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Cognitive Training: How can it be adapted for surgical education?

Abstract

Background

There is a need for new approaches to surgical training in order to cope with the increasing time pressures, ethical constraints, and legal limitations being placed on trainees. One of the most interesting of these new approaches is “cognitive training” or the use of psychological processes to enhance performance of skilled behaviour. Its ability to effectively improve motor skills in sport has raised the question as to whether it could also be used to improve surgical performance. The aim of this review is to provide an overview of the current evidence on the use of cognitive training within surgery, and evaluate the potential role it can play in surgical education.

Methods

Scientific database searches were conducted to identify studies that investigated the use of cognitive training in surgery. The key studies were selected and grouped according to the type of cognitive training they examined.

Results

Available research demonstrated that cognitive training interventions resulted in greater performance benefits when compared to control training. In particular, cognitive training was found to improve surgical motor skills, as well as a number of non-technical outcomes. Unfortunately, key limitations restricting the generalizability of these findings include small sample size and conceptual issues arising from differing definitions of the term ‘cognitive training’.

Conclusions

When used appropriately, cognitive training can be a highly effective supplementary training tool in the development of technical skills in surgery. Although further studies are needed to refine our understanding, cognitive training should certainly play an important role in future surgical education.

Keywords

- Cognitive training;
- Surgical education;
- Mental rehearsal;
- Surgical skills training

Introduction

The world of surgical training is changing. Both the standards expected and demands made of surgical trainees are higher than ever before, and consequently the efficiency of surgical education has come under increasing scrutiny. The traditional approach of ‘see one, do one, teach one’ that underpins apprenticeship style teaching has always been the mainstay of surgical education. More recently, however, it is increasingly accepted that this is no longer the optimum way to deliver surgical training [1]. Simultaneously, there has been a growing understanding of the cognitive demands placed on surgeons [2, 3]. As a result of such scrutiny, cognitive abilities such as problem solving and movement-planning have been highlighted as playing a crucial role in skill learning [3, 4]. These factors have resulted in a shift away from teaching that exclusively trains the motor skills required to carry out a surgery, and *towards* training that targets the thought processes of surgical trainees. The performance benefits of cognitive training have been firmly established in sport [5, 6], whilst studies in rehabilitative medicine have recognized its ability to develop motor skills [7]. These findings have raised questions concerning the degree to which cognitive training can play a role in surgical education, and furthermore, how it can be integrated optimally into surgical training programs.

What is cognitive training?

“Cognition” is a generic term used to describe the mental activities associated with thinking, learning, and memory [8, 9]. In its most essential form it is our ability to mentally process and manipulate information from the world around us. ‘Cognitive skills’ describes the various different components that make up a person’s cognition,

identifying them as separate mental abilities depending on their function. As the link between cognitive skills and performance became increasingly understood [10, 11], it was theorised that training targeted at developing cognitive skills would produce improvements in motor ability. Cognitive training aims to develop or alter the way in which we mentally manipulate information, in order to improve physical performance.

The scientific basis for cognitive training resides on Jeannerod's simulation theory [12, 13] and has been explored through the use of functional neuroimaging. This theory hypothesises that the motor system is part of a cognitive network that includes various psychological activities. Initial functional MRI investigations have shown that similar neural pathways are activated during cognitive training and actual performance of a task [12, 14]. Furthermore, a study by Debarnot et al. found that the brain changes resulting from cognitive training for a specific motor task mimic those observed after physical practice of the same skill [12, 15]. These findings help to explain why cognitive training can directly improve motor performance, and are discussed in 'Expertise and Mental Practice' by A. Moran [12], who summarizes that, not only does cognitive training 'induce neuroplasticity, but it also elicits task-specific, practice-induced cerebral activity'.

Recent development of cognitive training has seen several distinct branches emerge. At the forefront of research is the application of "mental imagery", defined as a mental simulation process which allows a person to represent a perceptual, multi-sensory scenario in their mind, without any actual sensory input [16]. This skill is applied in the form of mental rehearsal, where a motor task is rehearsed in the mind without actual physical movement. It often relies on a mental imagery script, which

consists of sensory descriptions of what a person will see, feel, and think during a task. Research has demonstrated mental rehearsal to be an extremely effective method for training elite athletes and musicians, benefitting both motor and non-technical skills [5, 12]. Another area of cognitive training that is gaining popularity is the concept of 'cognitive task analysis (CTA)' based interventions; a training method by which the intuitive knowledge and thought-processes of experts are used to construct a teaching program for novices [17]. CTA uses interview and observation methods to elicit the automated skills, strategies, and decisions that underlie expert performance [18]. This allows a task to be broken down into manageable steps that provide both technical and cognitive instructions, and has been proven as an effective teaching method in military and aviation settings [6]. Possibly the most popularly publicized field of cognitive training is 'brain training', which uses the repetition of short tasks or games to exercise specific cognitive functions, and has become a multi-million pound industry [19]. Other types of cognitive training are less well defined and often revolve around structured problem solving, interactive teaching, and development of critical evaluation skills [20].

Cognitive training in use

Cognitive training has been utilized within sport for many years and has become an important tool used by athletes at the elite level. Studies have shown that cognitive training can improve a variety of different motor skills in sport, as well as skill acquisition and physical strength [5]. It can also increase an athlete's overall performance by improving specific mental processes such as reaction and movement planning [5, 11]. Mental rehearsal is perhaps the most widely applied performance-enhancement technique in sports, with a meta-analysis by Feltz et al. [21] finding that

the average effect size of mental practice was 0.47, compared to an average effect size of 0.22 in the control groups. A randomized controlled trial of 183 tennis players found that the use of mental rehearsal gave a significant improvement in the execution of the forehand drive and concluded it was effective at enhancing motor performance in athletes [22]. Evidence also supports the use of techniques such as CTA [6] and computer-based cognitive simulation [23]. Another field that has embraced cognitive training is the aviation industry. Mauro et al. [24] noted that pilots are required not simply to remember the relevant information, but more importantly process and apply this knowledge effectively in the operational environment. A pioneering study done by Prof. D Gopher used a cognitive simulator to train pilots and found that it resulted in a record improvement in overall flight performance of more than 30% [25]. Cognitive training is now consistently integrated into aviation programs, commonly in the form of cognitive simulators [26].

The role of cognition in surgery

Arising from the demonstrated efficacy of mental rehearsal in sport, a number of studies have explored the degree to which mental imagery training can enhance surgical performance [27]. For example, a study of 58 expert surgeons by Cuschieri et al. found that more than 70% agreed that cognitive ability was one of the top attributes required by trainee surgeons [28], and various studies have investigated the cognitive skills required in surgery (Table 1). Surgeons are required to carry out complex motor tasks in time-pressured, high-stake environments in much the same way as pilots or athletes. Thus it is logical to hypothesize that the tools used in these fields could also be of value to surgeons, and studies are beginning to emerge that investigate how cognitive training can benefit surgical performance. This narrative

review explores the key evidence available on the use of cognitive training in surgery and draws conclusions on the role it can play in surgical education.

Paper	Carthey et al. 2000 [27]	Yule et al 2006 a [2]	Yule et al. 2006 b [4]	Kahol et al. 2007 [3]
Cognitive Skills Identified	<ul style="list-style-type: none"> • Situational awareness • Decision making 	<ul style="list-style-type: none"> • Situational awareness • Mental readiness • Assessing risks • Anticipating problems • Decision making • Adaptive flexibility • Workload distribution 	<ul style="list-style-type: none"> • Cognitive flexibility • Anticipation • Adaption • Safety awareness • Situational awareness 	<ul style="list-style-type: none"> • 2-Dimensional tracking • 3-Dimensional tracking • Orientation • Working memory • Preparatory attention

Table 1: Key cognitive skills required for surgery highlighted by specific studies

Cognitive Training in Surgery

Method

Literature published prior to 01/01/2016 was identified via searches on PubMed, Medline, and Embase. Searches were conducted using combinations of MeSH and free text terms (see table 2), to identify the relevant studies, and reference lists were analysed for appropriate inclusions. As a narrative review, the aim was to identify the key papers from the search results, in order to provide an overview of the current research, and this was done via discussion amongst the authors. For ease of comparison, studies were then divided into appropriate groups based on the type of cognitive training they covered, and can be found summarized in Tables 3-6. Mental rehearsal, CTA, and simulation-based training were identified as the types of

cognitive training discussed most within the available literature and therefore were a focus of the review.

MeSH terms	Free text terms for 'cognitive training'	Free text terms for 'surgical education'	Other search terms
<ul style="list-style-type: none"> • Practice (physiology) • Problem solving • Spatial processing • Spatial learning 	<ul style="list-style-type: none"> • Cognitive training • Cognitive learning • Mental rehearsal • Mental training • Mental imagery • Mental practice 	<ul style="list-style-type: none"> • Surgical education • Surgical training • Surgical teaching • Surgery • Teaching • Education • Training 	<ul style="list-style-type: none"> • Simulation • Simulator based training • Cognitive task analysis

Table 2: Summary of the key search terms used to identify studies

Mental Rehearsal

A study by McDonald et al. in 1995 established that 79% of the surgeons sampled used mental imagery and that experienced surgeons identified it as a critical skill [29]. This paved the way for research into the effectiveness of structured mental rehearsal in surgery. An influential study by Arora et al. [30] trained participants in mental rehearsal, using a validated mental imagery script, and found that it gave greater improvements in technical performance when compared to the control group, who viewed an online lecture as training. Participants performed five virtual-reality laparoscopic cholecystectomies, and, on average, the mental rehearsal group scored higher on the Objective Structured Assessment of Technical Skills (OSATS) scale in all five procedures. These findings were supported by Komesu et al. [31], who also demonstrated that mental rehearsal resulted in improved technical skills during surgical tasks. Additionally a study by Immenroth et al. [32] randomized participants to receive mental rehearsal training or practical training (additional time physically practicing), and assessed their performance pre- and post-intervention. Results

showed mental rehearsal to be the more effective intervention; giving a significant 23.0% increase in mean OSATS score from baseline, compared to a 5.2% increase in the practical training group. A handful of studies have also demonstrated the positive effect of mental rehearsal on non-technical factors [33, 34], for example a further study by Arora et al. [33] found that both objective and subjective stress levels were lower after using mental rehearsal ($p < 0.05$). Despite these promising results, not all studies report a beneficial effect of cognitive training, and studies by both Jungmann et al. [35] and Sanders et al. [36] demonstrated that mental rehearsal had no marked effect on surgical performance in any of the outcomes assessed. Furthermore, a study by Mulla et al. [37] found that mental rehearsal actually had a negative impact; reporting an overall performance score of 63.4% in the mental rehearsal group, compared to 69.0% in the no-training group.

On closer analysis, the studies that showed mental rehearsal to have a positive effect had a number of common features, which were not replicated in those that found equivocal/negative results. For example, consider the treatment regime involved. Specifically, the mental rehearsal employed in the “positive effect” studies involved longer and more repetitive sessions of mental rehearsal than those in the “negative effect” category. Sessions were at least 30 minutes long and instruction on how to carry out mental rehearsal was delivered by trained ‘cognitive trainers’ or experienced psychologists. Participants were guided through the process of mental rehearsal and, in some cases, rehearsal was repeated in a structured setting on multiple occasions [31, 34]. This directly contrasted the methodology of those studies that did not show any significant improvement, in which sessions were not only shorter, but also relied on participants to undertake unstructured rehearsal in their

own time. Another major limitation of these studies was the inappropriate timing of intervention delivery. A review by Sapien and Rogers [38] recommends a maximum 24-hour lag between mental rehearsal and the task, however in the studies highlighted training was delivered 7-10 days prior, or the timing was unclear. This limitation was not seen in the studies that found mental rehearsal to be beneficial, in which structured training was delivered immediately or <24 hours before the surgical task, with the exception of Komesu et al., which delivered it 24-48 hours prior. Given these comparisons, it is highly possible that, in the studies finding no benefit of cognitive training, the major methodological limitations discussed contributed to the lack of effect.

Title and Author	Design Overview	Details of MR	Key Findings
Arora et al. (2011a) [30]	<ul style="list-style-type: none"> •20 novice surgeons randomized •Participants performed 5 virtual reality laparoscopic cholecystectomies 	<ul style="list-style-type: none"> •30 minutes of MR directly before each surgery using a validated mental imagery script 	<ul style="list-style-type: none"> •OSATs and MIQ scores were higher in MR group on all 5 surgeries •Improved imagery lead to better performance
Arora et al. (2011b) [33]	<ul style="list-style-type: none"> •20 novice surgeons randomized •Participants performed 5 virtual reality laparoscopic cholecystectomies, with stress levels measured 	<ul style="list-style-type: none"> •30 minutes of MR directly before each surgery using a validated mental imagery script 	<ul style="list-style-type: none"> •Objective and subjective stress were reduced for MR group •Improved imagery lead to lower stress
Immenroth et al. (2007) [32]	<ul style="list-style-type: none"> •98 novice surgeons randomized to MR training, additional practical training, and no added training •Performed a laparoscopic cholecystectomy pre- and post- training 	<ul style="list-style-type: none"> •1-to-1 MR training for 90 minutes, involved self-talk, relaxation, visualization and an operation primer 	<ul style="list-style-type: none"> •MR group achieved the highest OSAT scores in task specific performance and gained similar global rating scores to the practical training group
Jungmann et al. (2011) [35]	<ul style="list-style-type: none"> •40 medical students randomized; all received 2 training sessions on a virtual reality simulator •MR group received MR teaching between sessions 	<ul style="list-style-type: none"> •MR training involved a surgical demonstration, task checklist, and an MR booklet •Told to practice MR for 3 mins/day 	<ul style="list-style-type: none"> •No difference in overall performance between the control and MR group •Higher scores on the visual-spatial test correlated with increased performance

Komesu et al. (2009) [31]	<ul style="list-style-type: none"> • 68 participants randomized to preoperative MR sessions or reading relevant texts • Compared using a 2-factor ANOVA 	<ul style="list-style-type: none"> • MR training involved a 1-to-1 session with the MR educator, using a set template • Training 24-48hrs prior to task 	<ul style="list-style-type: none"> • MR group gained higher performance scores and rated the intervention more highly • No difference in operative times between groups
Mulla et al. (2012) [37]	<ul style="list-style-type: none"> • 41 students randomized to 5 intervention groups, including no training (control), additional practical training, and MR training • Assessed: time, precision, accuracy, performance 	<ul style="list-style-type: none"> • MR training involved a 25 minute 1-to-1 session, done 1 week before final task • Told to practice MR for 15 minutes/day 	<ul style="list-style-type: none"> • MR group showed no significant improvements compared to control group • In accuracy and precision, the MR group scored worse than control group
Sanders et al. (2004) [36]	<ul style="list-style-type: none"> • 65 students randomized; physical practice and physical practice plus MR groups • Performed an assessed surgery on a live rabbit 	<ul style="list-style-type: none"> • MR training involved relaxation, guided imagery instruction, and visualisation • MR delivered 10 days before final task 	<ul style="list-style-type: none"> • Physical practice plus MR was statistically equal to additional physical practice • No performance benefit from using MR

Table 3: Summary of key studies investigating the use of mental rehearsal in surgery

Cognitive Task Analysis

The importance of the cognitive stage of motor skill learning is widely accepted, however a study by Sullivan et al. [39] demonstrated that experts omit about 70% of this knowledge during teaching. This study also determined that CTA was an effective method for capturing surgical expertise, supporting previous studies that demonstrated a 28-40% increase in information captured from experts during a task by using CTA [40-42]. CTA itself is not a method of cognitive training, but instead a way of capturing the cognitive information needed to complete a task. However three key studies [43-45] have advanced the role of CTA further, eliciting information via expert participation in CTA and then designing a cognitive training course for novices using this data. Luker et al. [45] demonstrated that their CTA-program resulted in improved decision-making ability and total knowledge, however, most notably, the

other two studies demonstrated its ability to improve technical skills. Velmahos et al. [43] compared their CTA-training program to traditional training (observation and practical practice), and found that the CTA-trained participants achieved higher technical performance scores (12.6 v 7.5) and required fewer attempts to complete the task (3.3 v 4.2), results which were statistically significant. Furthermore Sullivan et al. [44] noted that the advantages gained from CTA-training were still present at 6 months post-intervention, with participants scoring an average of 39.4 on the technical performance checklist during the follow up task, compared to 31.8 in the control group.

Whilst these studies present promising evidence, many of the existing trials involve <30 participants and consequently there is a need for larger, multi-institutional trials to be conducted. In addition, although there is an assumption that CTA-training is likely to be most effective at a novice level [6], this has yet to be verified. Another limitation of the available evidence is that few studies provide details as to which specific type of CTA they used, meaning that the effectiveness of different CTA methods cannot be compared. Further studies targeting these limitations could provide greater understanding of which types of CTA are most beneficial in surgical education, and at what stage of training they are best utilized.

Title and Author	Design Overview	Details of CTA	Key Findings
Clark et al. (2012) [42]	<ul style="list-style-type: none"> • 10 expert surgeons described a procedure via: free-recall, free-recall using visual aids, and CTA • 11th surgeon agreed the final CTA protocol 	<ul style="list-style-type: none"> • A CTA-trained interviewer conducted the interview using a validated method 	<ul style="list-style-type: none"> • The CTA interviews resulted in greater accuracy and surgeons in free-recall groups omitted >65% of necessary decision steps
Luker et al. (2008) [45]	<ul style="list-style-type: none"> • 10 plastic surgery trainees performed 3 tendon repairs • Didactic teaching after 1st surgery (control), CTA-based teaching between after 2nd surgery 	<ul style="list-style-type: none"> • 3 expert surgeons underwent 3 CTA interviews • Resulting data used to construct a training program 	<ul style="list-style-type: none"> • After CTA-based training participants displayed a statistically significant knowledge expansion from 2nd to 3rd trial
Sullivan et al. (2007) [44]	<ul style="list-style-type: none"> • 20 general surgery trainees randomized into CTA-curriculum group and control group • Performance assessed after 1 and then 6 months 	<ul style="list-style-type: none"> • 3 experts interviewed and filmed performing a tracheostomy • Resulting data used to construct a curriculum 	<ul style="list-style-type: none"> • The CTA group performed significantly higher at both 1 and 6 months than the control group, and demonstrated superior cognitive strategies
Velmahos et al. (2004) [43]	<ul style="list-style-type: none"> • 26 novice trainees randomized to CTA curriculum or traditional curriculum • Performed an assessed central venous catheterization within 2.5 months of training 	<ul style="list-style-type: none"> • CTA experts interviewed 2 experts on CVC • Resulting data used to construct a curriculum 	<ul style="list-style-type: none"> • CTA group gained higher skills (technical) and knowledge scores • CTA group also completed the task in less time, with fewer attempts

Table 4: Summary of key studies investigating the use of CTA-based training in surgery

Cognitive Training in Simulation

Cognitive training approaches have developed to complement simulation-based training, as the latter fulfills an increasingly important role in surgical education [46]. In industries such as aviation, simulation has emerged as a successful method for delivering cognitive training [47] and the possibility of adding a ‘cognitive layer’ to medical simulator programs is now being explored. A study by Kahol et al. [3] designed a selection of virtual reality tasks inspired by neuropsychological

assessment, with each task targeting a specific cognitive skill, including movement-planning, working-memory and preparatory-attention . A later study goes on to validate this methodology, both verifying the learning effect of the cognitive exercises and demonstrating that they led to greater technical proficiency when compared to training on a 'standard' simulator program [47]. Other simulator-based cognitive training programs have focused specifically on error recognition/feedback [48, 49].

One characteristic that makes simulator-based cognitive training particularly valuable is its ability to be delivered across a range of platforms. For example Guru et al. [50] developed cognitive skills software for the da Vinci™ Surgical System and Touch Surgery™ is a cognitive-task simulation app available for mobile devices [51]. Unfortunately there is limited research into simulation-based cognitive training and a fundamental methodological problem presents repeatedly. In many of the studies available the designed tools are incorrectly labeled as 'cognitive training' when in fact it is not clear how they differ significantly from didactic approaches. Another major limitation is the small study sizes, ranging from the largest, with 33 participants [48], to the smallest, with only 10 participants [47]. Although initial studies are promising, there is a need of further direction and research. Kahol et al. [47] sets out a generic framework for design, development and evaluation of a cognitive simulator, providing a potential guide for future research.

Title and Author	Design Overview	Details of Cognitive Simulator	Key Findings
Guru et al. (2009) [50]	<ul style="list-style-type: none"> • 10 students and surgical trainees randomized • All participants given anatomy training booklet 	<ul style="list-style-type: none"> • Intervention group trained with a cognitive training module on developed for the da Vinci™ Surgical System • Augmented reality based training 	<ul style="list-style-type: none"> • Cognitive training group gained significantly higher performance scores, faster times and more correct answers
Kahol et al. (2009) [47]	<ul style="list-style-type: none"> • 10 participants randomized • Trained on either a standard (control) or cognitive simulator 	<ul style="list-style-type: none"> • Simulator exercises targeted movement planning, preparatory attention, working memory and intermodal transfer 	<ul style="list-style-type: none"> • Demonstrated the learning effect of the tool and that the cognitive simulator led to greater proficiency
Loveday et al. (2010) [48]	<ul style="list-style-type: none"> • 33 novice trainees randomized to training on Integrated Cognitive Simulator or control simulator • Assessed by MCQ exam 	<ul style="list-style-type: none"> • Integrated text, anatomy, video, simulation, and a cognitive task timeline • ICS also provided various error feedback 	<ul style="list-style-type: none"> • 1st year trainees in the cognitive group scored higher (2nd years did not) • ICS was rated as highly usable
Palter et al. (2012) [49]	<ul style="list-style-type: none"> • 25 surgical trainees randomized to control or cognitive training • Performed an assessed laparoscopic right colectomy 	<ul style="list-style-type: none"> • Self-directed reading and video-based learning • Video training focusing on procedural steps and errors 	<ul style="list-style-type: none"> • Cognitive group gained higher technical ability and knowledge scores, and outperformed control group in 7 of 8 tasks

Table 5: Summary of key studies investigating the use of cognitive simulation training in surgery

Other Cognitive Training Strategies

The studies discussed above have all approached cognitive training along a specific pathway, but several studies take a more general approach. A study by Van Herzeele et al. [52] implemented one-to-one cognitive training that focused on procedural steps and error avoidance. Novices who underwent the program gained similar performance scores to those of experienced surgeons in the final surgical task, whereas the control group scored significantly lower. In addition, both Bingenger et al. [53] and Kohls-Gatzoulis et al. [54] implemented cognitive training

programs that were found to be effective at increasing error detection and avoidance. Unfortunately studies into more general cognitive training methods are plagued by similar limitations to those on simulation-based training. It is disputable as to whether the interventions delivered are in fact ‘cognitive training’ as intended, or whether they are simply variations of standard teaching methods. For example in the study by Van Herzeele et al. [52] the ‘cognitive training’ is delivered through teacher-led instruction and demonstration, which could certainly be described as a didactic, rather than interactive, approach.

Title and Author	Design Overview	Details of Cognitive Training	Key Findings
Bingener et al. (2008) [53]	<ul style="list-style-type: none"> •30 trainees randomized •The control and cognitive training group practised the task for 30 minutes 	<ul style="list-style-type: none"> •Video instruction on common errors prior to practicing the task 	<ul style="list-style-type: none"> •The cognitive group showed greater improvements in time and error identification •The OSATS improved equally for both groups
Kohls-Gatzoulis et al. (2004) [54]	<ul style="list-style-type: none"> •21 surgical trainees randomized to control or cognitive training for total knee arthroplasty •Control group taught only technical skills, with more practice time 	<ul style="list-style-type: none"> •Taught to focus on evaluating their end product with regards to overall quality •Lecture with emphasis on possible errors 	<ul style="list-style-type: none"> •OSATS and MCQ knowledge improved equally for both groups •The cognitive group scored better in error-detection test than the control
Van Herzeele et al. (2008) [52]	<ul style="list-style-type: none"> •47 surgical trainees randomized to receive control or cognitive training •Performed an assessed virtual endovascular procedure immediately after training 	<ul style="list-style-type: none"> •1-to-1 session covering indications, anatomy, procedural steps, and error recognition •Extensive demonstration with errors emphasized 	<ul style="list-style-type: none"> •The cognitive group scored equal to experts in qualitative assessments, control group scored significantly worse •Cognitive group took longer to complete the task than the control and experts

Table 6: Summary of key studies investigating the use of general cognitive training in surgery

Discussion

From the preceding evidence, it is clear that cognitive training can play a beneficial role in surgical education if performed correctly and at an appropriate time - hence a majority of studies in surgery have demonstrated its efficacy as a training tool. Furthermore, this review has highlighted its effectiveness at also improving some of the non-technical abilities that are so important for trainees to develop. Whilst some studies have failed to demonstrate the positive effect of cognitive training, significant methodological issues bring these findings into question. In fact, the results from these studies demonstrate the need for a greater understanding of how cognitive training interventions should be designed and implemented in order to be successful.

There are, of course, limitations and gaps in the current research, with the key limitation being the small sample sizes of the studies. To date no wide-scale trials have been conducted and consequently it is difficult to assess the feasibility of delivering cognitive training as a formal component of a training curriculum. The second major limitation is the apparent inconsistency in the definition of cognitive training, with a number of trials involving interventions that should not be classified as such. This point is raised by Kahol et al. [47], who observe that research does not 'elucidate how the cognitive training was different from conventional didactic training'. Researchers need to understand that training must deliberately exercise specific cognitive functions in order to create a cognitive training effect and clarification of this point would allow future research to be more relevant and focused.

Furthermore, there are at least three significant research gaps that need to be addressed in order to facilitate the implementation of cognitive training into surgical

teaching programs. Firstly, none of the available studies evaluate its cost effectiveness and, although a meta-analysis by Rao et al. [55] postulates mental rehearsal to be value efficient, minimal data exists on this subject. Secondly, a majority of the research conducted spans a short time-scale, and, with the exception of Sullivan et al. [44], none have investigated the effect of cognitive training on long-term retention of complex motor skills. Both of these points would need addressing by future studies in order to justify the implementation of cognitive training on a wider scale, such as integrated into a regional training program. Finally, most of the studies in this field are largely atheoretical in nature and hence cannot investigate the crucial question of what psychological mechanisms underlie the efficacy of cognitive training. Clearly, future research in this field needs to address this unresolved issue as an urgent priority.

So what direction should cognitive training take in the future? This review has highlighted the need for properly structured training interventions that can produce consistent results. It is clear that, whatever its mode of delivery, cognitive training requires formal instruction in order to be most effective. The studies that used trained instructors to deliver the cognitive training in a structured environment gained far superior results to those that relied on unsupervised participation or independent completion of the training. Evidence also demonstrates that cognitive training is most beneficial when used directly before the surgical task [5, 12], and it is vital that future interventions are designed to ensure minimal time between training and performance. In addition, it is widely understood that traditional skills training requires regular repetition in order to prevent the developed technical skills from declining [46, 56] and this concept should also be applied to cognitive training. Given the evidence

in functional neuro-imaging, it seems logical that training should be delivered in a repetitive manner, over an extended period, in order to reinforce the relevant neural pathways and provide the greatest benefit.

Future cognitive training interventions should be designed with these specifications in mind, in order to maximise their chance of success. Additionally, validation studies should be careful to avoid the methodological issues highlighted within this review, such as periods of more than 24 hours between training and assessment. Development of structured training tools, with proven validity and effectiveness, will allow us to further our understanding of how cognitive training is best utilised in the training of surgical skills. This will pave the way for its wider implementation into formal surgical training programs.

Conclusion

It is evident that cognitive training has a place in the future of surgical education. Its effectiveness at improving technical surgical ability, as well as a number of non-technical skills, supports its integration as a supplementary training tool for surgeons. Looking towards the future, this review has highlighted the need for greater clarification of what classifies as cognitive training, in order to increase the quality and relevance of further research. In addition, to allow further integration of cognitive training into surgical education, future studies should aim to investigate the practicality of implementing it on a larger scale and explore the role it can play in expert-level training. If progress continues, cognitive training could soon play an influential role in the way we train the surgeons of tomorrow.

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