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Refreshing medical students' intravenous-cannulation skills: a blinded observer three-arm randomised comparison of mental imagery, part-task trainer simulation and written instructions

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ABSTRACT

Introduction Intravenous cannulation is a core competence in medicine, but is considered challenging to learn. This study investigates the effectiveness of three educational strategies used to refresh the intravenous cannulation skills of first-year medical students: mental imagery, part-task trainer simulation and written instructions.

Materials and methods In this single-centre randomised controlled trial, first-year medical students were assigned to one of three different refresher tutorials on intravenous cannulation. Six months after their compulsory 4 hour instructor-led intravenous-cannulation course, each student was randomised to a 6 min self-learning tutorial: a mental imagery audioguide session, hands-on intravenous cannulation on a part-task trainer or reading written instructions.

Immediately after the refresher tutorials, trained evaluators who were blinded to the randomised group assessed the students' performance. Each evaluator completed a 15-item standardised checklist in an Objective Structured Clinical Examination (OSCE) station for intravenous cannulation. We performed a descriptive analysis of the data and a one-way analysis of variance. Additionally, we investigated the influence of previous intravenous cannulation experience on the total OSCE score.

Results and discussion On analysing the 309 students' results, we did not find differences in the total rating of the performance (in percentage) between the three groups at the OSCE station (mental imagery group: 72.0%±17.9%; part-task trainer group: 74.4%±15.6%; written instructions group: 69.9%±16.6%, p=0.158). Multiple linear regression showed a small but statistically significant effect of students' previous intravenous cannulation experience on OSCE performance. With the same outcome, written instructions and mental imagery had a better return on effort, compared with resource-intensive hands-on training with part-task trainers.

Conclusion A single, short refresher seems to have a limited effect on intravenous-cannulation skills in first-year medical students. Less resource-intensive interventions, such as written instructions or mental imagery, are effective compared with hands-on part-task trainer simulation for refreshing this simple but important skill.

Trial registration number AEARCTR-0008043.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ Randomised adequately powered three-armed study design.
- ⇒ Use of mental imagery as a form of non-physical simulation.
- ⇒ Single-centre study in first-year medical students, therefore, results might not be generalisable.

INTRODUCTION

Patient participation in healthcare education remains an essential part of student training, but practising on real patients raises ethical issues, particularly if it involves training of invasive procedures.[1] Additionally, technological, economic and regulatory changes, not only in anaesthesiology but in most medical specialities, have led to a considerable reduction in bedside teaching opportunities for medical students.[2] This has led to simulation as an educational approach in current competency-based curricula.

Simulation designed for the acquisition of technical skills aims to reproduce reality with varying levels of physical fidelity. It offers an alternative approach to learning complex psychomotor and procedural skills, with the opportunity to rehearse them in near-life scenarios in a safe, protected, learner-centred, simulated clinical setting.[3]

One of the most frequently performed basic medical skills is intravenous cannulation.[4 5] Although this is an invasive skill and challenging to learn,[6] proficiency may prevent serious complications, such as infiltration, phlebitis, pain or severe systemic infection.[7–9] Traditionally, medical students were taught this skill through didactic instruction, followed by practice on either an arm part-task trainer or on students or patients.[4] However, these traditional intravenous-cannulation teaching methods are time-consuming, expensive and the opportunities for practising the technique are often unavailable.[10]

Recently, mental imagery—a form of non-physical simulation—has been introduced in medical education to teach and maintain skills.[11] Mental imagery is a structured process of mental rehearsal before a procedure,[12] and involves visualisation, prompted by the use of the senses and recall, leading to a re-experiencing the initial stimulus at the moment of first exposure. Mental imagery is widely used and recognised as effective in the realms of stroke rehabilitation, cognitive behavioural therapy, high-performance athletics and professional musicianship,[13–15] as a means to improve performance and reduce procedural error.

Several studies have investigated mental imagery in postgraduate settings,[16–19] but only one small study used it during intravenous cannulation performed by undergraduate students.[20] Mental imagery, due to its simplicity, could facilitate learning and skill maintenance in undergraduate medical student curricula, and release educators from the physical and temporal presence of bedside teaching. Furthermore, it may provide an economic alternative to the more costly low-fidelity simulator model design.

This randomised study compared the effectiveness of three non-instructor-led teaching methods—mental imagery, low-fidelity part-task trainer simulation and traditional written instructions—in refreshing a simple medical psychomotor procedural skill (intravenous cannulation) in first-year medical students.

METHODS

Participants and setting

All first-year medical students from the Medical Faculty of the University of Bern were invited to participate in the study. Students who refused to participate or were late for the Objective Structured Clinical Examination (OSCE) were excluded from the study. Refusal to participate did not affect their formative assessment or any grades arising thereof. All procedures from this investigation met the criteria of the 1964 Declaration of Helsinki and its amendments.[21] All researchers complied with the Data Protection Act[22] and the Swiss Law for Human Research.[23 24] This article adheres to the Consolidated Standards of Reporting Trials checklist.

The compulsory intravenous-cannulation course for first-year medical students at the University of Bern took place between late October and mid-December 2020 in the Bernese Interdisciplinary Skills and Simulation Centre. All students attended two small-group teaching sessions, each 2 hours long. The first session consisted of practice on an arm part-task trainer (EZ-7010, Erler Zimmer, Germany), and the second consisted of practice on simulated patients using an armband part-task trainer (R16614, Erler Zimmer, Germany), and on fellow medical students. A short course and its learning outcomes are displayed in table 1. The physical practice of the students was individually supervised by trained course tutors (all medical students in their final years of university) and overseen by experienced intensive care unit nurses.

Study design and interventions

We carried out a three-armed, assessor-blinded randomised trial (figure 1, flow chart). Six months after the first-year medical students underwent standard intravenous-cannulation training, they received an invitation explaining the goals of the study. Students were unaware of the specific skill or interventions of the study. Participants were asked to be on-site 30 min before a formative OSCE at the end of the first semester. On arrival, all participants completed a questionnaire to ascertain previous experience in intravenous cannulation, including attempts and demographics. After that, they were randomly assigned to one of three groups:

1. Group A: A 6 min mental imagery audioguided tutorial: Students listened to a mental imagery audio recording of an intravenous cannulation procedure, in a dimmed room and using earphones, while lying down on a lounger. No intravenous-cannulation materials were available.
2. Group B: A 6 min part-task trainer simulation tutorial: Students practised on a low-fidelity arm part-task trainer like the one they had in their previous course sessions (EZ-7010, Erler Zimmer, Germany). All materials used during the course sessions were available.
3. Group C: A 6 min tutorial with written instructions: Students revised the intravenous-cannulation steps individually, with the aid of a laminated instruction sheet.

Randomisation procedure

Students were allocated according to a 1:1:1 ratio to either the mental imagery group (n=105), the part-task trainer simulation group (n=105) or the written instructions group (n=106) using block randomisation with a fixed block size of 9. The randomisation sequence was created through randomisation software (www.sealedenvelope.com). The allocation sequence was concealed from the students and the evaluators, as well as from those involved in the statistical testing of the data.

Construction of the mental imagery audio script and the audio guide

RG, RB and CCG (an anaesthesia-certified nurse), considered specialists in intravenous cannulation, recorded a 45 min online mini-focus group,[25] facilitated by JB-E, to develop the mental imagery script. They were asked to describe visual and kinesthetic clues at each step of intravenous cannulation and common pitfalls during intravenous cannulation. The focus group recordings were transcribed and analysed using iterative content analysis

Table 1 Interprofessional intravenous-cannulation course outline and learning outcomes

Flipped classroom (student effort: 1 hour): 1. Preparation with E-Book - The e-book contains the basics that are required for both parts (basics of hygienic hand disinfection, basics of venipuncture), combined with work assignments and study questions) ► Module 1: Hand disinfection: Theory and short MCQ questionnaire ► Module 2: Taking blood samples: where and how, pitfalls, tutorial video, 8 min (in German). (https://www.nanoo.tv/link/v/fuzPhkqU, CC BY-NC-ND 4.0) ► Module 3: Intravenous cannulation: where and how, contraindications, pitfalls, complications, with tutorial video, 9 min (in German). (https://www.nanoo.tv/link/v/vnfRZMCs, CC BY-NC-ND 4.0)	
Course part 1 (Duration: 2 hours)	Course part 2 (Duration: 2 hours)
Theory 15 min intravenous- cannulation 15 min taking blood samples	Practice (2 hours) practice on model /practice on peers (voluntary)
Practice (90 min) Practice on model Practice on peers	
Available materials: Positioning aids for the patient's arm, gauze, alcohol swab, tourniquet, intravenous cannulas (18G, 20G), cannula dressing, disposal container, gloves	
Tutor concurrent feedback	Tutor concurrent feedback
Further practice: Room and practice model provided for further practice	
Knowledge	List the indications, risks and complications of the procedure; Name the materials and preparatory steps necessary for the intervention; Explain the criteria for choosing a suitable location for the procedure; List and justify the hygiene guidelines for the procedure; Explain important basic rules of the technique; Describe common principles underlying the different institutional standards;
Skills	Adequately inform normal adults in a standard situation about the indications, risks and procedure of the intervention; Prepare for the procedure (including providing the necessary materials, labelling tubes, checking the patient's identity, positioning, etc); Determine a puncture site for the procedure; Correctly perform the intervention, following the hygiene guidelines; Assess own abilities and determine when to call for help in case of problems; Constructively exchange ideas with other participants.
Attitudes	Assess the patient's fears and apprehensions about the procedure; Assess how the procedure is experienced from the patient's point of view; Support a climate of constructive cooperation between different professions; Reflect on one's function and tasks within an interprofessional team

to create the mental practice script. This script was subsequently audiorecorded and piloted among all authors and one additional colleague, proficient in hypnosis (FL, in the Acknowledgements section).

The guided mental imagery tutorial that was presented to the randomised group of students consisted of a 6 min audio guide with instructions for intravenous cannulation embedded in relaxing breathing exercises. Students were advised to imagine the technique as if they were performing intravenous cannulation themselves. Instructions were delivered at a slow pace (circa 100 spoken words/minute) and emphasised the correct technique.

The intravenous-cannulation OSCE assessment

The intravenous-cannulation skill was assessed 6 months after the initial training, during the first year formative OSCE at the University of Bern's Faculty of Medicine. This OSCE comprised three different stations assessing (1) intravenous-cannulation skills, (2) basic life support and (3) history taking. Each station lasted 8 min and the students' distribution to one of these stations occurred randomly. As this was a formative OSCE, students were aware of the skills being tested. Students were not able to communicate with each other during the examination.

In the 8 min intravenous-cannulation OSCE station, a simulated patient used an intravenous-puncture model strapped to their arm (R16614, Erler Zimmer, Germany) for puncture. The assessment was conducted by trained evaluators using a 15-item OSCE checklist in use at the University of Bern, which was tested for internal consistency. This setting and the structure of the checklist ensured that procedural flow, psychomotor skills (a total of two cannulation attempts were allowed), as well

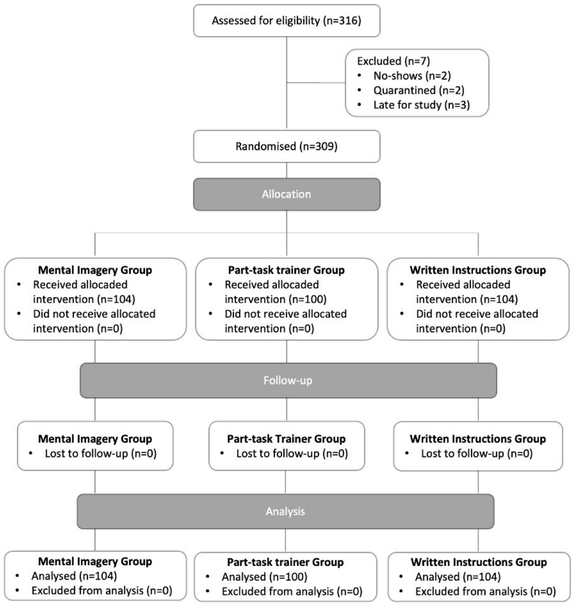

Figure 1 Study flow chart.

as communicative aspects of the students' intravenous-cannulation performance could be assessed. All six evaluators were all experienced anaesthesia study nurses (see the Acknowledgements section) blinded to the students' group rehearsal assignment. All evaluators took part in a 30 min training session in the use of the rating scales and on completing the checklist. We considered the assessor effect to be negligible, since the overall performance of the three intervention groups was of interest, and candidates were randomly assigned to the three intervention groups.

Statistical analysis

Our primary outcome was the total score in percentage of the 15-item OSCE assessment for the intravenous-cannulation station. Additionally, the influence of previous intravenous cannulation experience on the total OSCE score was examined.

We performed a multiarm sample size calculation, aiming to demonstrate superiority of one of the educational strategies using an a priori power analysis with G*Power V.3.1. (26) Assuming an effect size (f=0.305) for a one-way analysis of variance (ANOVA) with three groups (α=0.01, 1−β=0.80), we found that the minimum required sample size for three groups was n=156 (52 per group). To compensate for 20% of non-responders, we aimed for 180 participants.

Statistical analysis was performed using SPSS V.27 (IBM). Categorical variables were described as absolute (n) and relative frequencies (%). Continuous variables were described using mean and SD. In order to control for possible confounding effects, interdependence of categorical variables with the three groups was tested using a χ^{22} test for contingency tables, and one-way ANOVA were used to test possible differences in the means of continuous variables between the three groups. For reliability testing of the checklist, internal consistency was evaluated with Chronbach's alpha.

A one-way ANOVA was conducted to compare the means of the total OSCE score in percentages of the three groups. The number of previous attempts at intravenous cannulation using part-task trainer simulation and the number of previous attempts at human intravenous cannulation served as predictors in a multiple linear regression with the total score in percentage as dependent variable. To examine the influence of prior experience with intravenous cannulation on performance, multiple linear regression was performed. The OSCE total score in percentage served as the dependent variable, while the two variables 'number of previous attempts at live intravenous cannulation' and 'number of previous attempts at intravenous cannulation using part-task trainer simulation' served as predictors. A stepwise method was used to determine the influence of the predictors one by one. An a priori probability of less than 0.05 was considered to be statistically significant.

Patient and public involvement

No patient involved.

RESULTS

Three hundred and sixteen students were invited to participate in the study. After excluding students who did not attend the OSCE or arrived late, 309 students were enrolled (participation rate of 97.8%). The participants' characteristics did not differ between the three groups (table 2). Overall, the items in the checklist showed an internal consistency of α=0.691, which is considered acceptable.[26]

Figure 2 shows a histogram of the students' overall performance (in percentage). There was no statistically significant difference between groups in the one-way ANOVA on our primary outcome total score in percentage of the OSCE assessment: mental imagery scored 72.0%±17.9%, part-task trainer simulation scored 74.4%±15.6% and written instructions scored 69.9%±16.6% $\left(F_{2,\,306} = 1.856,\ p = 0.158\right)$.

Stepwise multiple linear regression showed that intravenous-cannulation experience during part-task trainer simulation had a significant but small effect on the OSCE performance $\left(R^2 = 0.015,\ p = 0.031\right)$. We performed diagnostics on the regression model and verified that the checked assumptions were met. Students reported the number of previous attempts at cannulation as 6.5±8.5, without differences between the three groups (p=0.224). The human intravenous-cannulation experience showed no additional contribution to the OSCE performance $\left(Beta\ In = 0.072,\ t = 1.245,\ p = 0.214\right)$ and the simple correlation between these two variables is not significant $\left(r = 0.091,\ p = 0.113\right)$.

DISCUSSION

Our study shows that the performance of intravenous cannulation, assessed at an objective, structured skills

Table 2 Participants' characteristics

	Total (n=309)	Mental imagery (n=104)	Part-Task trainer (n=100)	Written instructions (n=105)	P value
Age, years (mean±SD)	21.3±1.9	21.1±1.9	21.2±1.7	21.6±2.2	0.500
Female sex, n (%)	189 (61.2)	64 (62.1)	69 (68.3)	56 (53.3)	0.085*
German mother tongue, n (%)	282 (91.0)	92 (89.3)	92 (91.1)	98 (92.5)	0.545*
No previous experience in healthcare, n (%)	301 (97.4)	101 (98.1)	96 (95.0)	104 (98.1)	0.563*
Individual sum of previous attempts at intravenous-cannulation in part-task trainer simulation, n (mean±SD)	3.0±1.9	3.1±1.9	2.9±1.9	3.0±1.9	0.693
Individual sum of previous attempts at human intravenous cannulation, n (mean±SD)	3.2±8.0	2.3±1.9	3.8±9.0	3.6±10.4	0.372

*χ2.

exam, did not differ after three different refresher tutorials (mental imagery, part-task trainer simulation and written instructions).

Our results differ from those of several randomised controlled trials on mental imagery in postgraduate education. Studies that involved surgical trainees' 'warming up' with mental imagery[16 17] described significantly improved performance with a warm-up before laparoscopic surgery. However, when considering the effects of warm-up on the different aspects of psychomotor performance, Paschold *et al*[27] found that these were affected by the nature of the warm-up, the type of surgery and the expertise of the surgeon. This suggests that optimal warm-up strategies are task-specific and procedure-specific and may change with varying expertise,[19] consequently yielding conflicting results.

Use of mental imagery in anaesthesia studies also showed conflicting findings. A 2016 study reported improved fiberoptic intubation skills after a 5 min mental imagery warm-up on a virtual reality bronchoscopy simulator when compared with a control group.[28] In contrast, anaesthetists practicing mental imagery did not manage crises better during simulation.[29] The reasons proposed by the study authors for the negative results were the nature of the task, the limited 'dose' effect (20 min vs the 30–90 min reported in successful interventions), and the number reduced of cues in the mental script.

More recently, comparable effects of mental imagery and low-fidelity simulation were described in anaesthesiology residents learning to administer epidural anaesthesia.[30] Our study results align with the latter, as all three 'warm-up' methods resulted in similar student performance in an objective, structured skills exam.

It is of more interest to compare our results with the study by Sanders *et al*.[20] They also did not find a significant difference in medical students' venipuncture performance with or without mental imagery. But they did find a significant difference in student performance between part-task trainer simulation and a control. Those authors assessed their students immediately after their training session, while our assessment occurred following the refresher, at 6 months after the initial training. Thus, the two studies might not be readily comparable.

The number of previous intravenous-cannulation part-task trainer simulation attempts had a small but significant effect on the OSCE performance. Students in our study performed, on average, more than six attempts at intravenous cannulation in the 6 months before their first-year OSCE. This number is considered as the number of attempts necessary to achieve a plateau level of the learning curve for this procedure.[6 31] Additionally, our results may simply reflect that the part-task trainer was effective in teaching the canulation skills. That might partly explain why the three different refresher strategies resulted in comparable results. As our study participants reached the critical mass of medical students who had already acquired the necessary skills inintravenous-cannulation before the study took place, an improvement might be hard to detect, and our students probably did

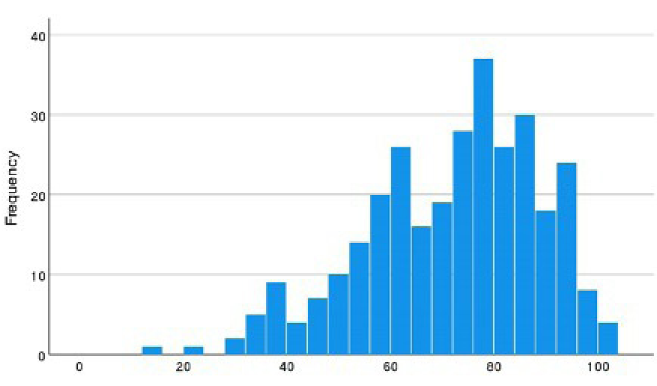

Figure 2 Histogram of OSCE total performance (in percentage). OSCE, Objective Structured Clinical Examination.

not necessarily profit from these refreshers. That might explain the puzzling finding in our study that the written instructions group was just as effective as the other two interventions, and questions the need for such a refresher shortly before an OSCE at all.

Although we did not formally assess the cost of our three interventions, it seems obvious that written instructions and mental imagery are far more economical than the purchase and maintenance of a low-fidelity part-task arm, including the instructor's salary and time spent teaching). This cost-effectiveness argument needs to be further investigated in a properly performed cost-effectiveness analysis.

Our study has several other limitations. It assessed the effectiveness of different refresher techniques for intravenous-cannulation skills, but its successful transfer to clinical practice could not be ascertained. We assume that our results can be applied to related techniques which require venipuncture, like taking blood samples, but despite our robust design, our results may not be generalisable to other cohorts. Additionally, due to the post-test methodology of the study, no conclusion can be taken regarding the student's performance of intravenous cannulation before the intervention. Finally, it is possible that the 6 min intervention was simply too short to detect a difference in the teaching strategy and its effect on the performance of the skill.

In summary, these results suggest that all interventions were successful at refreshing intravenous-cannulation procedures in undergraduate medical students.

CONCLUSIONS

Medical schools currently seek to offer more efficient, cost-effective and innovative methods to enhance learning. Our study comparing three 6 min refresher strategies, indicates that part-task trainer simulation is not superior to mental imagery and written instructions for refreshing intravenous-cannulation skills in first-year medical students. Both mental imagery and written instructions have a far better effort-return ratio than resource-intensive hands-on training with part-task trainer simulation. Mental imagery and written instructions cannot completely replace physical clinical skills training in intravenous cannulation, but may effectively supplement it, similar to other fields involving complex psychomotor skill learning.

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Contributors JB-E wrote the outline and performed the data collection, demographic statistical analysis and interpretation of the data. RB and MB contributed to the outline, performed the data collection, and helped in data interpretation and the writing process. DS performed the statistical analysis and helped interpret the data. RG initiated the study, supervised the creation and adaptation of the outline, and critically reviewed the manuscript. CB supervised the creation and adaptation of the outline, performed data collection and helped in data interpretation and the writing process. All of the authors read and approved the final version of the manuscript. JB-E is the guarantor.

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Competing interests RG is the Director of Training and Education of the European Resuscitation Council, the Task Force Chair Education, Implementation, and Team of ILCOR, and a member of the Direction of the MME Program of the University of Bern. The remaining authors report no declarations of interest.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval All participants provided written informed consent to participate, and the Bern Cantonal Ethics Committee (Req-2021-00096, 26.01.2021) waived the need for ethical approval as no patients were involved.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available in a public, open access repository. Data are available on reasonable request. Datasets containing student information are available after anonymisation from the corresponding author on reasonable request. The remaining data are available in a public, open access repository information at https://doi.org/10.1257/rct.8043-1.0.

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