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Simulation as a suitable education approach for medical training in marine and off-shore industries: theoretical underpinning

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ABSTRACT

Healthcare providers in marine and offshore industries must often perform high-risk procedures outside of their usual scope of practice, frequently using novel, complex telemedical technologies to perform an already unfamiliar task — often while multitasking, and sometimes in extreme environmental conditions. Given all the novelty occurring at once, the probability of medical error increases. This increase can be explained by the Cognitive Load Theory, which states that too much demand on the working memory can tax the ability of the long-term memory.

This article will show that one solution to this situation is to use simulation in the medical training of offshore and marine medical practitioners. Contextualised simulation practice creates automatic schemas that reside in the long-term memory, minimising strain on the working memory — and, in a marine medical context, also minimising the risk of medical error.

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Key words: simulation, education, training, cognitive load, performance, skills

INTRODUCTION

When a medical emergency occurs in the marine or offshore industry, medical staff must perform low-frequency, high-stakes medical procedures — sometimes for the very first time in their careers. Performing a novel procedure is challenging in itself, but performing one in marine environments comes with all kinds of other novel stimuli — extreme environmental conditions; motion; and the sophisticated, ever-evolving telemedicine technology used to communicate with medical practitioners on shore. Meanwhile, during emergency procedures, practitioners are multitasking — stabilising and monitoring the patient; following instructions provided by telemedical guidance; and communicating patient status with relevant on-board and distant (i.e., on shore) crew members. This creates a lot of demand on the cognitive resources of one individual at one time in an already unfamiliar situation.

The Cognitive Load Theory states that when the cognitive demands of a task exceed the capacity of the task performer's working memory, performance and learning are impaired — in other words, practitioners may not properly perform the procedure if there is too much else to think about. Given the amount of cognitive demand placed on medical staff in marine and offshore medical emergencies, the risk for Cognitive Load in such emergencies — and, conversely, for medical errors in such emergencies — runs high.

One possible solution to this situation is to use simulation in the medical training of offshore and marine medical practitioners. Contextualised simulation practice minimises the demands on the working memory by allowing the de-

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velopment of automatic schemas that live in the long-term memory, improving performance in real-life settings. Various medical and para-medical training settings are already employing medical simulation to help practitioners develop and maintain relevant skills in various environments; this paper will demonstrate, using the Cognitive Load Theory, why simulation is a viable educational tool for marine and offshore medical training as well.

DISCUSSION

Simulation is broadly defined as the "imitation of some real thing, state of affairs, or process" [1]. Most modern healthcare provider education programs have already adapted simulation as a standard of practice; pharmacy, social work and nursing programs all include simulation exercises as part of their training. Research demonstrates that simulation is an effective educational tool that improves the skills of healthcare providers on simulators, and helps practitioners transfer these skills to real-life settings [2–4]. Simulation is also becoming an important part of the training of medical personnel on board ships and other offshore installations. The Cognitive Load Theory offers one possible explanation why simulation would be particularly important for the development of practical skills by medical personnel working in the marine and offshore industry.

MULTITASKING

In order to fully grasp the Cognitive Load Theory, it is useful to first explore the relationship between multitasking, experience level and performance. Recent findings in the area of the impact of multitasking on the skilful performance of healthcare providers demonstrate that these conditions often lead to suboptimal medical performances in novice providers — but not in expert providers [5]. Specifically, when experienced surgeons were asked to perform a difficult technical surgical procedure while listening to a medically relevant conversation, their surgical performances were relatively unaffected and, later, the surgeons could recall relevant details about the conversation. However, junior surgical trainees who were familiar with but not expert at the procedure did not perform well on the technical aspect of the task while concurrently listening to the conversation, and later recalled fewer details from the conversation than the experienced surgeons did. Subsequent studies revealed that providing surgical trainees with simulation-based practice could lead to a reduction in these multitasking-related performance deficits [6].

THE COGNITIVE LOAD THEORY

Broadbent's 1958 [7] model of information processing (also see Atkinson and Shiffrin, 1968 [8]) serves as a useful overview of how information is processed and stored in memory. This model can be used to understand how, for example, signs and symptoms of a clinical diagnosis, or the steps in a clinical procedure, can be processed and stored in memory. According to Broadbent's model [7], as articulated by Baddeley [9], memory formation begins when information from the environment is processed by our sensory system. While this initial sensory processing can deal with a seemingly unlimited amount of incoming sensory information, it is estimated that the time that elapses before the incoming information is lost is extremely short — between 0.25 s and 1 s [10, 11]. This initial stage of information processing occurs automatically and unconsciously unless the stimulus is specifically attended to [9, 12]. In this way, attention acts as a filter that determines what information reaches a conscious information processing stage [13]. An attention filter is necessary for learning so that relevant stimuli (e.g. a patient's physical exam findings) can be screened-in and irrelevant stimuli (e.g. movement in the examination bay) can be screened-out [14].

However, human attention is limited; if the load required for attending to a stimulus consumes all available resources, a bottleneck can occur [15]. As a result, the perception of other stimuli, particularly of those indirectly related to the task at hand, may be impaired.

Once information passes through the attention filter, it is incorporated within the working memory [14, 16]. Here, it can be organised or re-organised alongside other sensory information and prior knowledge for the purposes of task performance or learning, and subsequent storing of this information in the long-term memory [14]. The working memory system holds information in a state that is accessible to our consciousness, allowing it to be manipulated [17]. By providing an interface between sensory perception, long-term memory, and the intended action, the working memory supports a range of complex cognitive activities, including analytic procedures (e.g. calculating dosage); reasoning (e.g. making a diagnosis); comprehension (e.g. understanding the directions of the medical personnel on the other side of the telemedical line); and learning (e.g. incorporating new information with information already existing in long-term memory from courses or prior interactions with similar cases) [18, 19].

There are two specific characteristics of the working memory system that are relevant to this discussion. First, the working memory system can only store information for a short period, approximately 20 s, unless refreshed through rehearsal [12, 14, 20]. Second, the working memory system has a limited storage capacity [17]. This means that a task that severely taxes working memory capacity can also significantly tax performance.

The exact working memory storage limit is the subject of some debate. Miller [21] proposed that working memory storage is capable of holding between 5 and 9 independent elements of information at one time. Miller suggests that only the number of elements is limited, and not their size and complexity [17]. Therefore, what constitutes an independent element is important to the discussion of the role of simulation to improve performance. For example, to a child just learning the alphabet, the letters "O-N-E" function as 3 separate elements, whereas to a literate adult the 3 letters become a single element due to the adult's existing knowledge of the word "one". In this way, the capacity limits become pronounced when novel information is processed, as the absence of prior knowledge requires that each element be processed separately in working memory. Current research findings suggest that when interacting with completely novel situations, individuals are only able to retain up to 4 elements of information at a time [16]! Furthermore, when information needs to be actively organised, contrasted, or combined rather than simply held in the working memory, the number can be as low as 2 [14, 17, 20]. Applying this logic to a medical practitioner not only attending to a patient with severe trauma, but doing so in adverse environmental conditions while receiving information via a telemedical device, dictates that there is a high potential that information elements may be dropped from the practitioner's working memory.

A key attribute of working memory is that its capacity is limited. Despite this, humans are capable of achieving impressive intellectual heights and high-order cognitive functioning, even under extreme environmental conditions. Despite the limitations to working memory capacity, humans are capable of achieving impressive intellectual heights and high-order cognitive functioning, even under extreme environmental conditions. The temporal and storage limits of the working memory are overcome when information is encoded as a relatively permanent memory trace in long--term memory, which is believed to have a limitless capacity [14, 20].

SCHEMA FORMATION

The capacity limits of working memory may also be overcome by making use of prior knowledge stored in long-term memory when executing cognitive tasks, such as reasoning and learning. The knowledge that an individual accumulates over their lifetime is purported to be held in long-term memory in the form of schemas, domain-specific representations that organise and store information elements according to how they relate to each other and in the manner in which they will be used [14, 17, 21–23]. The process occurs when individuals actively combine information elements held in working memory together to form more complex ideas (such as, for example, combining the individual letters O, N and E to form the word "one") and elaborate these with relevant prior knowledge activated in long-term memory (for example, associating a new word with others that have similar meaning) [14, 17].

Schema formation serves two distinct purposes [17]. Firstly, it facilitates learning or skilled performance by providing a mechanism for integration and organisation of novel information with prior knowledge. Secondly, it reduces working memory demands, because an entire schema (no matter how much information it contains) can be processed in the working memory as a single element.

The process of schema construction itself does not alter the base capacity of working memory and thus must operate within its limits — that is, processing between 2 and 4 chunks at a time. However, with extensive practice (such as hundreds of trials where a schema is repeatedly retrieved from long-term memory and subsequently applied to perform a task), schemas may gradually shift from requiring controlled, effortful processing to becoming automated, thereby requiring little or no conscious effort [17, 20]. This shift occurs because, once automated, a schema can operate as an independent central executive that directs behaviour without needing to be processed in the working memory [20]. This allows tasks associated with the automated schema to be performed accurately and fluidly, while optimising performance and learning by freeing up the maximal amount of working memory resources to process less familiar aspects of a task [17]. For instance, after completing thousands of trials of one-handed surgical knot-tying (either in clinical training or through simulation-based deliberate practice), an on-board medic will automate this basic skill such that it can be performed on demand with little or no cognitive effort, thereby freeing up working memory resources to attend to other tasks, such as listening to telemedical instructions.

This is where simulation comes in. A simulated environment gives medical trainees an opportunity to try out the tasks they might be asked to perform in a marine environment — such as suturing or intubating a patient in a rich-motion environment — so that the experience can be committed to the long-term memory via a schema. This way, should the practitioner have to perform a task in an extreme environment, the task itself no longer poses a threat to the practitioner's cognitive load.

CONCLUSIONS

In summary, Cognitive Load Theory is primarily concerned with how information made available during instruction interacts with human cognition during the process of learning [24]. The theory emphasizes that working memory constraints are the primary determinant of performance and learning effectiveness [17, 25]; these constraints are the "bottleneck" for learning and performance. Based on the memory architecture described here, the theory makes two assumptions regarding human performance and learning [14, 17, 20]. First, performance and learning are impaired when cognitive overload occurs — that is, when the cognitive demands associated with a task exceed the limited working memory capacity. In this way, working memory capacity creates a 'bottleneck' for performance and learning, particularly for complex tasks that require integration of multiple unfamiliar information elements. Conditions requiring multitasking, especially when some of the tasks are novel and/or when there are environmental stressors, will affect the working memory. Second, the theory states that, with practice, these skills are organised in highly elaborated schemas that are stored in long-term memory. These schemas help to automatise the skills, which in turn reduce the working memory demands. Because schema formation is highly contextualised, simulation practice may offer the most effective learning option outside of a real-life setting.

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