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The Effectiveness of the Constraint-Led Approach in Developing Medical Procedural Skills

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Abstract

Background: *The constraint-led approach is new for teaching clinicians motor skills most utilised in sports, physical education, and rehabilitation medicine domains. Thus far, it has not been used to teach medical procedural tasks. This mixed methods study explores how the constraint-led approach can teach a complex medical procedural task, ultrasound-guided peripheral venous access. It compares its effectiveness in teaching novice performers to an established blended training course employing a traditional cognitive approach.*

Methods: *Medical students were taught using the constraint-led approach, and practising clinicians (control group) completed a blended course utilising a cognitive approach. Teaching effectiveness was assessed by measuring the time required to perform the task on a manikin simulator.*

Results: *The median time to complete the task for the medical student group was 623 seconds (IQR 470-783) compared to the control group time of 724 seconds (IQR 624- 1002), with a p-value of 0.73. The self-rated medical student group's confidence in performing the task was significantly greater after the training than in the control group, with a p-value of 0.023.*

Conclusions: *The Constraint-Led Approach is as effective as conventional teaching for a complex medical procedure. Further research is needed to assess the effectiveness and sustained learning benefits of teaching medical procedures in different participants, environments, and tasks.*

Keywords: *Constraint-Led Approach, Effectiveness, Medical Procedural Skills, Teaching, Ultrasound-Guided Cannulation.*

BACKGROUND

This study compares the efficacy of teaching a medical procedure to novices using a constraint-led with a cognitive-based representational approach. The cognitive pedagogical approach is the dominant approach.

The Traditional Approach for Teaching Medical Procedures

This approach, founded in the middle of the 20th century, is based on existing taxonomies underpinning the psychomotor domain. (1) The taxonomies describe a progression of procedural skill development through a continuum of stages. (2) The cognitive approach aims to create a mental representation of the procedure, with an initial phase of acquiring cognitive knowledge. A visualisation of the procedure follows this learning. (3) The popular Peyton and Walker four-step training is used to enhance procedure representation by demonstration, deconstruction, and comprehension of the prescribed movements of all the steps of a procedure before practice. (4, 5) Feedback from the instructor corrects the prescribed movements and representation for future improved performance. The mental representation of the procedure forms a motor plan controlling all movements and performance, with feedback improving the mental model. Practice involves repetition until the prescribed movements are mastered. Signal noise should be avoided and eliminated during teaching. The method can be summarised as learn, see, practice, and prove. (5)The traditional approach is sequential, stepped, and relies on the learner imitating the movements in practice to learn the task.

Changes in Concepts of Movement and Cognition

The theoretical basis for the cognitive approach has changed over the last century. Goal-directed movements are presently considered using an ecological dynamics framework, and the concept of a set of prescribed movements is considered inadequate to explain and train for complex tasks encountered in real-world settings. (6)The performer, environment, and task form a complex adaptive system. Constraints form the limits of the various possible states of the system. The performer perceives opportunities for movement to achieve an intention. An intention is the step of a complicated procedure and the goal the movement must achieve. The movement is not prescribed but emerges as a consequence of the performer-environment system. Movement control is distributed in the performer-environment complex. The brain forms one component of the complex adaptive system with the property of self-organisation.

The contemporary idea of cognition is that it is embodied, embedded, enacted, and extended. (7) These new insights, coupled with deficiencies in the cognitive model of motor control, have led to the constraint-led approach (CLA) for developing motor skills. (8) The constraint-led approach (CLA) is most utilised in sports, physical education, and rehabilitation medicine. It is relatively unknown in medical education and has yet to be used to teach clinical procedural tasks.

The Constraint-Led Approach

In the CLA, appropriate manipulation of the constraints of the environment, task, and learner, combined with the intention of the movement, generates the perception of the opportunity for action and a movement to satisfy the intention. The appropriate movement emerges, resulting in a task performance that enables learning to emerge or arise.(9)Skill learning is adjusting to the situation's context instead of reproducing isolated ideal movements outside of the learner's context. (10)

The instructor sets a movement problem, such as manipulating the tip of the cannula, seen as a white hyperechoic image of the dot on the ultrasound machine screen, into the centre of the vein. The instructor manipulates the constraints by task simplification and using a large-sized cannula and a large vein to allow the learner to make the appropriate movement. to the task. The cannula size and vein diameter are adjusted once the movement problem is solved.

The principles of CLA are (a) forming an intention for the teaching session, (b) manipulating constraints to allow the performer to perceive movement opportunities, (c) using a teaching environment representative of the performance environment, and (d) practice by building in appropriate stability and variability – repetition without repetition – to allow the learner to be adaptable.(11)

Unlike the cognitive information processing approach, which is sequential, stepped and deconstructed into cognitive and practical components of a procedure's steps, the CLA develops the movements of the procedural steps, integrating the cognitive, practical, and affective components for learning and mastering the skill. The instructor's role is to design the environment robustly that meets the learning requirements. (12) It is, therefore, learner-centred in nature. (13)

Comparing CLA with Conventional Training Methods

Adopting the CLA for medical procedural skill training requires evidence of its effectiveness, efficiency, and overall benefits to support a change in training learners. This study explores whether CLA can effectively teach novices ultrasound-guided peripheral venous access (USGPVA), a complex medical procedure. It compares the effectiveness of teaching novice medical students with a CLA approach to teaching in an established course using a standard cognitive training approach to novice medical and nursing practitioners with

MATERIALS AND METHODS

Overview of Study

The primary research question of this study is:

How does CLA's teaching effectiveness and ability compare with an established traditional course with the exact duration of teaching?

The secondary questions are whether learners accept CLA as a teaching approach and an assessment of their self-reported confidence in performing the task.

We hypothesise that a more effective teaching approach would result in a shorter time for cannulation, the number of errors during the performance, the number of cannulation attempts, and greater self-reported confidence in learners' performance.

Participants

During their two weeks of required anaesthesia critical care rotation, the intervention group consisted of senior year (4th year) medical students at The University of Queensland, Brisbane, Australia. Students learn practical and theoretical aspects of anaesthesia, including how to perform a safe intravenous cannulation. Students are currently not allowed to perform intravenous cannulation on patients using ultrasound at the hospital. Students were invited to participate in a simulation-based study voluntarily. They formed the intervention group, labelled as the CLA group.

The comparator group, labelled as control, consisted of medical practitioners and nurses voluntarily enrolled in an established course teaching ultrasound-guided peripheral venous cannulation at the simulation centre. The course participants were invited to take part in this study. The course teachers and coordinators permitted the course learners to participate in this study. All participants were novices at USGPVA but routinely performed intravenous cannulations as part of their studies. Students are not allowed to enrol in this course.

Participants were excluded from the study if they had previously completed a course on ultrasound-guided cannulation or were trained as paramedics and certified to perform intravenous cannulation using an ultrasound device. All participants were novices in using ultrasound and advanced beginners at intravenous cannulation.

Procedure

Previous qualitative movement analysis of USGPVA identified the instructional strategy and CLA teaching requirements. The CLA course group required students to learn four preliminary tasks at skill stations before learning the complete task. The four stations included i) learning to use the ultrasound machine with ergonomic alignment, ii)pre-scanning to select an appropriate vessel, iii) identification of the tip of the cannula on an ultrasound image, and iv) tracking the cannula tip as the cannula is advanced in the skin and into the vein.

The CLA group were trained in the simulation centre of the anaesthetic department of The Royal Brisbane and Women's Hospital. In the first three-hour session,they were trained in the preliminary skills. Cognitive elements such as names of veins, indications, contraindications, and the type of transducer to use were integrated into the practical component of the stations. No separate theory session was provided, and no demonstration of the tasks was provided. In a second session students practised the complete task over three hours without instruction other than the intentions of their movements (the steps of the procedure).

Specific constraint alterations provided appropriate movement opportunities, including pre-scanning on each other with their non-dominant hand, a task alteration. Students were asked to map the veins on paper with their dominant hand. Learning cannula tip identification was achieved by commencing with large-diameter cannulas before proceeding to long 20G cannulas. Tip tracking was altered by covering their hands with a sheet to focus attention on the ultrasound machine's screen. These constraint manipulations were aimed to provide appropriate perceptions and movement opportunities. to generate the required movements. Variation in the task was provided by practising on different-sized vessels in the trainers. The students were asked to consider if they had learnt how to do the task rather than complete an assessment.

The study measurements were performed after the second session. For every four learners, one tutor had knowledge of CLA-based training.

The comparator group course was an established professional blended course at the Clinical Skills Development Centre. The centre is an established training centre attached to the hospital and healthcare service. Participants completed a specific online teaching program block of two hours at home before attending a practical face-to-face session of four hours at the training centre. The compulsory online learning component covered the underpinning theory, including an introduction to ultrasound theory and the US machine, vascular device selection and decision-making, the aseptic approach and insertion techniques. A short multiple-question test was administered with feedback to check for comprehension and learning. The workshop focused on the practical skills needed to perform ultrasound-guided peripheral intravenous cannulation safely. The session consisted of part-task training using the ultrasound machine, pre-scanning each other in pairs with vein selection, sterile technique for cannulation, needle tip tracking and cannulation performed on a four-vessel branched vascular access trainer with short and long axis views. Each part-task section consisted of a demonstration, including a video and task deconstruction before practice. The complete task was taught after part-task training was completed. A feedback tool constructed for the course with specific points on ultrasound machine set-up, vein selection, and needle tip tracking was used to provide consistent feedback to the learners on each procedure component. Participants completed a standardised assessment session consisting of performing the entire procedure at the end of the course. A checklist was used to check for errors, and feedback or retraining was provided as required. Tutors supported participants and the group in achieving the prescribed actions during practice.

The study measurements were performed after they had learned the complete task. One tutor was employed for every four participants in the course.

Equipment

We used a Branched 4 Vessel Vascular Access Ultrasound Training Model (Bluephantom.com) and a Blue Phantom GenII PICC w/IV & Arterial Line Ultrasound Model Training Arm trainer. The trainer models used were the same in both courses. The students used a Phillips US machine (Phillips, Andover, MA), and the comparator group used a Sonosite M Turbo Portable ultrasound machine. Similar image resolution was present on both machines.

Study Measures

Participants were asked to complete two tasks. In the first task, all participants were provided with the same clinical scenario: an adult patient with difficult venous access requiring a peripheral intravenous cannula for treatment. The Blue Phantom Gen II PICC w/IV & Arterial Line Ultrasound Model Training Arm trainer was used for the assessment to simulate a real arm. A validated measurement tool for the placement of ultrasound-guided peripheral intravenous access was used in the study.(14)A high degree of interrater agreement was reported for the tool (kappa rate of 0.93), suggesting good reliability. (14)A checklist consisting of ten essential performance steps was used to assess the participants' competency. Participants were allowed up to three attempts at venous cannulation. The time for cannulation was measured from a starting point after presenting the scenario to the time when a successful intravenous flush of saline was demonstrated on the ultrasound image.

Participants were asked to cannulate a 2mm vessel with ultrasound guidance on the Branched 4 Vessel Vascular Access Ultrasound Training Model in the second task. The time from the cannula touching the trainer model to complete cannulation was measured. This task was intended to evaluate tip-tracking of a more difficult task and, this time, represented an assessment of successful intravenous cannula tip tracking.

Each participant provided an evaluation of the training approach. The evaluation form consisted of items related to confidence in performing USGPVA on a manikin and a patient, satisfaction with the training received, understanding of the links between theory and practice, satisfaction with the feedback provided, amount of time provided for practice, the value of the demonstration, and student's motivation to learn more about the task. Learners scored these items on a five-point Likert scale, with one rated as the least positive value and fiveas the most positive. Participants also provided free-text comments on the teaching approach, when they were most engaged in learning, and what task elements were most difficult to learn.

Statistical Analysis

A statistician (SL) reviewed the study protocol before the study. The main variable was the time required for performing the main task. For a power of 80%, with an alpha level of 0.05 and a beta level of 0.8, a sample size of 11 participants per group was estimated to show a 20% difference between the groups if it existed. Participants were recruited based on their enrolment in the courses, resulting in twelve participants in each group.

The quantitative parameters analysed were time for the cannulation task (task 1), number of attempts, number of errors, and time for tip tracking task (task 2). Data were summarised with frequencies and percentages for categorical data, median (interquartile range (IQR)) for non-normally distributed continuous data and mean (standard deviation (SD)) for normally distributed continuous data. The associations between teaching groups and outcomes were assessed using Mann-Whitney U tests for continuous data or using Fisher's exact test for categorical data, with statistical significance considered at a p-value < 0.05 (two-sided). Stata version 15 (Stata Corp, College Station, TX, U.S.A.) was used for analyses.

The qualitative analysis was performed on the free-text questions using inductive descriptive coding. (15) The text of the answers was directly transcribed into a table. KT reread each text, and a code was generated as directed by the text. The codes were then categorised into sub-categories, and KT reviewed the categories to ensure the meaning of the answers provided to the question. Following the second review, the categories were combined into themes related to each question.

Ethics

Ethics and institutional approval for the study were obtained from the Human Research Ethics Committee of Queensland and the Royal Brisbane and Women's Hospital (HREC/2021/QRBW/77123). We obtained written informed consent from each participant in the study. Participants were allowed to withdraw at any time from the study without any repercussions. All study data was de-identified during the trial and subsequent analysis.

RESULTS AND DISCUSSIONS

There were no significant differences between the CLA group and the comparator (control) group on (a) time to complete both tasks, (b) number of errors, and (c) number of attempts.

Demographics

The study consisted of 24 participants. Their median age (IQR) was 25.0 years (24.0-28.8). Ten females and 14 males were enrolled in the study. All participants were novices at USGPVA. The intervention CLA group consisted of 12 final-year medical students with a median age (IQR) of 24.5 years (24.0-25.8). There were 11 males and one female in the group. The control group had a median age (IQR) of 28.5 years (25.0-40.3). There were nine females and three males in this group. All females and one male in the control group worked in chemotherapy units. The other males were a junior doctor and a specialist trainee. (Table 1)

Table 1. Participant characteristics by randomised group

Study Characteristics	Total	CLA*	CONTROL
	N=24	N=12	N=12
Age (years), median (IQR)	25.0 (24.0-28.8)	24.5 (24.0-25.8)	28.5 (25.0-40.3)
Sex, n (%)			
F	10 (42%)	1 (8%)	9 (75%)
M	14 (58%)	11 (92%)	3 (25%)

*CLA Constraint-Led Approach

Task Performance

There was no statistical difference in the time to perform ultrasound-guided intravenous cannulation on the upper limb trainer. The median time to complete the task for the CLA group was 623 seconds (IQR 470-783) compared to the control group time of 724 seconds (IQR 624- 1002) p-value of 0.73. All participants in the CLA group required only one attempt to complete the task, whereas two members (17%) of the control group failed at the first attempt and were provided further training. Both were successful at the second attempt. This was not found to have a statistically significant difference (p-value 0.14). (Table 2)

There was no difference in the tip-tracking assessment, requiring a cannula to be inserted in a 2mm vessel. The median time (sec) for the CLA group was 84 (IQR 69-96) compared with the control group time (sec) of 59 (43-86), p-value 0.057. (Table 2)

Table 2. Participant outcomes overall and by randomisation group

Tasks	**Total Median (IQR)**	**CLA* Median (IQR)**	**CONTROL Median (IQR)**	**p-value**
	N=24	**N=12**	**N=12**	
Task 1 - total time (sec)	678 (568-861)	623 (470-783)	724 (624-1002)	0.073
Task 1 - no. attempts, n (%)				0.14
1	22 (92%)	12 (100%)	10 (83%)	
2	2 (8%)	0 (0%)	2 (17%)	
Task 2 - total time (sec)	71 (59-95)	84 (69-96)	59 (43-86)	0.057

*CLA Constraint-Led Approach

Post-Course Evaluation

Participants evaluated the training course based on a 5-point Likert scale. There were no statistical differences regarding satisfaction with the teaching method used, understanding of the links between theory and practice, the value of teaching demonstrations, time available to practice, amount of time expended on teaching as a ratio to the time available to practice, and in the motivation levels to learn more about the task. The students self-rated their confidence significantly higher in performing the task on a trainer unsupervised than the control group did at a p-value of 0.023. This study demonstrates that CLA is an equally effective approach in teaching novices complex medical procedures and has the advantage of being flexible and adaptable to variations in the clinical environment. The confidence in performing the task unsupervised on a patient was not significantly different between the groups. (Table 3)

Table 3. Participant post-teaching survey response overall and by teaching group

Experimental Outcome	**Total Median (IQR)**	**CLA* Median (IQR)**	**CONTROL Median (IQR)**	**p-value**
	N=24	**N=12**	**N=12**	
Overall satisfaction with the teaching method you were exposed to, number (%)				0.59
4	4 (17%)	1 (8%)	3 (25%)	
5	20 (83%)	11 (92%)	9 (75%)	
Understanding the link between the theory and the practice, number (%)				1.00
4	5 (21%)	3 (25%)	2 (17%)	
5	19 (79%)	9 (75%)	10 (83%)	
The values of the demonstration of the procedure	5.0 (4.0-5.0)	5.0 (4.0-5.0)	5.0 (5.0-5.0)	0.21
The value of time available to you to practice	5.0 (4.0-5.0)	5.0 (4.0-5.0)	5.0 (4.0-5.0)	0.74
The value of the duration of teaching time as opposed to hands-on time	4.0 (4.0-5.0)	4.0 (3.5-5.0)	5.0 (4.0-5.0)	0.11
The value of the feedback provided	5.0 (5.0-5.0)	5.0 (5.0-5.0)	5.0 (4.5-5.0)	0.57
Your confidence in performing the task on a trainer unsupervised	4.0 (4.0-5.0)	5.0 (4.0-5.0)	4.0 (3.5-4.5)	**0.023**

Your confidence in performing the task on a patient unsupervised	4.0 (3.0-4.0)	4.0 (3.0-4.0)	3.5 (3.0-4.0)	0.27
Your motivation to learn more regarding the skill or its application, n (%)				1.00
4	5 (21%)	3 (25%)	2 (17%)	
5	19 (79%)	9 (75%)	10 (83%)	

*CLA Constraint-Led Approach

Analysis of Text Answers

The qualitative analysis of the free-text evaluation responses to the questions regarding the training course revealed differences and similarities between the groups. The CLA group liked the hands-on approach to learning (N=9) and the time available to practice (N=4), but one student commented on the difficulty with the initial setup. The control group liked the learning atmosphere in terms of group size, feedback, reassurance, and equipment (N=6). Four of the participants liked the instructions and directions provided, and one person liked the hands-on demonstrations. Most of the CLA group was most engaged during the entire practice (N=10), with one participant learning most by self-reflection and another by observing other participants perform the task. Nine control group members were most engaged in learning during practice, two in using the ultrasound machine and seven in learning the procedure steps. Only two participants commented on being most engaged in learning during the assessment phase when the phantom arm was cannulated, representing the entire task. (Table 4)

Table 4. Participant post-teaching evaluation qualitative responses by group

List of Questions	CLA*	CONTROL
	N=12	N=12
Comments on the method of learning the skill	9 - liked the hands-on approach. 4 - liked the time available to practice. 1 - felt the initial setup was harder to learn.	6 - liked the learning atmosphere - (group size, feedback, reassurance, equipment). 4 - liked the instructions and directions. 1 - liked the hands-on demonstrations.
When were you most engaged in learning?	10 - during all the practice. 1 - In self-feedback. 1 - while observing others.	9 - during practice (2 with US machine, 7 steps). 2 - when cannulating the patient's arm (assessment).
What was most difficult to learn?	5 - Coordination of both arms and the machine. 3- Knowledge of the task. 2- Sterile technique.	10 - Trying to understand the correct movements. 3 - Knowledge of the procedure and its many steps. 1- The US machine.

*CLA Constraint-Led Approach, US Ultrasound

DISCUSSIONS

This mixed methods study demonstrated that the CLA is equally as effective at teaching a complex psychomotor clinical procedure (USGPVA) compared to the established cognitive approach when learning is defined as the ability of the student to reproduce what was taught. This is the first study comparing the effectiveness of the CLA in teaching clinical motor skills to the gold-standard cognitive approach. Effective teaching is defined as the ability to produce multi-faceted learning competencies.(16) The CLA group performed the task faster and reported greater levels of self-confidence. This may result from more time spent on hands-on practice and may also reflect the variability of practice repetition. The two approaches differ in what is being taught. The CLA focuses on generating movements based on the perception of affordances. In contrast, the cognitive approach aims to create a mental representation with students expected to imitate the movements of the task. This may account for the faster performance times. There was no difference in cannula tip-tracking, suggesting that this component was equally well learned.

The post-course evaluation revealed no differences in satisfaction levels regarding the allotted teaching time or the time available to practice. The students had not previously experienced a CLA teaching approach, and to our surprise, they accepted it well as a method for teaching clinical procedural tasks.

The qualitative analysis of the free-text responses revealed that learners prefer different components of the approach. The control group considered the learning atmosphere, instructions, and directions provided to replicate movements significant for sustained learning. The CLA group considered the hands-on approach more significant to sustaining their learning from their experience as they were most engaged with learning during practice. The CLA group also considered their body coordination the most difficult challenge. In contrast, the control group considered obtaining the correct movement as demonstrated as the most difficult part of the training course. This reflects the different characteristics of the two teaching approaches. The CLA does not consider a single correct set of movements for a task, and the movements performed reflected the interactions of the environment, task, and performer constraints.

This begs the question, about what exactly is acquired during skill acquisition? (17) In cognitive and experimental psychology, learning refers to establishing an internal model or a mental representation of an act that is believed to be acquired through learning and task experience. From an ecological perspective, the term learning suggests skill acquisition may not refer to an entity but rather to the emergence of an adaptive, functional relationship between an organism and its environment. While both training approaches successfully achieved cannulation, what may have been learned by the two groups might differ.

LIMITATIONS

There are several limitations to this study. First, all the members of the intervention group in our study were medical students in their senior and final year in Australia (4th year), limiting the external generalisability of our findings. Second, most of the students were male. The study was conducted in the post-COVID-19 period. The university reallocated the distribution of student teaching blocks as students could not attend hospital teaching during COVID-19 isolation. The uniformity in participants reduced the interference from other factors due to age, prior knowledge, and physical ability. The control group had more females as the participants enrolled from specific workplaces such as chemotherapy centres. It is unlikely that the gender distribution affected the results. While the two groups are not directly comparable, from a learning perspective, they were novices. Third, the lack of simulation trainers limited the CLA training, preventing it from providing a complete educational course. This limited the study and the range of comparisons between the training approaches. Fourth, we were restricted in measuring learning to a cognitive approach focussed on reproduction rather than including adaptation. In this study, we were limited to this measuring of learning as the comparator group were not usually assessed with variations. Reproducibility is the hallmark of training in a cognitive representative approach. Measuring learning competencies from a CLA viewpoint would require demonstrations of cannulation in different environments, patient arms, and using different ultrasound machines and other external constraints. A meaningful assessment needs to consider the USGPVA task performance under real-world conditions. Fifth, learning retention is an essential issue in teaching. Our study was not designed to measure learning retention as both groups were lost to follow-up after training.

Students are widely distributed geographically across many learning sites once the university term is completed. Future studies should include the measurement of retention of learning over time. Sixth, while the cognitive approach is stepped and sequential, many variations exist in its applications. (18) Blended courses using simulation tend to follow constructivist views that allow learners to customise their learning individually. This supports the learning potential of an approach closer to the CLA. Finally, a complete evaluation and comparison of the two approaches requires extensive input from learners and independent observers to gauge if there are meaningful differences in the effectiveness of the two methods.

While this study considered the effectiveness of teaching, the complexities of measuring learning effectiveness and efficacy require new ways to define and apply learning formulations.

CONCLUSIONS

The CLA is an effective approach to teaching novices complex medical procedures. It also has the advantage of being flexible and adaptable to variations in the clinical environment. However, further research is needed to assess the effectiveness and sustained learning benefits of teaching medical procedures in different participants, environments, and tasks before adopting the constraint-led approach for training complex medical psychomotor skills.

Abbreviations

CLA - Constraint-Led Approach

US - Ultrasound

USGPVA - Ultrasound-guided peripheral venous access

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