

**The effect of expertise on diagnosis accuracy, non-technical skills and
thought processes during simulated high-fidelity anaesthetist scenarios**

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RUNNING HEAD: Decision-making in anaesthetists

ABSTRACT

We examined the thought processes and performance of anaesthetists during simulated environments. Verbal reports of thinking and the Anaesthetists Non-Technical Skills (ANTS) were recorded to examine cognitive processes, non-technical behaviours and diagnosis accuracy during fully immersive, high-fidelity medical scenarios. Skilled (n = 6) and less skilled (n = 9) anaesthetists were instructed to respond to medical scenarios experienced in theatre. Skilled participants demonstrated higher diagnosis accuracy and ANTS scores compared to less skilled participants. Furthermore, skilled participants engaged in deeper thinking and verbalised more evaluation, prediction and deep planning statements. The ability to employ an effective cognitive processing strategy, more efficient non-technical behaviours and superior diagnosis is associated with superior performance in skilled participants.

WHAT THIS PAPER ADDS

- High-fidelity medical simulation is an ideal tool to examine differences in knowledge and performance of anaesthetists because scenarios can be standardised and replicated.
- Diagnosis accuracy, ANTS and concurrent verbal reports can be used as performance measures during simulation to compare anaesthetists of different levels of expertise.
- Concurrent verbal reports are a technique that offers important inferences about thought processes.
- Skilled anaesthetists are characterised by their ability to make more evaluation statements about the current situation, predict future events and outcomes, and forward plan actions.
- Simulation training may present an ideal context for developing higher levels of expertise and the associated cognitive and technical skills

INTRODUCTION

Anaesthesia in the modern operating environment requires a range of attributes and skills to ensure patient care and safety. Furthermore, each patient poses a unique set of challenges and constraints that make it difficult to directly compare performance levels between and across individuals. For example, some patients present with complex and difficult problems, compared to more straightforward diagnosis and treatment pathways. The challenge for educators and researchers is to capture and examine technical skills, non-technical skills, thought processes and performance using standardised (i.e., valid, objective and reliable), representative tasks.(1) Recent developments in high-fidelity medical simulators provide more realistic, fully immersive environments for examining cognitive (decision-making), behavioural (technical and non-technical skills) and performance (diagnosis accuracy) differences between participants.(2-4) Furthermore, simulators allow control and replication of scenarios while maintaining ecological validity. In this study, the expert performance approach was used to develop anaesthetist, high-fidelity medical scenarios to examine differences in performance, cognition and behaviour.(5)

The expert performance approach has been used in sport, music, education and medicine to examine expertise.(6-11) First, experts are observed *in situ* so that the essential skills and competencies underpinning expertise can be captured. Based on these observations, simulated representative laboratory or field-based task(s) are created so that skill based differences in performance can be reliably and objectively measured under more controlled conditions. Second, to promote understanding of expertise, process-tracing measures such as think-aloud verbal reports and /or eye-movement recordings to examine perceptual and cognitive mechanisms that support

1 performance. Finally, development of expert skills and mechanisms are traced to
2 identify how and when they were acquired, while considering the practical
3 implications for guiding practice and instruction.

4 In medicine, high-fidelity simulators are used as a valid and reliable tool for
5 assessment of competency and training because scenarios can be standardised,
6 repeated and require the participant to interact with the patient to provide care.(3,12-
7 14) Performance is assessed using diagnosis accuracy, response time, rating scales,
8 non-technical behaviours (e.g., Anaesthesia Non-Technical Skill, ANTS) and
9 technical skills with little focus on examining the thought processes and decision-
10 making (i.e., cognition) simultaneously.(3,4,15,16)

11 Cognitions are recorded and analysed using think-aloud verbal reports and
12 protocol analysis, providing a quantifiable measure that represents the thought
13 processes underpinning participant actions.(17) Fox et al. (18) conducted a meta-
14 analysis of 94 studies and found no difference in task performance when comparing
15 think-aloud verbal reports to a matched condition without verbal reports. Therefore,
16 they suggested that the cognitive processes mediating task performance do not alter,
17 allowing researchers to make inferences about performance based on verbalised
18 cognitions (see Ericsson and Simon (17) for a more detailed theoretical rationale).
19 Furthermore, Whyte et al. (19) reported that concurrent think-aloud verbal reports
20 provide a more complete representations of nurse's cognitions when admitting a
21 patient suffering from an acute exacerbation of congestive heart failure to a simulated
22 intensive care unit.

23 Think-aloud protocols have been used by researchers to examine cognitions and
24 make inferences on performance in law enforcement, sport and medicine (20-22). For

1 example, Cormier et al. (2) examined cognitions and performance of low and high
2 performing student nurses during high-fidelity medical simulations. They measured
3 verbal statements coded as ‘observations’ (e.g., context, patient and monitor) or
4 ‘actions’ (e.g., based on orders or patient condition) and physiological data of the
5 patient’s respiratory status. High performing student nurses were better at observing
6 relevant cues suggesting patient deterioration and forward plan responses that
7 positively altered the patient’s physiological trajectory. In comparison, low
8 performing student nurses verbalised more irrelevant cues and failed to perform
9 action directly related to the patient’s condition.

10 In the current study, we use high-fidelity scenarios so that the cognitive processes
11 associated with expertise can be fully understood. Diagnosis accuracy and non-
12 technical behaviours of skilled and less skilled anaesthetists were examined while
13 they provided think-aloud concurrent verbal reports during the scenarios. It was
14 hypothesised that skilled anaesthetists would demonstrate superior diagnosis accuracy
15 compared to less skilled anaesthetists. Second, the Anaesthetist Non-Technical Skills
16 (ANTS) was used as a valid and reliable tool for assessing non-technical
17 behaviours.(23) It was hypothesised that skilled participants would score a higher
18 global rating compared to less skilled anaesthetists. Finally, skilled anaesthetists’
19 superior performance would be supported by more evaluation, prediction and deep
20 planning statements when compared to less skilled counterparts.

21 **METHOD**

22 **Participants**

23 Nine less skilled (mean age = 29.4 years, SD = 2.3) and 6 skilled (mean age =
24 37.2, SD = 4.5) anaesthetists were recruited. Less skilled participants were pre-FRCA

1 trainees in their first 2 years of anaesthesia with a mean of 4.2 years (SD = 1.1)
2 experience as a doctor. Skilled participants were at consultant or experience staff
3 grade level with a mean of 13.3 years (SD = 3.1) experience. The study was approved
4 by the lead institute's Research Ethics Committee and carried out under its ethical
5 guidelines.

6 **Simulated Test Environment (STE)**

7 A simulated task environment (STE) was developed. The STE consisted of a high-
8 fidelity adult METI human patient simulator (CAE Healthcare, Florida, USA) and
9 fully equipped operating theatre, that included an anaesthetic machine, monitoring
10 familiar to the anaesthetists, realistic functioning medical gases, intravenous pumps
11 (IV), a real crash cart with defibrillator, medication and medical supplies. The STE
12 allowed real-life scenarios to be dynamically presented to participants with the onset
13 and choice of patient response under full experimenter control. METI human patient
14 simulator responded to treatment in a realistic manner exhibiting applicable changes
15 in cardiovascular, pulmonary, physiological, pharmacological, metabolic,
16 genitourinary and neurological states.

17 **Scenarios**

18 Three tightly scripted and highly standardised simulator scenarios were
19 developed. Each scenario lasted approximately 15 minutes, involved an emergency
20 developing during the course of an operation and required the anaesthetist to intervene
21 and administer treatment.

22 In scenario one (anaphylaxis), the patient is a 68-year-old man, non-smoker, no
23 medication, allergies or airway problems, drinks alcohol occasionally, no previous

1 history of general anaesthetic (GA) and suffers from active reflux so requires an
2 endotracheal tube (ETT). In addition, he has requested a GA, as he ‘didn’t like the
3 sound of a spinal’. A confederate Surgeon, Scrub nurse and Operating Department
4 Practitioner (ODP) are on hand to provide assistance when requested. The participant
5 enters the room and is guided over to the anaesthetic machine where they receive a
6 handover from a colleague who is being relieved for lunch. “The patient has just been
7 anaesthetised for a left knee replacement under GA. Skin is prepared for surgery and
8 the surgeon and scrub nurse are ready. Patient-controlled analgesia (PCA) is planned
9 for post-operative pain relief”. The Surgeon requests 1.5g of Cefuroxime prior to
10 tourniquet inflation. Administration is rapidly followed by cardiovascular system
11 (CVS) collapse and bronchospasm. The patient will require 100% oxygen,
12 termination of the suspected agent, administration of adrenaline and referral to the
13 intensive treatment unit (ITU).

14 In the second scenario (Malignant Hyperpyrexia), the patient is a 69-year-old
15 man, non-smoker, no medication, allergies or airway problems, drinks alcohol
16 occasionally, no previous history of GA or anaesthetic problems and has active reflux
17 so was intubated for the procedure. A confederate Surgeon and Scrub nurse are busy
18 operating with an ODP on hand to provide assistance if requested. The participant
19 receives a handover in the theatre from a colleague who is being relieved for a
20 meeting. “The patient was anaesthetised 20 minutes ago for removal of metalwork
21 from the left ankle. PCA is planned for post-operative pain relief”. Malignant
22 hyperpyrexia gradually starts once the participant is settled. The participant will be
23 required to stop the volatile, hyperventilate the patient to reduce end tidal CO₂, give
24 patient 100% oxygen, change breathing circuit/anaesthetic machine, administer
25 Dantrolene and actively cool patient.

1 In the third scenario (Supraventricular Tachycardia post induction), the patient is a
2 59-year-old man, who is fit and well, no previous GA problems, no allergies or
3 airway problems, ex-smoker and drinks alcohol occasionally. The patient takes an oral
4 dose of Lansporazola (30mg) and has well-controlled reflux. A confederate ODP is on
5 hand to provide assistance when requested. The participant receives drugs ready
6 drawn up in a kidney bowl and a handover, before they enter the theatre. “The patient
7 is due to have an elective laparoscopic cholecystectomy for gallstones. PCA for post-
8 operative pain relief is planned if an open procedure is required”. The participant will
9 induce anaesthesia. Once intubated, the patient develops narrow complex tachycardia
10 and his cardiovascular function becomes compromised. The participant will be
11 required to give DC shock cardio version to the unstable patient.

12 **Procedure**

13 Participants completed a biographical (i.e., age, number of years training and
14 details of training activity) information sheet and provided informed consent.
15 Participants were instructed in a think-aloud verbal reporting method by Ericsson and
16 Simon (17) that has been used previously in sport, law enforcement and medicine
17 .(19,20,24) Participants practised giving verbal reports while solving non-clinical
18 alphanumerical problems until the criterion for providing concurrent verbal reports
19 were met. For example, if the researcher asked, “What the third letter after A is?”, you
20 might respond “D, I counted three letters forward” but your actual thoughts might
21 have been “A, B, C, D”. The former is an example of a summary, whereas the latter
22 are your actual thoughts. During the training, participants accuracy on alphanumerical
23 tasks were not recorded, as the objective was to provide feedback so that they could
24 understand the difference between verbalising a summary of their thoughts compared

1 to think-aloud statements about their thoughts. Following their verbal report training,
2 participants were familiarised with the STE using a structured protocol and then
3 completed a simple practice trial while providing a concurrent verbal report. The
4 practice trail required them to check the equipment and conduct an objective
5 assessment of the patient. Concurrent verbal reports were selected as they provide a
6 more complete cognitive representation of performance within the STE, compared to
7 retrospective reports.(19) Following their practice trial, participants were given an
8 opportunity to ask further questions prior to the experimental scenarios and further
9 feedback were provided.

10 Participants were fitted with a lapel microphone and radio transmitter and in
11 conjunction with 2-angle video cameras, visual and audio observations were captured.
12 The orders of scenarios presented to each participant were counterbalanced across the
13 participants to reduce order and learning effects. Participants interacted with the
14 patient and confederate staff involved. In order to standardise the scenarios,
15 confederates were equipped with a two-way radio transceiver so that the
16 experimenters could control the information provided to the participant. If the
17 participant remained silent for an extended period of time, the confederate ODP was
18 instructed to remind them to concurrently verbalise their thoughts using the prompt
19 “think-aloud”. Each scenario terminated when the 15 minutes elapsed.

20 **Data analysis**

21 **Diagnosis data**

22 A diagnosis response was marked as correct and awarded a score of ‘1’ if the
23 participants verbalised the correct scenario diagnosis. If participants failed to provide
24 or provided an incorrect diagnosis response, a score of ‘0’ was recorded for that

1 scenario. Diagnosis accuracy was defined as the total number of correct responses
2 (i.e., frequency score) divided by the total number of scenarios ($N = 3$) and multiplied
3 by 100 to create a percentage score. An independent samples *t*-test was conducted to
4 compare diagnosis accuracy between skilled and less skilled participants.

5 Anaesthetists' Non-Technical Skills (ANTS) data

6 The Anaesthetists' Non-Technical Skills (ANTS) system was used to assess
7 behavioural markers during the medical scenarios. The ANTS system's validity and
8 reliability has previously been established when assessing non-technical
9 behaviours.(23) A consultant anaesthetist trained and qualified in the use of the ANTS
10 system reviewed videotapes of the participants' non-technical skills during the
11 scenarios. ANTS describes the main observable non-technical skills associated with
12 good anaesthetic practice.

13 The ANTS system comprises of four skill categories and beneath these are fifteen
14 skill elements (see Table 1). Each element has a definition and examples of good and
15 poor behaviours. The reviewer rated the 15 skill elements based on a four-point scale
16 (i.e., 4 = good; 3 = acceptable, 2 = marginal; 1- poor; 0 – not observed). The rating
17 score for each element was added together to calculate the participant's global
18 performance score for each scenario. A mean ANTS score was calculated based on
19 the participant's global scores from the three scenarios. A higher score on the ANTS
20 represented better non-technical behaviours during the scenarios. An independent
21 samples *t*-test was conducted to compare differences in ANTS scores between skilled
22 and less skilled participants.

23

1 Table 1: ANTS four skill categories and fifteen skill elements

Category	Elements
Task Management	Planning and preparing Prioritising Providing and maintaining standards Identifying and utilising resources
Team Working	Co-ordinating activities with team members Exchanging information Using authority and assertiveness Assessing capabilities Supporting others
Situation Awareness	Gathering information Recognising and understanding Anticipating
Decision Making	Identifying options Balancing risks and selecting options Re-evaluating

2

3 Verbal Report data

4 Scenario videos were captured and analysed using Studiocode, version 3.5
5 (Sportstec Ltd, Australia), an analytical tool that allows the researcher to mark and
6 code segments of video and audio into categories. Following the procedures outlined
7 in Ericsson and Simon (17) verbal reports were initially segmented using natural
8 speech and syntactical markers.

9 Verbal statements were coded based on categories developed and previously used
10 by McRobert et al. (22) to monitor thought processes of participants during
11 emergency medicine simulated scenarios. To ensure logical validity and remove the
12 individual bias of the researcher a panel of anaesthetists (N = 3), medical educators (N

1 = 2) and researchers (N = 2) reviewed the sample of statements from the simulated
 2 scenarios that had been assigned to the coding categories. (25,26) The panel provided
 3 written feedback and agreed that the categories and operational definitions were
 4 appropriate for analysing concurrent verbal statements.

5 Table 2: Verbal report statement categories and definitions

Category	Definition
Monitor	Statements representing information that was present or previously present in the current environment.
Evaluation	Some form of positive or negative assessment of a prior action, event or statement.
Prediction	Statements about what could, would and should occur next in the environment.
Deep Planning	Statements are about future actions and options in a future situation.

6

7 The primary experimenter analysed all participant data and assigned each
 8 concurrent verbal statement to the monitor, evaluation, prediction or deep planning
 9 category (Table 2). Fifty verbal statements were selected at random to establish
 10 objectivity and reliability using the inter- and intra-observer percentage agreement
 11 formulas.(27) The primary experimenter coded the 50 statements on four separate
 12 occasions (i.e., prior to coding, after 6, 12 and 18 participants) with an intra-observer
 13 agreement range from 95% to 98%. Inter-observer agreement was assessed prior to
 14 coding (92%) the statements, and after 12 participants (93%) by an independent
 15 experimenter.

Two-way analysis of variance (ANOVA) was conducted with group (less skilled/skilled) as the between participant factor and verbal statement type (monitor/evaluation/prediction/deep planning) as the within-participant factors. Partial eta squared (η^2) values are provided as a measure of effect size. When making comparisons between two means, Cohen's d measures are reported. Posthoc Bonferroni corrected pairwise comparisons are reported as follow-ups where appropriate.

RESULTS

Diagnosis data

An independent samples t -test was conducted to compare differences in diagnosis accuracy between skilled and less skilled participants. Levene's test for homogeneity of variance was violated ($p < .05$); therefore the test statistic for equal variance not assumed was reported. There was a significant difference in diagnosis accuracy scores for less skilled and skilled participants, $t_{13} = -2.688$, $p = .02$. Skilled participants ($M = 94\%$, $SD = 14$) diagnosis accuracy scores were significantly higher than less skilled participants ($M = 63\%$, $SD = 31$).

Anaesthetists' Non-Technical Skills (ANTS) data

The independent samples t -test was conducted to compare ANTS score differences between skilled and less skilled participants. There was a significant difference in ANTS scores between skilled and less skilled participants, $t_{13} = -3.215$, $p = .02$. Skilled participants ($M = 22$, $SD = 4$) ANTS scores were significantly higher than less skilled participants ($M = 13$, $SD = 6$).

Verbal Report data

ANOVA showed a significant Group \times Verbal Statement Type interaction ($F_{3,39} = 20.33$, $p < .001$, $\eta p^2 = .52$). As predicted, less skilled participants made more monitoring statements ($d = 1.19$) compared to their skilled counterparts (see Figure 1). In contrast, skilled participants made more evaluation ($d = 2.2$) and deep planning ($d = 1.76$) statements compared to less skilled participants. Skilled participants did make more prediction statements compared to less skilled participants, however this was only a medium effect size ($d = 0.52$). The Cohen's d effect size score quantifies the magnitude of the difference between the skilled and less skilled groups. There is a larger difference between the skilled and less skilled groups for evaluation and deep planning, compared to prediction. It is worth noting that skilled and less skilled standard deviations for the monitor, evaluation and deep planning are relative to the mean. In contrast, the standard deviation for prediction is large relative to the mean score. The large variance could be due to the low number of prediction statements compared to the other categories.

Significant main effects for group ($F_{3,39} = 10.83$, $p < .05$, $\eta p^2 = .45$) and verbal statement type ($F_{3,39} = 67.12$, $p < .001$, $\eta p^2 = .83$) were observed. Skilled participants ($M = 12$, $SD = 8$) made more verbal statements, compared to less skilled participants ($M = 10$, $SD = 5$). Pairwise comparisons demonstrated that all participants made more evaluation and deep planning than monitor and prediction statements ($p < .05$). Second, a higher number of monitor statements were coded compared to prediction statements ($p < .05$).

1 INSERT FIGURE 1 HERE.

2

3 **DISCUSSION**

4 We examined the cognitive processes, diagnosis accuracy and non-technical
5 behaviours in anaesthetists during simulated medical scenarios. Skilled and less
6 skilled participants were required to diagnose the patient's condition and engage in
7 effective treatment during fully immersive, high-fidelity, medical scenarios. Verbal
8 reports were collected concurrently during the simulation as an index of thought
9 processes. In addition, the Anaesthetists' Non-Technical Skills (ANTS) were assessed
10 retrospectively to rate the effectiveness of the participant's behaviours. It was
11 hypothesised that skilled participants would demonstrate superior diagnosis accuracy
12 and a higher global rating score on the ANTS, compared to less skilled participants.
13 Moreover, skilled participants' would be characterised by a higher total number of
14 statements, specifically more evaluation, prediction and deep planning statements.

15 As predicted, skilled participants outperformed less skilled participants on
16 diagnosis accuracy. Findings support differences in skilled and less skilled
17 performance reported previously by researchers in medicine and other domains such
18 as aviation, law enforcement and sport using dynamically evolving simulated
19 tasks.(3,20,28,29) In addition, skilled participants had higher ANTS scores suggesting
20 that as a group their task management, team working, situation awareness and
21 decision-making skills when managing the scenarios are better.

22 Think-aloud concurrent verbal reports and protocol analysis was conducted to
23 examine if there were any differences between less skilled and skilled anaesthetists

1 thought processes. Skilled participants made more verbal statements in total,
2 compared to less skilled participants. In addition, skilled participants' made more
3 evaluation, prediction and deep planning and fewer monitoring statements, compared
4 to less skilled participants'. Moreover, these differences are larger for evaluation and
5 deep planning statements between the groups compared to prediction. Skilled
6 participants appear to be characterised by their ability to make more evaluation
7 statements about the current situation, predict future events and outcomes, and
8 forward plan actions. In addition, the verbal report data in this study support previous
9 work demonstrating skilled participants thought processing during dynamically
10 evolving tasks in sport and law enforcement.(20,21)

11 To provide further context, monitoring statements often refer to an observation of
12 oxygen saturation, core temperature or actions such as administering oxygen,
13 adrenaline and reducing end tidal CO₂ that have taken place during the scenario.
14 Monitoring statements are just observations, whereas evaluation statements involve an
15 assessment of the observed information or action. Evaluation statements would
16 involve the observation of oxygen saturation or core temperature followed by an
17 assessment of the value compared to the norm value expected. Prediction statements
18 are assumptions or forecasts about what might or should happen next based on
19 evaluation of observed information (e.g., change in patient vitals) or most recent
20 action (e.g., patient intervention). Deep planning statements provide information on
21 future actions that the participant will to undertake in order to manage potential future
22 situations that might occur. This action plan profile is often based on a primary
23 diagnosis and differential diagnosis for so that they can plan a series of future actions
24 to deal with anaphylaxis (e.g., provide 100% oxygen, terminate suspected agent,
25 administer adrenalin and referral to eth intensive care unit), malignant hyperpyrexia

1 (e.g., stop the volatile, hyperventilate the patient to reduce end tidal CO₂, give 100%
2 oxygen, change breathing circuit/anaesthetic machine, administer Dantrolene and
3 actively cool) and supraventricular tachycardia (e.g., give DC shock cardio version).

4 The current findings have implications for those in medicine that have used the
5 recent developments in high-fidelity simulation for the training and assessment of
6 competency.(2-4) Our data provides construct validity for the use of high-fidelity
7 medical simulation as a vehicle for assessment of skill competency. Moreover, such
8 simulations may provide an ideal vehicle for training because it presents a safe
9 environment, where scenarios can be replicated so that the examiner is confident that
10 each individual can experience and be evaluated on the same factors. In sum, it
11 presents a valid, reliable and objective environment for testing and training expertise
12 in medicine. Furthermore, simulators can conduct scenarios that occur on a rare basis.
13 This ability to present novel or rare scenarios will allow participants to develop
14 domain-specific knowledge that can facilitate diagnosis and patient care if the
15 scenario was to occur during their normal working hours. However, it is worth noting
16 that the size, expense and staff support required to manage a simulation environment
17 are often a barrier to widespread use, particular outside of large hospitals and major
18 cities. Finally, the recording of verbal reports provides an opportunity to design
19 educational programmes that specifically target clinical reasoning based on an expert-
20 model approach (30,31). Immersive simulation techniques often involve uninterrupted
21 real-time cases, followed by an individual or group debriefing. Introducing think-
22 aloud verbal reporting during a scenario, allows participants to retrospectively reflect
23 on their thought processes in conjunction with the educator to identify knowledge
24 gaps or reframe clinical reasoning (i.e., cognitive processing).

1 In conclusion, we examined the cognitive processes and non-technical skills used
2 by skilled and less skilled anaesthetists during high-fidelity medical scenarios. Skilled
3 participants demonstrated superior diagnosis accuracy, better non-technical
4 behaviours and verbalised more evaluation, prediction and deep planning statements,
5 and, compared to less skilled participants. In comparison to less skilled participants,
6 skilled participants were characterised by the ability to evaluate the current situation
7 and engage in prediction of future events and to forward plan actions rather than
8 thinking about immediately available information. Our findings suggest that
9 simulations present a valid method for quantifying and exploring expertise in medical
10 contexts, whereas at a practical level the significant potential to use such
11 environments for training health care practitioners is highlighted.

12 **Contributions**

13 MAW, DR and APM were responsible for the conception and design of the
14 current study. Second, DR, SM, JG and APM collected the data and engaged in many
15 hours of subsequent analysis and interpretation of this data. Third, ARM was
16 responsible for the initial draft of the article, revisions and approval of the final
17 version submitted. Finally, MAW, DR and SM were responsible for critically revising
18 drafts for intellectual content and quality of submission.

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21 **Competing interests**

22 There are no competing interests.

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Figure legend

Figure 1: Number of verbal statement types (with *SD* bars) for skilled and less skilled participants.

