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Cognitive Training for Technical and Non-Technical Skills in Robotic Surgery:

A Randomised Controlled Trial

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Abstract

Objectives

To investigate the effectiveness of motor imagery (MI) for technical and non-technical skills (NTS) training in minimally invasive surgery.

Materials and Methods

A single blind, parallel group randomised controlled trial was conducted at the Vattikuti Institute of Robotic Surgery, King's College London. Novice surgeons were recruited by open invitation in 2015. Following basic robotic skills training, participants underwent simple randomisation to either MI training or standard training. All participants completed a robotic urethrovesical anastomosis task within a simulated operating room. In addition to the technical task, participants were required to manage three scripted NTS scenarios. Assessment was performed by 5 blinded expert surgeons and a NTS expert using validated tools for evaluating technical skills (Global Evaluative Assessment of Robotic Skills (GEARS)) and NTS (Non-Technical Skills for Surgeons (NOTSS)). Quality of MI was assessed using a revised Movement Imagery Questionnaire (MIQ).

Results

33 participants underwent MI training and 29 underwent standard training. Interrater reliability was high, Krippendorff's $\alpha = 0.85$. Following MI training, mean GEARS score was significantly higher than after standard training (13.1 ± 3.25 vs 11.4 ± 2.97 , $p = 0.03$). There was no difference in mean NOTSS scores (25.8 vs 26.4 , $p = 0.77$). MI training was successful with significantly higher imagery scores than standard training (mean MIQ score 5.1 vs 4.5 , $p=0.04$).

Conclusions

MI is an effective training tool for improving technical skill in MIS even in novice participants. No beneficial effect for NTS was found.

Trial Registration: ISRCTN Identifier ISRCTN47552076

URL: <http://www.isrctn.com/ISRCTN47552076>

Key words: Minimally Invasive Surgery, Surgical Education, Mental Training, Simulation

Introduction

The advantages of proficiency based training in driving skill acquisition over historical models of experiential learning are widely recognised in medicine¹. Whilst experience is often still considered synonymous with expertise, increasingly goal-directed, focussed training forms the basis of curricula across the spectrum of specialities^{2,3}. Expansion of simulation training has allowed adoption of the deliberate practice model of training centred on repeated, effortful practice directed through feedback to improve performance⁴. The wide variety of simulation tools now available has enabled training to move towards a more individualised, proficiency-based approach. However physical simulation is not the only approach available for surgical training. Mental training in the form of motor imagery is used as an important training adjunct in a variety of fields ranging from sport and music to rehabilitation medicine⁵. Motor imagery (MI) is defined as the mental rehearsal of a motor task without physical execution of the movements involved⁶. Functional equivalence of MI and motor execution is well established⁷. Neuroscientific evidence shows both similar patterns of neural activation between MI and motor execution alongside similar physiological responses such as heart rate and electromyography^{8,9}. Yet in contrast to elite sports and other performance-based roles, the potential for such cognitive training to confer further educational and performance gains in surgery remain largely unexploited^{10,11}.

Alongside offering numerous advantages, minimally invasive surgery (MIS) poses new technical and non-technical skill (NTS) challenges to the surgeon. Operative differences such as the reduction or loss of haptic feedback cause difficulties particularly for trainee

surgeons^{12,13}. The minimally invasive surgeon is also confronted by new NTS challenges due to the alterations to the working environments and team setup. Specific NTS training is vital to ensure the surgeons continue to operate safely and effectively¹⁴. Physical simulators have been extensively incorporated into training curricula, particularly for minimally invasive surgery, to meet these new training demands. The objective of this study is to determine whether evidence-based MI can successfully be used for training technical and non-technical skills in minimally invasive surgery.

Methods

A single blinded, parallel group randomised controlled trial was conducted. Local ethics committee approval was granted (LRS15/161950) and the trial was registered with the ISRCTN registry (ISRCTN47552076).

Participants were recruited from three large London hospital trusts and four associated medical schools by open invitation between May 2015 and August 2015. Recruitment was open to junior doctors and medical students who had completed at least one year of clinical training. Novice level was defined as having no prior experience in performing MIS either within an operating room or simulation. More senior trainees (trainee surgeons and above) were excluded from the trial to ensure an homogenous baseline ability across both groups.

The trial was conducted in the Vattikuti Institute of Robotic Surgery, King's College London. Participants were required to attend three separate sessions (Figure 1). Initially all participants completed a basic skills training course. This consisted of didactic and hands-on-

training in basic robotic skills and robotic suturing. Robotic training was performed using a virtual reality simulator, the Da Vinci Surgical Simulator (DVSS) attached to the Da Vinci Xi Surgical Robot (Intuitive Surgical Inc, Sunnyvale, CA, USA). All participants completed two basic robotic skills modules (Pick and Place; Pegboard 2) in addition to a robotic suturing module (Interrupted Suturing). Inbuilt proficiency scores from the simulator were used to guide training. The score from the initial attempt of Pegboard 2 provided an objective baseline measure of competency.

Following successful completion of the basic skills training course, simple randomisation was performed using a random number generator to assign participants to either cognitive training or control (GraphPad Software, Inc. La Jolla, CA, USA). Randomisation and allocation of participants was concealed from the researcher enrolling participants to the further trial sessions. Given the nature of the trial, blinding of the participants or trial organisers was not possible. The independent expert surgeons evaluating the final skills assessment were blinded to the intervention assignment. Participants were invited to return for further training in groups of four according to their randomisation status. The assessment task selected was urethrovesical anastomosis (UVA). This specific procedure was selected to provide the necessary degree of complexity to differentiate participants whilst also being accurately simulated using a synthetic, dry lab model (3-Dmed, OH, USA). Prior to training all participants in both arms were shown a 30min video explaining the steps for UVA using the same synthetic model. The control group underwent standard training which comprised a further instructional video on the correct technique for the UVA. The intervention group underwent MI training. Training involved mentally rehearsing a UVA with the aid of a MI script. Initially participants being taken through the MI script with an experienced trainer.

Following this training session participants then continued their MI training in their own time. The MI script was developed in collaboration with experts in MI and expert robotic surgeons using the PETTLEP model¹⁵. The model provides a structured checklist to address key imagery processes for successful imagery. PETTLEP is an acronym identifying the seven domains for developing an effective motor imagery script (Physical, Environment, Task, Timing, Learning, Emotion, Perspective). The MI checklist was developed according to this protocol. The checklist instructed participants to complete the MI training in the same seated position as at the robotic console (Physical). Training was initially undertaken in the same setting (Environment). Participants were asked to imagine completing all the steps of the UVA task, focussing on specific technical factors for example ensuring correct rotation of the wrist to pass the needle cleanly through the tissue (Task). Participants were instructed to imagine the task in real time (Timing) and from a first-person Perspective (imagining the action through one's own eyes). The checklist also provided a number of sensory triggers to encourage the accurate Emotional imagery of the task. These domains were emphasised to the participants to stimulate vivid and effective imagery.

During the third session, participants underwent identical technical and non-technical skill assessment. First participants completed a warm-up exercise using the Da Vinci Xi surgical robot to complete a basic skills dry-lab training model (Pea on a Peg, 3-Dmed, OH, USA) before completing a practice attempt of an UVA (not assessed). Following this warm up, participants underwent assessment within a simulated operating room (OR). An inflatable, simulated OR, the Igloo, was used to accurately recreate the OR environment with actors playing the roles of scrub nurse and anaesthetist. A variety of auditory and visual cues were used to further increase the realism. The actors followed identical scripted scenarios for all

participants. Each scenario was limited to 15min. Whilst completing the UVA task, participants were exposed to three stressor events to test their NTS. These increased in difficulty, ranging from being engaged in simple conversation with the surgical team to the patient becoming haemodynamically unstable. Participant performances were recorded using both the video feed from the Da Vinci endoscopic camera as well as three external room video cameras. The video recorded scenarios were blindly assessed post-hoc by four expert robotic surgeons (defined as having performed over 200 robot assisted radical prostatectomies independently) and a surgical non-technical skills expert. A nested design was used whereby all participant videos were assessed by two raters. The primary outcome measures of the study were technical and non-technical skill. Technical skill was assessed using Global Evaluative Assessment of Robotic Skills (GEARS) whilst the Non-Technical Skills for Surgeons (NOTSS) behavioural rating system was used to rate NTS. The secondary outcome measure was the quality of MI. This was evaluated using the Movement Imagery Questionnaire (MIQ), a validated subjective assessment of MI quality, modified for robotic surgery¹⁶⁻¹⁸.

Statistical Analysis

Power calculations were based on a prior studies of MI training using global rating scale (GRS) to assess performance^{17,19-21}. To detect significance at $p = 0.05$, a 15% difference in the mean GRS following training with a power of 80% assuming a 10% drop out rate, required a minimum sample size of 53 was required.

Data was found to have a Gaussian distribution. Between group differences were analysed using independent samples T-tests. Interrater agreement was measured using

Krippendorff's alpha. Strength of association between baseline variables and mean GEARS scores was measured using the Pearson correlation coefficient. Analysis of covariance (ANCOVA) was used to control for the effects of potential covariate effects. Statistical analyses were conducted using SPSS v23 (Chicago, Illinois). Graphs were created using Prism version 7.0 (GraphPad Software, Inc. La Jolla, California, USA).

Results

90 participants responded to the initial recruitment invitation and 77 completed the basic training programme. Of these 64 returned for randomisation and completed the full study. Videos of two participants in the control arm were corrupted and could not be assessed. Per protocol analysis comprised data from 33 participants randomised to MI training and 29 to standard training (Supplementary Figure 1). The two groups were well matched in terms of basic demographics, and clinical experience. Following initial VR training, baseline MIS ability measured using the DVSS was found to be equivalent between groups (Table 1). Interrater reliability between raters of technical and non-technical skills assessment was high, Krippendorff's $\alpha = 0.85$.

Technical Skill Assessment

Comparison of technical performance using the total GEARS showed MI training to be significantly superior to standard training alone (Figure 2). MI training resulted in a mean ($\pm$ standard deviation) GEARS score of 13.1 ± 3.25 compared to 11.4 ± 2.97 following standard training ($p = 0.03$). Detailed analysis of the constituent subscales is shown in Table 2.

Significant improvements in performance were seen in 3 of the 6 domains assessed by GEARS; Bimanual Dexterity, Efficiency and Robotic Control. Analysis of potential covariates showed weak correlations between mean GEARS and both baseline technical ability ($r = 0.27$, $p = 0.051$) and clinical experience ($r = 0.24$, $p = 0.06$). MI training effects remained the most significant factor in determining technical performance after controlling for the effects of these potential confounders ($p = 0.016$, $F(1,50) = 6.21$).

Non-Technical Skills Assessment

NTS performance did not differ significantly between MI and standard training participants (mean total NOTSS score $\pm$ SD 25.8 ± 7.34 vs 26.4 ± 9.13 respectively, $p = 0.77$). No demonstrable differences were found either in overall NOTSS scores or individual subcategory scores between the two groups (Supplementary Table 1).

MI Assessment

54 of the participants completed the post assessment MIQ. Overall MI training resulted in a significantly higher movement imagery score than standard training ($p = 0.04$). Greater motor imaging ability was demonstrated across the majority of the MIQ nodal points but these did not reach significance (Table 3).

Discussion

This single-blinded randomised controlled trial has demonstrated the effectiveness of MI in supporting MIS simulation training. Structured MI training using the PETTLEP model led to a significantly greater improvement in technical performance over standard training with 1.7

mean difference in GEARS score. In contrast, there was no benefit of MI training on NTS performance. Furthermore, MI training was confirmed as being effective in improving the imaging ability of participants.

GEARS is the most widely validated trial for global skills assessment in robot surgery during live surgery and in the simulation setting²²⁻²⁴. It provides a reliable global assessment of robotic technical skill rather and was therefore chosen over procedure specific tools such as the Robotic Anastomosis Competency Evaluation (RACE) which focus on the specific skills required for anastomosis²⁵. Improvements in GEARS scores were predominantly found in domains representing tasks associated more with the cognitive challenges of robotic surgery than purely technical skill. With MI training, participants scored higher for depth perception, bimanual dexterity and efficiency. Variations in the effectiveness of MI training according to the type of task have been seen previously. Cognitive tasks exhibit greater training effects than motor or strength exercises^{17,26}. In contrast MI training did not translate into NTS improvements, agreeing with the findings of Louridas et al²⁰. Given the MI training provided in this study focussed on the technical performance of a UVA anastomosis, this negative finding may be as a result of a lack of far transfer of learning in MI²⁷. However previously specific MI training in NTS has also not be found to be beneficial which raises the question whether the more abstract nature of NTS prevents effective mental visualisation and training²⁸.

This trial was designed to provide the best available evidence to evaluate the utility of standardised MI training for complex MIS surgical procedures. Whilst it was performed in a simulated operating room environment, distributed simulation such as the Igloo used in this

study has been shown to effectively recreate the operating room environment²⁹. It offers high fidelity, immersive simulation enabling the effective assessment of the participants technical and non-technical skills. Likewise, the single point of assessment limits the conclusions that can be drawn as to the degree of benefit derived from MI training. In spite of this, MI imagery training resulted in a global improvement in technical performance. Further investigation is necessary to investigate the effect of MI on the complete learning curve and in other training environments.

Different forms of imagery elicit different patterns of neural activation and result in different training effects⁶. For effective motor skill learning, kinaesthetic imagery in which the feeling of performing the task is mental rehearsed in contrast to visual imagery whereby only a visual representation of the movement is produced³⁰. As a result, the content of the MI script is critically important in establishing the correct form of imagery. MIQ results from this study show that the PETTLEP model can be used for effective and reproducible MI training in surgery. A key question in MI training that remains unanswered is the influence of participant experience on MI outcomes. No comparative studies in surgical training have been undertaken but trials with experienced participants have greater rates of success compared to those involving novices³¹. It has been argued that experts are better able to undertake kinaesthetic imagery due to more established motor representations of the action and consequently derive more benefit from MI^{32,33}. In contrast, there is evidence to suggest that novices demonstrate a greater capacity for improvement through MI training particularly in cognitive tasks²⁶.

A key focus of this study was the provision of structured motor imagery training. For the first time, a MI script written in accordance with evidence base principles of PETTLEP was effectively applied to surgical training. MIQ results support the use of this model of MI training for inexperienced trainees. Focussing on promoting first person, kinaesthetic imagery rather than 3rd person or visual based imagery enables more effective motor skill learning^{34,35}. Functional MR imaging has shown that MI not only leads to the extended neural activations involved in the complex movements required for MIS which require considerable cognitive and motor control but that MI training results in more efficient and focused neural activation^{34,36}.

In medicine there is a growing recognition that the attainment of expert proficiency requires persistent active learning. Simulation training is increasingly being used to enable the repeated and focussed training necessary to gaining technical and non-technical skill. The results of this study provide evidence for the integration of MI training alongside existing simulation training programmes for MIS. In comparison to standard training alone, the addition of MI training was beneficial to the process of technical skill training. Structured MI training can be successfully used in inexperienced surgeons and offers flexible training than can easily be applied to other areas of medicine. Teaching surgeons in how to effectively utilise MI within their current training programmes will promote further gains in attainment and efficiency.

Conclusion

This study provides evidence for the utility of structured MI to augment simulation training for novice surgeons in minimally invasive surgery. Use of the PETTLEP-based MI script led to better imagery of the procedure and consequently improved technical performance.

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Figure Legends

Figure 1: Trial protocol

Figure 2: Technical Performance of MI Training and Control Groups

Supplementary Figure 1: Consort Flow Diagram

Table Legends

Table 1: Demographics, Clinical Experience and Baseline Skill

Table 2: Comparative analysis of GEARS subscale score for the MI and Control Groups

Table 3: Summary Results from MIQ

Supplementary Table 1: Comparative analysis of NOTSS subscale score for the MI and Control Groups