A (2024) University of Bergen, Norway
165. Bansal A et al (2024) Role of Ultrasound-Based Therapies in Cardiovascular Diseases. Struct Heart, 100349
166. Atkinson RC, Shiffrin RM, Human Memory (1968) A Proposed System and its Control Processes. in *Psychology of Learning and Motivation*, Vol. 2 (eds. Spence, K.W. & Spence, J.T.) 89–195Academic Press

Figures

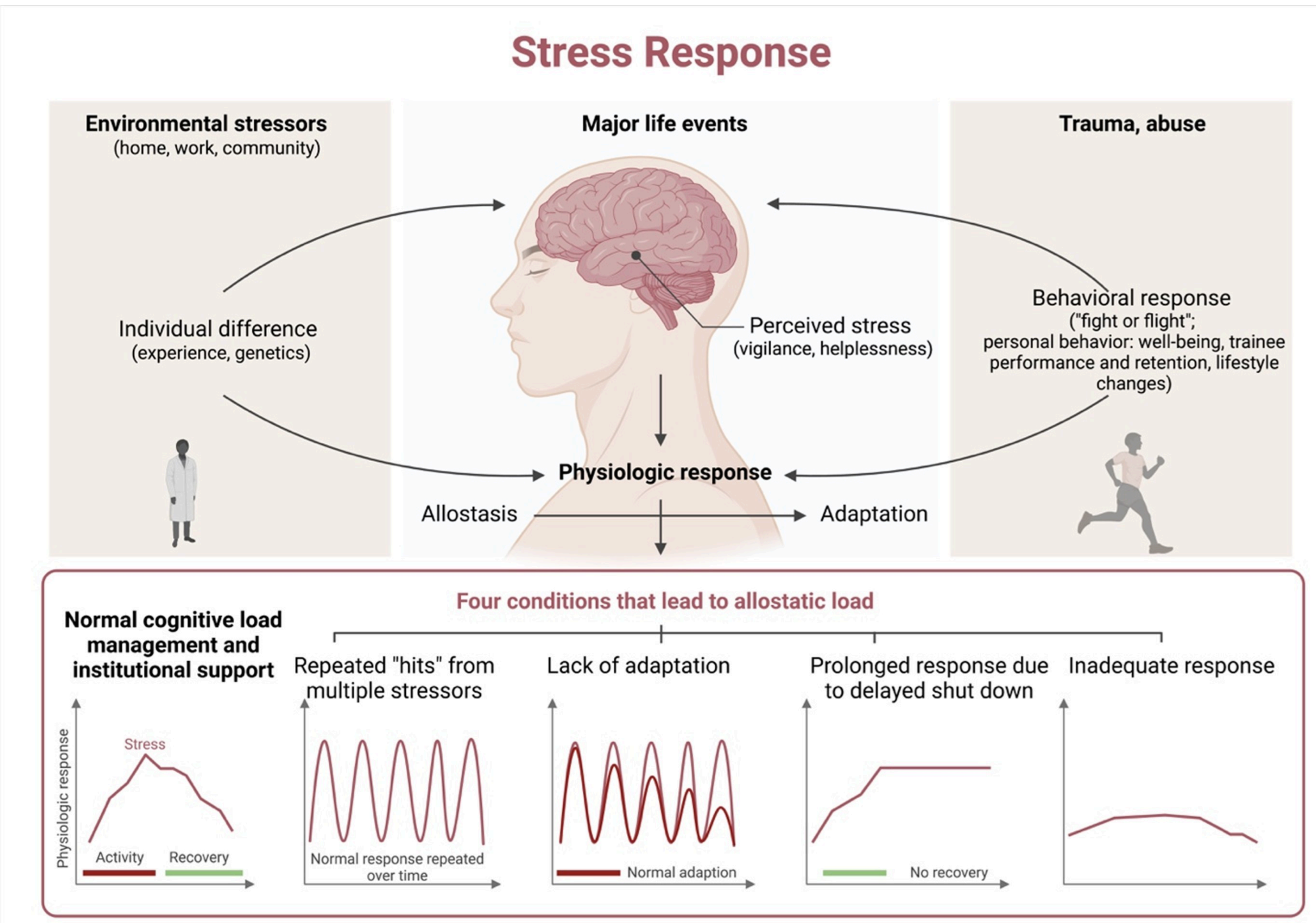

Figure 1

Behavioural and physiological response to stressors among healthcare workers.

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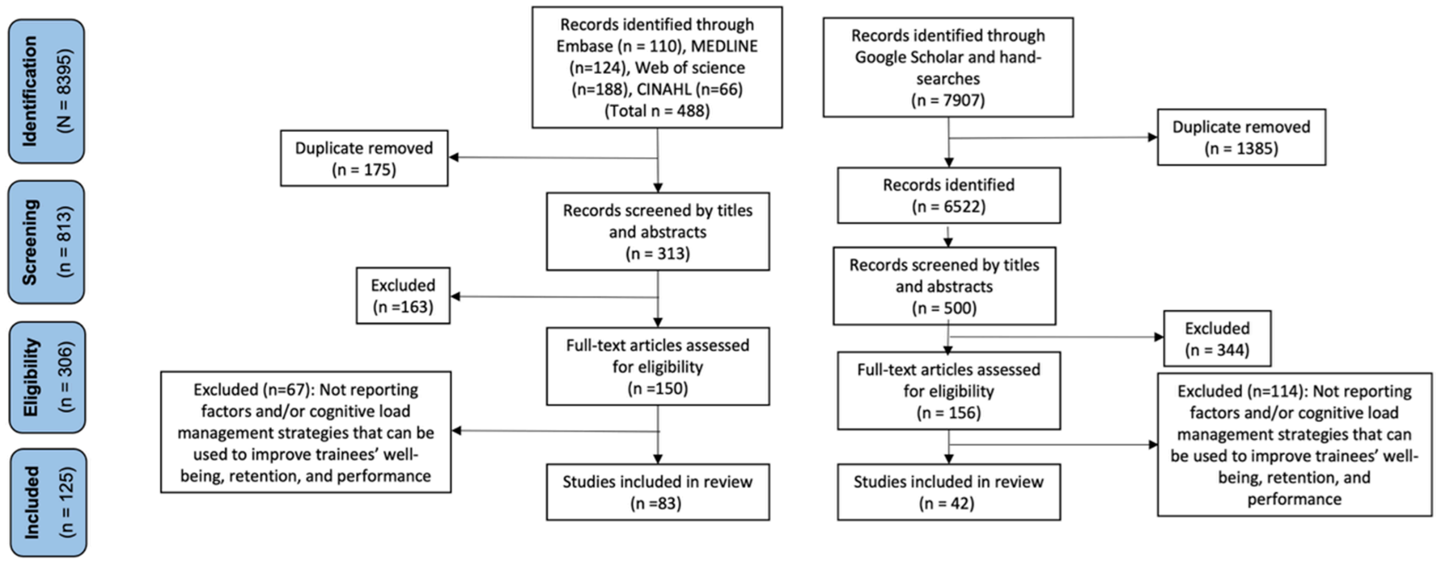

Figure 2

PRISMA-ScR flowchart for searches, screening and full-text review.

Records identified: 8,395 (Embase 110; MEDLINE 124; Web of Science 188; CINAHL 66; Google Scholar/hand-searching 7,907 wherein first 500 records were considered after deduplication). Searches: 18-19 February 2025 (databases); 27 February 2026 (Google Scholar/hand-searching). After deduplication and screening, 125 studies were included in the narrative synthesis. Inclusion required alignment to the eligibility frameworks and reporting of outcomes relating to well-being, retention/intent-to-stay, or performance (skills, reasoning, errors, patient outcomes). A meta-analysis was not planned.

Abbreviation: PRISMA-ScR, Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.

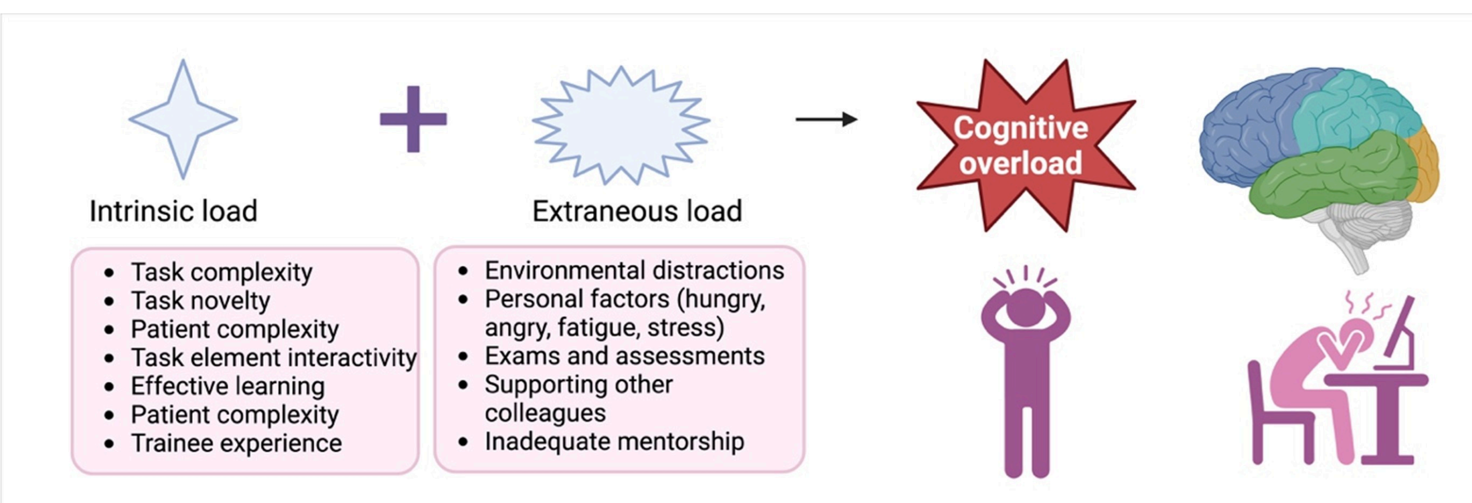

Figure 3

Potential cognitive overload factors in healthcare settings.

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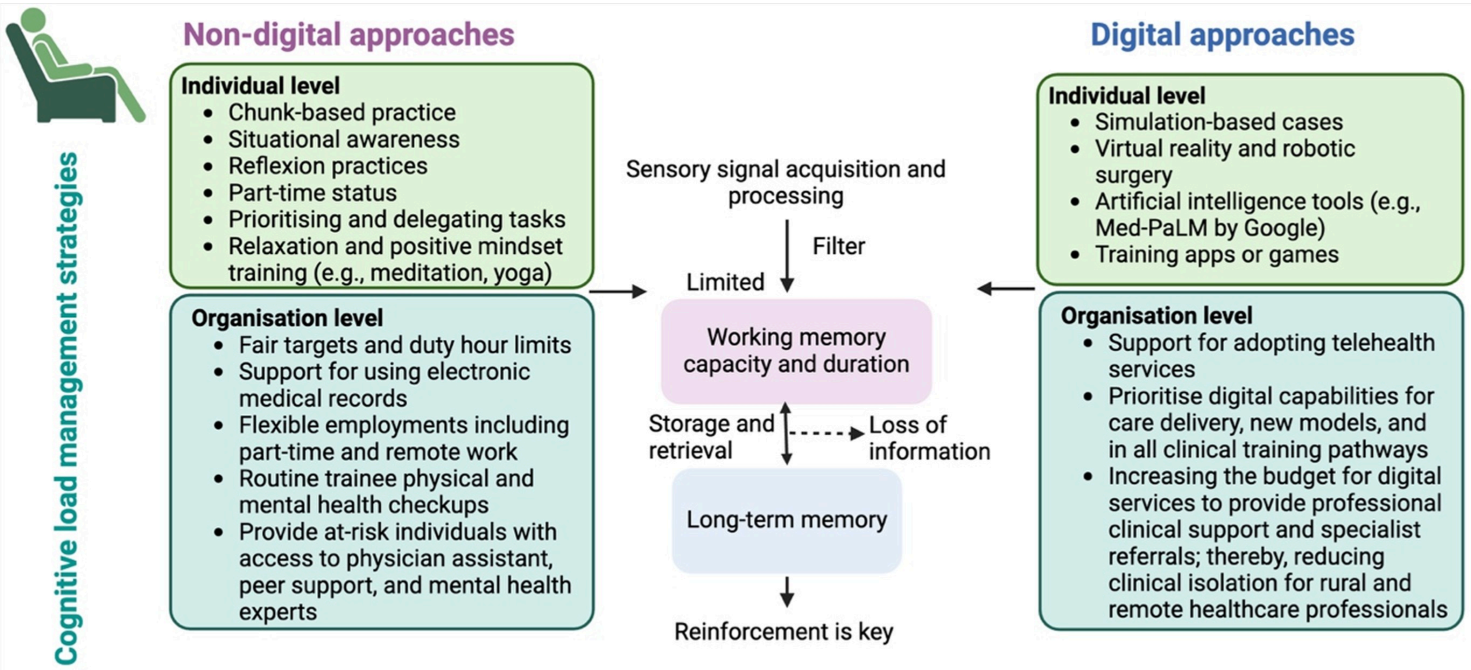

Figure 4

Cognitive load management strategies in healthcare settings.

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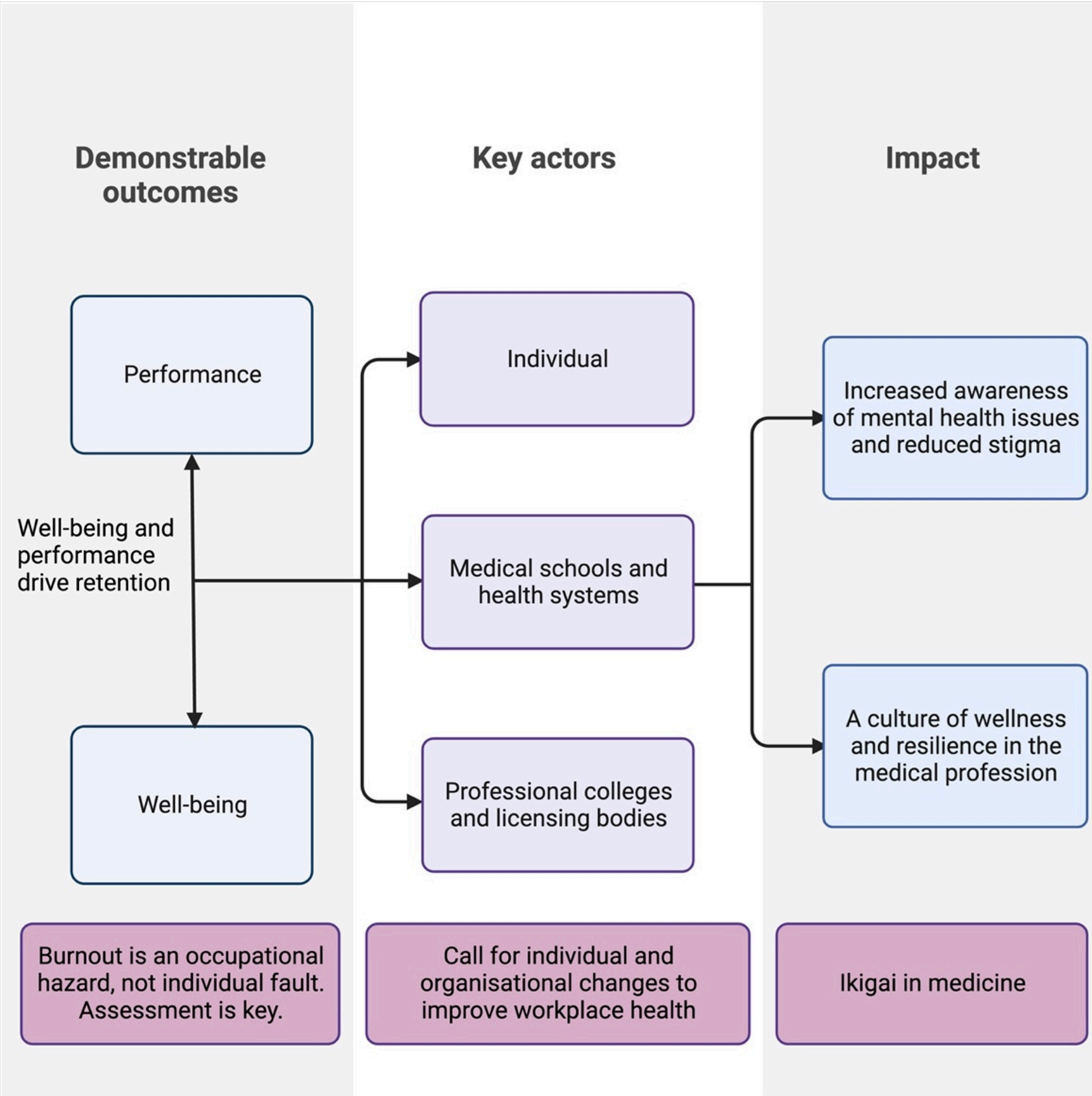

Figure 5

Potential key actors for promoting wellbeing and excellence in healthcare settings.

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Supplementary Files

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