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Effect of mental rotation skills training on ultrasound-guided regional anaesthesia task performance by novice operators: a rater-blinded, randomised, controlled study

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Abstract

Background: The effect of mental rotation training on ultrasound-guided regional anaesthesia (UGRA) skill acquisition is currently unknown. In this study we aimed to examine whether mental rotation skill training can improve UGRA task performance by novice operators.

Methods: We enrolled 94 volunteers with no prior experience of UGRA in this randomised controlled study. After a baseline mental rotation test, their performance in a standardised UGRA needling task was independently assessed by two raters using the composite error score (CES) and global rating scale (GRS). Volunteers with low baseline mental rotation ability were randomised to a mental rotation training group or a no training group, and the UGRA needling task was repeated to determine the impact of the training intervention on task performance. The study primary outcome measure was UGRA needling task CES measured before and after the training intervention.

Results: Multivariate analyses controlling for age, gender, and previous performance showed that participants exposed to the training intervention made significantly fewer errors (CES B=-0.66 [standard error, SE=0.17]; P<0.001; 95% confidence interval [CI], -0.92 to -0.26) and displayed improved overall performance (GRS B=6.15 [SE=2.99], P=0.048, 95% CI=0.06 to 12.13) when undertaking the UGRA needling task.

Conclusions: A simple training intervention, based on the manipulation and rotation of three-dimensional models, results in improved technical performance of a UGRA needling task in operators with low baseline mental rotation skills.

Keywords: medical training; mental rotation skill; nerve block; skill acquisition; task performance and analysis; ultrasonography; ultrasound-guided regional anaesthesia

Editor's key points

- The effect of mental rotation training on ultrasound-guided regional anaesthesia skill acquisition in 94 volunteers was assessed in a randomised, controlled study.
- A simple mental rotation skills training intervention improved technical performance of an ultrasound-guided regional anaesthesia needling task in novice operators with low mental rotation ability.
- Mental rotation test screening coupled with our training intervention could enhance expertise acquisition in ultrasound-guided regional anaesthesia.

The traditional approach to procedural skill acquisition, typified by the mantra '*see one, do one, teach one*', is no longer valid

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in the modern anaesthesia learning environment.[1] The primacy of patient safety in clinical encounters, together with reduced patient exposure during postgraduate training programmes,[2] has led to the exploration of bench-model trainers, manikins, visuohaptic simulators, and virtual reality simulators as tools to facilitate procedural expertise.[3] However, these tools are themselves associated with barriers to learning, such as equity of access, cost, and the need for faculty and trainer development. It would, therefore, be advantageous to pre-train or supplement procedural skill acquisition with inexpensive, self-directed educational interventions to improve procedural skill.[4]

In this regard, mental rotation (defined as the visuospatial ability to manipulate mental representations of three-dimensional objects) is a prime candidate for intervention development.[5] This is based on evidence that mental rotation ability is predictive of performance in endoscopy,[6] ultrasound-guided regional anaesthesia (UGRA),[7] and radiological interpretation.[8] Furthermore, mental rotation skills training is associated with improved performance of mental rotation tasks,[9] which in turn have translated to improved novice performance of laparoscopic tasks.[10] Previous studies of mental rotation skills training interventions have either used direct practice with mental rotation problems, visualisation, or manual manipulation on a computer screen using a joystick.[11–13] However, none has involved actual physical manipulation of an object, which is a key feature of procedural skill performance in medicine.

Thus, we have developed a novel educational intervention to build on the ideas of manipulation and visualisation in order to determine whether mental rotation skills training is associated with improved performance of an ultrasound-guided needle task. Building on previous work,[7,10] the primary research question of this study is whether mental rotation skills training translates to improved technical performance of a UGRA needle task in learners with low baseline mental rotation ability. The study null hypothesis (H_0) was that there is no difference in technical performance of a UGRA needling task by learners who have had mental rotation skills training compared with learners who have not received such training. The study primary outcome measure was UGRA needle task composite error score (CES). Secondary outcome measures were UGRA needle task global rating scale (GRS) and pre- and post-training mental rotation test (MRT) scores.

Methods

Study design

This single-centre, rater-blinded, volunteer, prospective randomised controlled study was prospectively approved by the Faculty of Medicine & Health Sciences Research Ethics Committee, University of Nottingham (Reference: C15092015SoM) and conducted at the University Department of Anaesthesia, Queen's Medical Centre, Nottingham University Hospitals NHS Trust, Nottingham, UK.

Study population

Undergraduate students from medicine or science, technology, engineering, and mathematics courses (STEM) at the University of Nottingham were invited to participate in this study using poster and social media advertising. Students who expressed a wish to participate were provided with a participant information leaflet and an invitation to attend the study. Students with previous experience of UGRA or mental rotation testing or training were excluded. Previous studies have demonstrated that medical students' performance of a UGRA task is comparable with that of doctors in-training and therefore representative of the performance of novice anaesthetists who have not performed UGRA tasks before.[14,15]

Study procedures

After obtaining written informed consent on the day of study, a questionnaire was administered seeking baseline participant characteristics including age and gender. All participants, blinded to the study hypothesis, completed a standardised MRT,[16] consisting of 24 problems with each requiring participants to mentally rotate four stimulus figures about their axes and match two of these figures to a single target figure (Fig. 1). Based on our previous work establishing the mental rotation ability of the study population,[7] we identified participants with high mental rotation ability as scoring >14 out of 24 on the initial MRT (Group MRT-High), and those with low baseline mental rotation ability as those scoring 14 or less (Group MRT-Low). Group MRT-Low went on to receive the study training intervention because we felt that this group was likely to benefit the most from the training intervention.

All participants watched an informational video[17] mapped to specific learning objectives, which demonstrated expert performance of a standardised UGRA task[15] in an animal-tissue bench model.[18] Participants were instructed to replicate this UGRA task using a 38 mm high-frequency linear array ultrasound transducer (Fujifilm Sonosite Limited, Bedford, UK) and a 50 mm Stimuplex® Ultra 360 needle (B. Braun AG, Melsungen, Germany) on the same bench model (ultrasound task 1). Participants were independently assessed in this task by two anaesthetists experienced in UGRA who were blinded to participant MRT scores. Each rater completed an additive CES[7,14,15] and GRS[7,15,19] assessment of participant performance (see Online Supplementary materials). The raters had

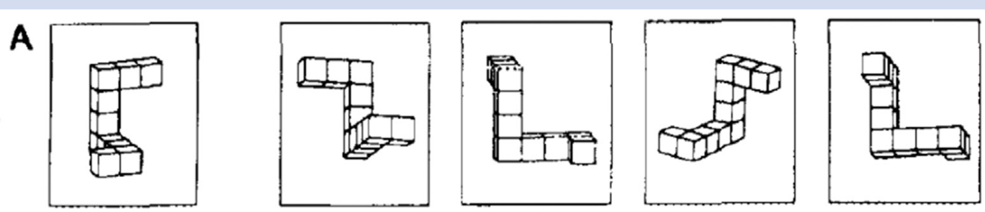

Fig 1. Example item from mental rotation test. A target figure on the left and four stimulus figures on the right. The participant must find the two stimulus figures on the right which match the single target figure on the left. Reproduced with permission.[16]

undergone specific training and practice in the use of these assessment tools. The CES was calculated by adding the total number of errors, number of needle passes, and image quality score for each participant. A lower CES is associated with better accuracy and task performance. The GRS consisted of seven items each rated on a 5-point scale. The GRS assesses more general behaviours and the overall performance of the participant. Upon completion of ultrasound task 1, MRT-High participants ceased study involvement. MRT-Low participants continued involvement and were randomised into two parallel groups by six-block design using an online random number generator[20]: those who would receive the mental rotation training intervention (group MRT-Low [Training]) and those who would not (group MRT-Low [No Training]).

Intervention

The training intervention lasted 30 min and required participants to view in a mirror a two-dimensional image of a three-dimensional model constructed from Lego Duplo® bricks (LEGO System A/S, Billund, Denmark), and then to recreate the model with only the mirror image to view (Fig. 2). After they had completed building the model, they were able to compare it directly with the original model. If they failed the task, they were asked to return to the mirror and make good any errors. This process was repeated until the participant completed the model correctly. Participants in the training group were given 30 min to repeat this process for up to 10 models of increasing difficulty. Participants randomised to no training were taken to a separate room and asked to wait for 30 min. Participants in both groups then repeated the same MRT. After this, both raters re-assessed participant performance in the same standardised UGRA needling task (ultrasound task 2). Both raters remained blind to group allocation. Study participation ceased once ultrasound task 2 was complete.

Statistical analysis

We calculated the intra-class correlation (ICC) for each assessment to determine their inter-observer reliability. We assessed the internal consistency of each assessment by calculating Cronbach's alpha coefficient (α) and the associated standard error of the mean (SEM). We initially modelled count data for CES using Poisson models, and if these were over-dispersed we used negative binomial modelling. Ordinary least squares (OLS) models were used to analyse GRS data. To explore the effects of the training intervention on task performance, we regressed post-intervention scores for CES and GRS to a training dummy (0, not trained; 1, trained) for participants in Group MRT-Low. In these models, we controlled for age and gender as both affect mental rotation[21] and therefore may influence outcomes. We also controlled for participants baseline CES and GRS scores. This is to control for any learning effects that may occur, independent of training effects, as a result of completing the assessment twice and levels of previous performance.

Fig 2. Room set-up for performance of mental rotation training.

Sample size calculation

The effect of mental rotation training on CES and GRS relating to UGRA needling tasks is unknown. Therefore, our sample size calculation was based on the effect size of mental rotation training on laparoscopic skill acquision.[10] We felt that laparoscopic skill acquisition was a reasonable surrogate psychomotor task on which to base our calculation, as it requires coordinated interaction between hand, eye, screen, laparoscope, and patient, which is similar to UGRA. As such, we calculated that 20 participants per group would be required to achieve a power of 0.90 with a P-value of 0.05 to detect a minimum primary outcome (CES) effect size of r=0.3–0.5. A study flow diagram is shown in Fig. 3.

Results

Rater agreement

CES and GRS were psychometrically reliable across both study periods (pre-training ultrasound task 1 and post-training ultrasound task 2): CES α (SEM)=0.732–0.769 (0.92–1.59) and GRS α (SEM)=0.917–0.945 (0.82–1.01), respectively. These outcome measures also showed a high degree of inter-rater agreement across the study periods. The pre- and post-training ICC between the two raters were 0.96 (r=0.94) and 0.95 (r=0.95) for CES and 0.73 (r=0.59) and 0.88 (r=0.81) for GRS. As such, we summed the rater scores for each participant, for both assessments. There was only one rater for two participants in group MRT-Low (No Training); these data were not analysed for CES or GRS (Fig. 3).

Baseline characteristics

The characteristics of the study population at baseline are summarised in Table 1. There was no difference in baseline CES between the groups for ultrasound task 1 (Kruskall–Wallis; $\chi^2_{(2)}$=4.93, P=0.085). GRS for ultrasound task 1 was significantly lower for group MRT-Low (Training) compared with both group MRT-High and group MRT-Low (No Training) (one-way analysis of variance [ANOVA]; $F_{(2,60)}$=4.21, P=0.019). Baseline mental rotation score for group MRT-High was significantly higher than both group MRT-Low (Training) and MRT-Low (No training) (one-way ANOVA; $F_{(2,62)}$=60.31, P<0.001).

Effect of training intervention on CES and GRS

The impact of the training intervention on CES and GRS are presented in Table 1. Summary data for the effect of the training intervention on CES and GRS are presented in Fig. 4a and b, respectively. The count data for CES were over-dispersed (Pearson's dispersion=8.22); therefore, these data were modelled using a negative binomial regression (Table 2).

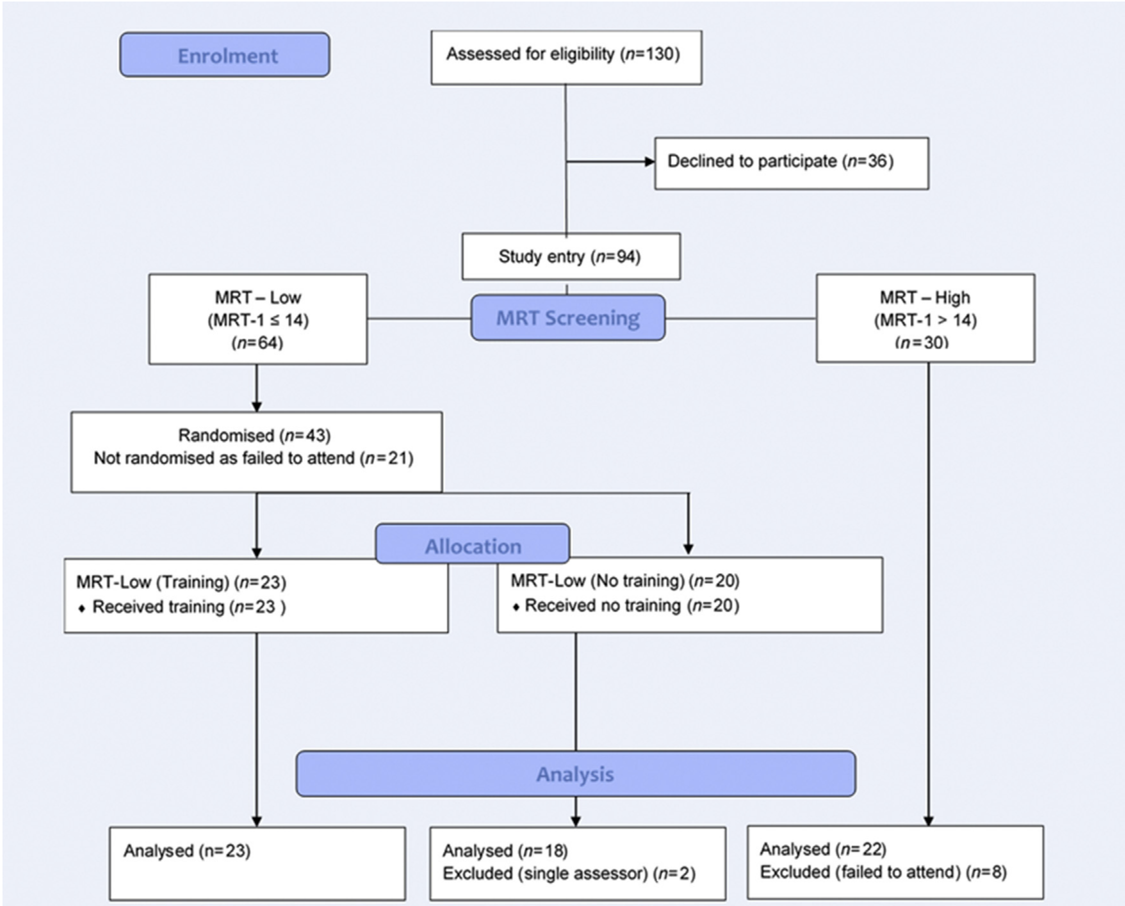

Fig 3. Study flow diagram.

Participants exposed to the training intervention made significantly fewer errors compared with those who did not receive the training intervention, even after controlling for their pre-training CES. Those who were younger also made significantly fewer errors. Likewise, OLS regression (Table 2) showed that participants exposed to the training intervention scored significantly higher GRS than those who did not receive the training intervention, even when their pre-training GRS was controlled. The effect sizes of training on both CES (Cohen's d=0.91, r=0.41) and GRS (Cohen's d=0.92, r=0.42) were large.

Effect of training intervention on MRT score

Data for the effect of the training intervention on MRT score are presented in Fig. 4c. We calculated the change in MRT score (MRT score post-training subtracted from MRT score pre-training) for participants. Although MRT scores improved in both groups, there was no significant effect of training on the change in MRT (Mann–Whitney U=206.50, P=0.989).

Discussion

We showed that a simple training intervention, based on manipulation and rotation of three-dimensional Lego Duplo® brick models, led to reduced errors measured by CES (study primary outcome measure) during performance of a UGRA task in operators with low mental rotation skills. As such, the training intervention translated to improved technical performance of a UGRA needle task. Also, the training intervention improved GRS scores (study secondary outcome measure).

Context of results

Mental rotation scores can be improved by engaging in complex and intensive and repetitive spatial tasks involving two or more interventions.[10] In their study of mental rotation relating to laparoscopic skills, Stransky and colleagues[10] showed marginal improvements in mental rotation scores, similar to those seen in our study, after a single mental rotation skills training session. Our finding that MRT scores did not increase significantly after one training session is unsurprising and may indicate that mental rotation skill change may not be the primary mechanism for the observed effects of training. Other complementary psychological processes known to enhance task performance may have been affected (e.g. self-efficacy – the belief that a person has the ability or skill to perform the task).[22] This warrants exploration in future studies.

Table 1 Group participant characteristics and the effect of training intervention on composite error score and global rating scale and mental rotation test score. Data presented as *n* (%) or mean (SD). MRT, mental rotation test; SD, standard deviation.

	MRT-High (*n*=22)		MRT-Low (Training) (*n*=23)		MRT-Low (No Training) (*n*=18)	
Age (yr)	20.3 (1.6)		21.7 (3.6)		24.0 (6.5)	
Male gender	16 (72.7%)		5 (21.7%)		4 (20.0%)	
	Pre-training	Post-training	Pre-training	Post-training	Pre-training	Post-training
Composite error score	17.1 (10.9)	–	22.6 (9.5)	14.1 (4.1)	17.9 (13.6)	25.0 (24.5)
Global rating scale	34.0 (13.2)	–	24.9 (9.9)	35.4 (10.3)	33.3 (11.6)	35.7 (11.7)
Mental rotation test score	17.6 (2.4)	–	9.0 (3.2)	13.0 (4.2)	9.7 (2.2)	13.8 (4.7)

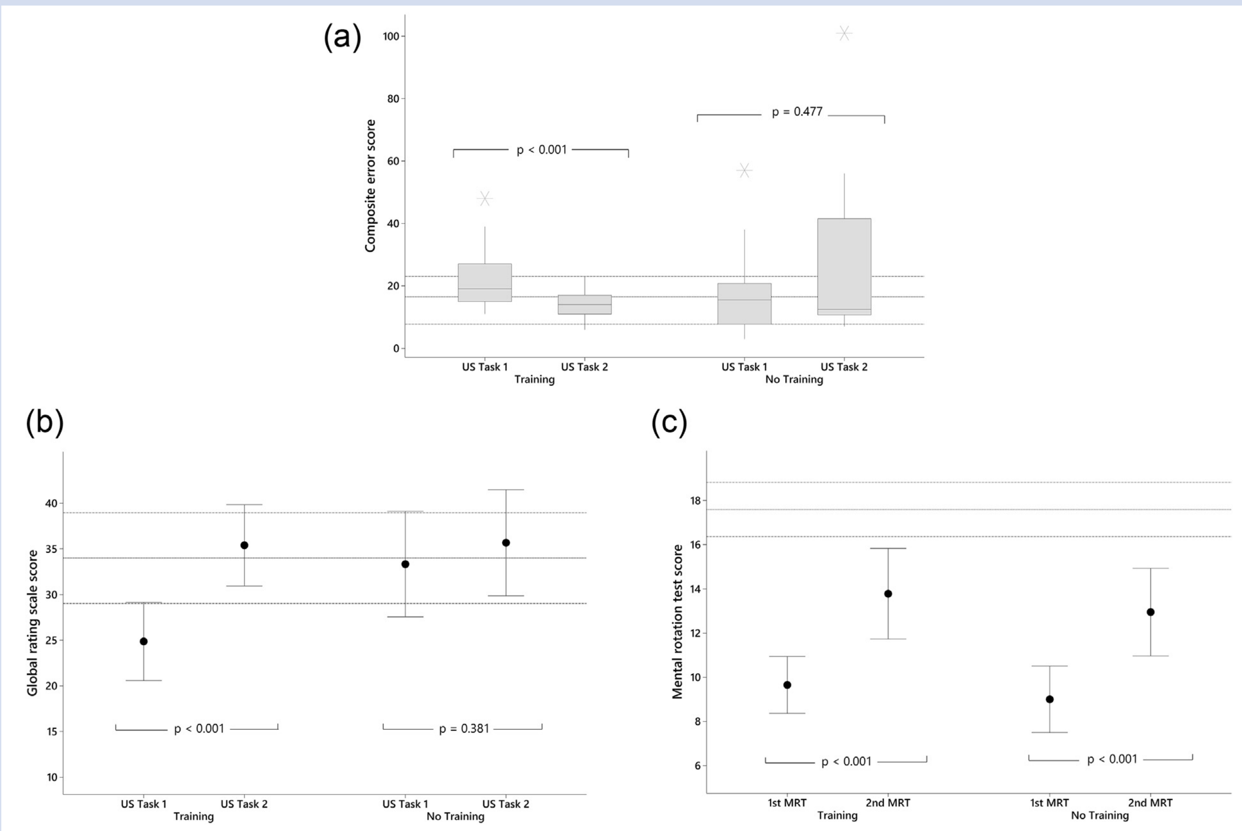

Fig 4. Ultrasound task performance and mental rotation test score before the training intervention (ultrasound task 1) and after training (ultrasound task 2) in participants exposed to training (MRT-Low [Training]; *n*=23), and in those not exposed to it (MRT-Low [No Training]; *n*=18). (a) Boxplot of CES (median [IQR]) and whiskers (1.5×IQR) with outliers (*). (b and c) Mean (95% CI) GRS and MRT score. Horizontal dashed lines represent the median (IQR) or mean (95% CI) CES, GRS or MRT score for participants in group MRT-High (*n*=22). P values are displayed for within-subject intervention effects. A lower CES score is associated with fewer errors during task performance. A higher GRS is associated with improved task performance. A higher mental rotation test score is associated with better mental rotation performance. MRT, mental rotation test; CES, composite error score; GRS, global rating scale; IQR, inter-quartile range; CI, confidence interval.

Impact of findings

The training intervention described in this study could be generalisable to any procedural task that requires the manipulation and rotation of a medical device. Theoretically, any training that enhances spatial awareness should be beneficial to any task that requires such skills. Therefore, in order to improve procedural task performance, learners could train on a very different task to that performed clinically. In this case, training with Lego Duplo® brick models is generalisable to the much more complex spatial array of the ultrasound needling task.

Table 2 Negative binomial regression model for the effect of the training intervention on composite error score (CES) and ordinary least squares regression model for the effect of the training intervention on global rating scale. Coefficients are unstandardised (95% CI). n=41 consisting of group MRT-Low (Training; n=23) and group MRT-Low (No training; n=18). SE, standard error; CI, confidence interval; MRT, mental rotation test.

	Coefficient (SE)	P	95% CI
Composite error score			
Training Intervention (0=no training, 1=training)	-0.66 (0.17)	<0.001	-0.92 to -0.26
Mental rotation test score before training (MRT-1)	-0.05 (0.04)	0.259	-0.13 to 0.03
CES before training	0.01 (0.007)	0.161	-0.004 to 0.02
Age	-0.03 (0.02)	0.033	-0.06 to -0.002
Gender (0=female, 1=male)	0.121 (0.23)	0.590	-0.32 to 0.57
Mental rotation test score after training (MRT-2)	-0.008 (0.03)	0.785	-0.07 to 0.05
Constant	4.33 (0.54)	0.000	3.28 to 5.38
α	0.21 (0.05)		0.12 to 0.34
R^2	0.07		
Global rating scale (GRS)			
Training Intervention (0=no training, 1=trained)	6.15 (2.99)	0.048	0.06 −12.13
Mental rotation test score before training (MRT-1)	-0.32 (0.69)	0.648	-1.74 to 1.09
GRS before training	0.63 (0.15)	0.000	0.33 to 0.93
Age	0.39 (0.26)	0.144	-0.14 to 0.92
Sex (0=female, 1=male)	-5.35 (3.54)	0.140	-12.55 to 1.84
Mental rotation test score after training (MRT-2)	0.43 (0.48)	0.380	-0.55 to 1.40
Constant	3.45 (7.87)	0.664	-12.54 to 19.44
R^2	0.50		

We have confirmed previous findings that MRT scores are predictive of CES and GRS scores.[7] We had previously been unable to suggest an MRT score below which training interventions would provide the most benefit to the learner in terms of procedural skill acquisition. Based on our findings, novice learners with an MRT score <15 benefit from our simple training intervention. However, we are unable to state whether individuals with higher MRT scores would benefit and to what extent.

Study limitations

We studied UGRA task performance by STEM undergraduates on an inanimate animal-tissue bench model in a non-clinical environment. Thus, it is unclear whether the performance gains we have measured would arise clinically in the hands of an anaesthetist in-training. Although unanticipated missing data for two participants allocated to the non-training group presents a small risk of type 1 error, this is not a significant concern as the effect sizes are large, and *post hoc* calculation shows a power of 0.79 for CES and -0.80 for GRS.

Conclusions

A simple, low-resource mental rotation skills training intervention can improve technical performance measured by CES and GRS of a UGRA needling task in novice operators with low mental rotation ability. Based on our findings, MRT screening of novice UGRA operators coupled with our training intervention could enhance expertise acquisition in UGRA for this group of learners. In the absence of screening, a more pragmatic approach might be to provide the training intervention to all UGRA novices because it requires minimal resources. Future research should examine whether our novel training intervention translates to enhanced performance of other skills used in anaesthetic practice such as flexible videobronchoscopy[23] and whether such findings can be translated, and sustained, in clinical practice.

Declarations of interest

DWH and NMB have administered departmental grants from B. Braun Medical AG to support clinical research. B. Braun Medical had no role in the design, execution, analysis or write-up of this study. JGH is the associate editor-in-chief of the *British Journal of Anaesthesia* and accepts fees for advising in civil, criminal, and coronial medicolegal cases. SS, RK, EF and RAM have no interests to declare.

Authors' contributions

Study design/planning: JGH, NMB, EF, RAM
Study conduct: DWH, RK, SS, RAM
All authors participated in writing and revising the manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bja.2020.04.090.

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