Universal Library of Medical and Health Sciences
Research Article

Volume 2, Issue 1

Open Access | PP: 70-77

The Efficiency of the Constraint-Led Approach in Teaching External Chest Compressions to Medical Students

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Abstract

The cognitive approach is the dominant approach for teaching medical procedures. However, the theoretical basis for the approach has changed over the last century. The constraint-led approach is a new approach for teaching 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 study considers whether the constraint-led approach can be used to teach external chest compressions and compares its efficiency in teaching novice performers (medical students) with a cognitive approach that includes the Peyton and Walker 4-step method consisting of demonstration, deconstruction, comprehension, and practice. Our results show that the constraint-led approach is more efficient than the more traditional cognitive approach for teaching this skill. The median (IQR) total teaching time was 6.0 (6.0-9.0) minutes using the constraints-led approach compared to 24 (18.0-26.0) minutes in the cognitive approach. The median (IQR) time to teach the practical component, as measured by the number of cycles of compression required, was also significantly less with a constraint-led approach 2.0 (2.0-3.0) cycles than the cognitive approach 4.0 (3.0-5.0), p-value 0.001. We posit efficiency is gained by an integrated teaching approach and directed movement generation. The results suggest further studies of the efficiency of teaching with other medical procedures incorporating different participants, environments, and tasks are required before accepting the constraint-led approach for developing medical psychomotor skills.

Keywords: *Anaesthesia, Constraint-Led Approach, Efficiency, External Chest Compressions, Procedural Skills*

INTRODUCTION

Medical education currently faces many challenges including an exponential growth of knowledge, technological developments, healthcare reform, and societal changes [1]. The traditional skills training, experience-based model is currently being replaced by a competency-based model with results-based proficiency [2]. Technological advances have introduced new procedures with increasing complexity, requiring learning by students, trainees, and practitioners [3]. A growing curriculum, with reduced teaching time available for skill teaching and an increased number of students, is challenging educators to develop and allocate the time to train the required core skills efficiently and effectively [4].

The Halsted mentorship model for training surgeons with repetitive opportunities to care, commonly referred to by the aphorism "see one, do one, teach one", introduced early in the twentieth century, is rapidly falling out of favour. [5]. The motor learning theorists in the last half of the twentieth century posited the required steps to teach a psychomotor skill. [6]. This allowed teachers to derive the principle that skills are best learned by following a sequenced and stepped approach to teaching – whether simple or complex as expressed in medical teaching literature. This cognitive approach is exemplified in Peyton's 4-Steps approach [7], George and Doto's five-step approach [8], and more recently in the 'Learn, See, Practice, Prove, Do, Maintain' framework [5]. While the cognitive approach dominates current teaching, there is a growing awareness that it may not be adequate or optimal for large or complex procedural tasks [9].

New insights into the fundamental concepts of psychomotor performance related to cognition [10], movement theory [11], and motor learning [12] have challenged the accepted narrative of the cognitive sequential, stepped teaching approach. Learning is increasingly currently considered a non-linear phenomenon, and the way learners process a practical task that requires psychomotor movement qualitatively changes through the phases of skill development [13]. Goaldirected movements emerge from the complex interactions of the environment, performer, and task constraints [14]. The sports and physical education domains were early adopters of these new concepts and generated the successful constraint-led approach (CLA). This integrated approach is focused on manipulating task, environment, and learner constraints to enable movements to emerge appropriate to the movement problem and environment of performance rather than to follow or imitate prescribed actions. In the medical domain, evidence is required before CLA can be accepted and adopted for teaching medical procedural tasks.

This study considers whether CLA is effective in teaching medical students a procedural task and compares its efficiency with current teaching methods. The task chosen for the study comparison is external chest compression (ECC) as part of CPR training. ECC is an essential skill in critical care training and requires correct performance to save lives. The primary research questions we posed are (a) Can CLA be used to teach the task to medical students, and (b) How efficient is CLA in teaching ECC to medical students as compared with the current cognitive approach, including procedural performance and theoretical knowledge? Secondary outcome measures included the learner's acceptance of the teaching method and the gain in self-reported confidence in their performance.

MATERIALS AND METHODS

Ethics and institutional approval were obtained for the study 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.

Medical students in the fourth year of their medical course at The University of Queensland, Brisbane, Australia complete their critical care rotation in conjunction with other disciplines in a twelve-week block. The critical care rotation consists of three weeks of emergency medicine, two weeks of intensive care, and two weeks of anaesthesia. Advanced life support is a component of a much larger curriculum of anaesthesia.

Students were invited to participate in the study during their fortnight anaesthesia block. Participants were excluded from the study if they had performed chest compressions or participated in a resuscitation in real life or on a course within the previous six months, if they had been trained as a paramedic, or had physical deformities such as fractured limbs that would prevent them from performing compressions.

The main parameters measured were the total teaching time required to teach the theoretical and practical aspects of ECC and the practical teaching time required to develop effective compressions. Ethics and institutional approval were obtained for the study 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.

The null hypothesis, H_0, considered that there is no difference in the efficiency of teaching ECC to novice performers (time to teach to a nominated performance level), between the current cognitive approach and CLA. Efficiency is defined in this study as the time taken to teach ECC to a prescribed standard of performance. A statistician reviewed the study protocol before the study. The main variable was the teaching time required for the learner to achieve greater than 95% efficacy of chest compressions, measured by a 'SkillGuide', on two consecutive two-minute cycles with a two-minute rest in between. For a power of 80%, with an alpha level of 0.05 and a beta level of 0.8, a sample size of 12 participants per group was estimated to show a difference between the groups if it existed.

On enrolment into the study, all students completed:

i) A pre-study survey questionnaire and provided demographic data regarding their age, gender, height, and weight. The pre-study survey questionnaire consisted of items related to confidence in performing ECC on a training manikin, performing ECC on a human cardiac arrest, knowledge of the anatomy of the chest, and preferences in learning practical skills from verbal description, video, and practical performance on a five-point Likert scale. The participants were also asked to provide their thoughts on how they had learned other practical skills, what kept them most engaged with learning a task, and what was most difficult in learning practical tasks.

ii) A multiple-choice questionnaire consisting of ten questions related to the theoretical knowledge of performing external chest compressions (ECC).

Each student also completed a two-minute cycle of ECC on a training manikin, Resusci Anne QCPR. A 'SkillGuide' was attached to the manikin and provided a composite efficacy score. The 'SkillGuide' is a CPR device that offers learners real-time feedback and an objective review of their performance via summative feedback on the device. It can operate in a blind mode or feedback mode which provides learners with information on compression rate, depth, recoil, and correct hand position during compressions. In the debrief mode it provides a compression score for the period which is an efficacy score of chest compressions formed from a composite of compression rate, depth, release, and learner's hand position. In a compressions-only session, the ideal score should be 100%. In the trial, the target for adequate learning was greater than 95% efficacy for two consecutive two-minute cycles of ECC with a two-minute rest in between.

The blocks of students were randomised to the cognitive approach using the Peyton and Walker 4-step method (Group-PW) or constraint-led group (Group-CLA). Students in the cognitive approach (Group-PW) received a tutorial on the cognitive aspects of ECC with opportunities to ask questions. This was followed by a demonstration of ECC by the instructor, a deconstruction of the task, followed by comprehension of the movements. Comprehension was checked by students verbally guiding the instructor on how to perform compressions. Students subsequently performed two-minute cycles of compressions with the SkillGuide attached. After each cycle, students rested for two minutes during which feedback on performance and its improvement were provided by the instructor. Students continued training until they reached the accepted standard.

A qualitative movement analysis was initially conducted with experts trained in advanced life support to determine the constraints that needed to be modified for teaching with CLA. This formed the basis for CLA instruction. Constraints are factors in the environment, task, and performer that influence and can be manipulated for training. For ECC, this included motivation, positioning, external focus of attention, full recoil, and maintenance of position with physical tiredness.

Students in the Group-CLA initially had their hands correctly positioned by the instructor for chest compressions. The SkillGuide was positioned in front of them, with a marker placed on the floor sufficiently forward to allow their upper limbs to maintain a vertical position above the lower half of the sternum. A chair was positioned behind the student to act as a prompt, stopping them from leaning backwards during compressions thus losing the vertical force. Students were instructed to compress the chest and provide recoil to achieve correct compressions as informed by the SkillGuide. During the two-minute rest periods, the instructor provided information relating their actions to the effects on cardiac output, survival to discharge, and theoretical knowledge related to compressions. The instructor provided no feedback on chest compressions.

All participants, after completion of training, repeated the multiple-choice question test with the questions randomised and provided an evaluation of the training approach. The evaluation consisted of items related to confidence in performing compressions on a manikin, or a patient, satisfaction with the training, understanding of the link between theory and practice, satisfaction with the feedback provided, amount of time provided for practice, the value of the demonstration, and motivation to learn more. Learners scored these items on a five-point Likert scale with 1 rated as the least positive value and 5 being most positive. They also provided free-text comments on the teaching approach, when they were most engaged in learning, and what was most difficult to learn. One week later all students repeated the randomised multiple-choice question test and completed a two-minute cycle of compressions with the compression score measured.

Quantitative statistical analysis was performed by a statistician associated with the institution. The quantitative parameters analysed were total teaching time, time to teach the practical component, number of cycles required to achieve the target ECC score, MCQ scores, and ECC efficacy scores at enrolment and one week after training. 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. 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 (StataCorp, College Station, TX, U.S.A.) was used for analyses.

Qualitative analysis was performed on the free-text questions using inductive descriptive coding [15]. The text of the answers were directly transcribed into a table. Each text was read again, and a code was generated as directed by the text. The codes were then categorised into sub-categories, and the categories were reviewed to ensure the meaning of the answers provided to the question. After reviewing the categories were combined into themes related to each question.

RESULTS AND DISCUSSIONS

This study aimed to establish that CLA can be used to develop procedural skills and compare the efficiency of teaching ECC to novice performers (medical students) using a constraint-led approach (group CLA) with the cognitive approach (group PW). Learners were expected to learn both the practical and theoretical elements of external chest compressions.

The study consisted of 24 participants. No significant differences were found between the groups related to age, height, weight, MCQ score, and ECC score at enrolment. There were six females and six males in the CLA group, whereas the PW group had five females and seven males. (Table 1). The mean (SD) MCQ score at enrolment was 4.6 (1.2) in the CLA group and 4.4 (0.9) in the PW group. The median (IQR) ECC scores were 89.5% (83.5-93.0) in the CLA group and 86.0% (59.0-93.5) in the PW group. (Table 1).

Table 1. Participant characteristics overall and by randomisation group. Values are mean (SD) or median (IQR).

Characteristic	Total Mean (SD)	CLA Mean (SD)	PW Mean (SD)
	N=24	N=12	N=12
Age (years), median (IQR)	25.0 (24.0-27.0)	25.0 (24.0-27.0)	25.0 (24.5-27.0)
Gender, n (%)			
F	11 (46%)	6 (50%)	5 (42%)
M	13 (54%)	6 (50%)	7 (58%)
Weight, kg	68.8 (12.3)	70.5 (13.5)	67.2 (11.3)
Height, cm	171.6 (10.5)	172.2 (8.4)	171.1 (12.6)
Pre-ECC score (%), median (IQR)	87.5 (69.0-93.0)	89.5 (83.5-93.0)	86.0 (59.0-93.5)
Pre-MCQ score	4.5 (1.1)	4.6 (1.2)	4.4 (0.9)

CLA- Constraint-Led Approach group PW (Peyton Walker (cognitive approach group))

The median (IQR) total teaching time was 6.0 (6.0-9.0) minutes in the CLA group compared with 24 (18.0-26.0) minutes in the PW group. This was statistically different with a p-value <0.001. The median (IQR) time to teach the practical component, as measured by the number of cycles of compression required to reach the target, was significantly less in the CLA group 2.0 (2.0-3.0) cycles, compared with 4.0 (3.0-5.0) in the PW group, p-value 0.001. (Table 2)

Table 2. Comparison of participant outcomes by teaching group. Values are median (IQR), or number (% of group).

Outcomes	Total N=24	CLA N=12	PW N=12	p-value
No of Cycles, median (IQR)	3.0 (2.0-4.0)	2.0 (2.0-3.0)	4.0 (3.0-5.0)	0.001
Total Teaching Time (min), median (IQR)	13.0 (6.0-24.0)	6.0 (6.0-9.0)	24.0 (18.0-26.0)	<0.001
1Wk ECC Score (%)	98.0 (97.0-98.5)	98.0 (98.0-100.0)	97.5 (96.5-98.0)	0.035
Post MCQ Score				0.093
9	4 (17%)	0 (0%)	4 (33%)	
10	20 (83%)	12 (100%)	8 (67%)	
1Wk MCQ Score				0.22
9	3 (13%)	0 (0%)	3 (25%)	
10	21 (88%)	12 (100%)	9 (75%)	

CLA- Constraint-Led Approach group PW (Peyton Walker (cognitive approach group))

One week after training the retention was statistically better in the CLA group but not of practical significance. There were no statistically significant differences between the groups in the MCQ scores post-training and one week later (Table 2). The CLA group achieved a score of 10 post-training and one week later. In Group PW, eight students scored 10, with four scoring nine out of ten. One week later this was maintained at nine learners scoring 10 and three scoring nine out of ten. There were no significant differences between the groups in the pre-training survey regarding the questionnaire items. However, participants in both groups self-reported a preference for learning by doing as compared with learning by verbal instruction or by watching a video. (Table 3).

Table 3. Participant pre-teaching survey response overall and by randomisation group on Likert scale ranging from 1- least to 5-most positive. Values are median (IQR).

ITEM	Total	CLA	PW
	N=24	N=12	N=12
I have confidence in performing this task on a trainer unsupervised, median (IQR)	4.0 (3.5-4.0)	4.0 (3.0-4.0)	4.0 (4.0-4.0)
I have confidence in performing this task on a patient unsupervised, median (IQR)	3.0 (3.0-3.0)	3.0 (2.5-3.0)	3.0 (3.0-3.5)
I have adequate knowledge of the anatomy of the chest, median (IQR)	4.0 (3.0-4.0)	3.5 (3.0-4.0)	4.0 (3.5-4.0)

I like to learn skills directly from a book or video – verbal instruction, median (IQR)	3.0 (3.0-4.0)	3.0 (2.5-3.0)	3.5 (3.0-4.0)
I like to learn skills by doing them with guidance, n (%)			
4	11 (46%)	7 (58%)	4 (33%)
5	13 (54%)	5 (42%)	8 (67%)
I can easily perform fine motor skills, median (IQR)	4.0 (3.5-4.0)	4.0 (3.5-4.0)	4.0 (3.5-5.0)
I find pre-course theory learning with assessment important to perform the task, median (IQR)	3.0 (3.0-4.0)	3.0 (2.5-4.0)	3.5 (3.0-4.0)
I come motivated to teaching but loose it in lectures before training, median (IQR)	3.0 (3.0-4.0)	3.0 (3.0-3.0)	3.0 (2.5-4.0)

CLA- Constraint-Led Approach group PW (Peyton Walker (cognitive approach group))

In the CLA group, 11 students rated the duration of practice time at five on the Likert scale, and one scored its value at four. This was significantly better than the PW group with six students scoring five and six providing a value of four (p-value 0.03). There was no difference in the Likert scores related to student satisfaction with the teaching approach, understanding of the link between theory and practice, the value of feedback, and the value of demonstrating the task (Table 4).

Table 4. Participant post-teaching evaluation response overall and by teaching group. Values are Likert scores (least positive to 5 most positive) %, as median (IQR) for Likert items.

Outcome	**Total**	**CLA**	**PW**	**p-value**
	N=24	**N=12**	**N=12**	
Overall satisfaction with the teaching method you were exposed to, n (%)				0.37
4	7 (29%)	2 (17%)	5 (42%)	
5	17 (71%)	10 (83%)	7 (58%)	
Understanding the link between the theory and the practice, median (IQR)	5.0 (4.0-5.0)	5.0 (5.0-5.0)	5.0 (4.0-5.0)	0.17
The value of the demonstration of the procedure	5.0 (4.0-5.0)	5.0 (4.0-5.0)	5.0 (4.0-5.0)	0.50
The amount of time available for you to practice, n (%)				0.069
4	7 (29%)	1 (8%)	6 (50%)	
5	17 (71%)	11 (92%)	6 (50%)	
The value of the duration of teaching time as opposed to hands-on time, median (IQR)	5.0 (4.0-5.0)	5.0 (5.0-5.0)	4.0 (4.0-5.0)	0.032
The value of the feedback provided n (%)				0.32
4	5 (21%)	1 (8%)	4 (33%)	
5	19 (79%)	11 (92%)	8 (67%)	
Your confidence in performing on a trainer unsupervised, median (IQR)	5.0 (4.0-5.0)	5.0 (5.0-5.0)	5.0 (4.0-5.0)	0.26
Your confidence in performing on a patient unsupervised, median (IQR)	4.0 (4.0-4.0)	4.0 (4.0-4.5)	4.0 (4.0-4.0)	0.25
Your motivation to learn more regarding the skill or its application, median (IQR)	4.0 (4.0-5.0)	5.0 (4.0-5.0)	4.0 (4.0-5.0)	0.14

CLA- Constraint-Led Approach group PW (Peyton Walker (cognitive approach group))

Both groups self-reported a significant improvement in confidence in performing ECC post-training compared with pre-training. Nine of the 12 participants in the CLA group and 6 of the participants in Group PW self-reported an increase in confidence in performing ECC unsupervised on a mannikin, and 11 participants in the CLA self-reported an increase in confidence in performing ECC on a patient as compared with eight students in the PW group. (Table 5).

Table 5. Change in participant self-reported confidence from pre-teaching to post-teaching. Values are number and %.

Outcome	Total n (%)	CLA n (%)	PW n (%)
	N=24	N=12	N=12
Confidence in performing ECC on a trainer unsupervised, score change from pre-teaching			
No change	9 (38%)	3 (25%)	6 (50%)
Increase	15 (63%)	9 (75%)	6 (50%)
Confidence in performing ECC on a patient unsupervised, score change from pre-teaching			
No change	5 (21%)	1 (8%)	4 (33%)
Increase	19 (79%)	11 (92%)	8 (67%)

ECC- External chest compressions

DISCUSSION

This is the first trial comparing CLA with the traditional cognitive approach for training medical psychomotor skills. The results of this trial indicate that CLA can effectively teach medical procedural tasks. The ECC was considered an appropriate procedural task for the study as an objective measure of effective compressions can be made by the SkillGuide. We demonstrated that learning occurred as evidenced by the gains in MCQ scores after the CLA training and the increase in confidence in performing ECC tasks. In this trial, we were able to show that learning retention was good at one-week post training.

We demonstrated that CLA was more efficient than the cognitive approach for teaching ECC to novice medical students, developing both its theoretical and practical elements. The total teaching time and the time to teach the practical aspects of performing external chest compressions were significantly shorter than that required using the cognitive approach. Several mechanisms likely gained efficiency. First, the CLA is an integrated teaching approach. The time required to first learn the skill from verbal or video instructions was not required. The contemporary understanding of cognition is that it is embodied, enacted, embedded, and extended in action [16-17]. The theoretical knowledge, often described as declarative knowledge, is directly linked to the actions and movements. This knowledge is embedded in the form of intentions and outcomes or effects. Education of intention is a key concept of CLA and ecological dynamics theory [11].

Secondly, the CLA focuses the learner towards making appropriate movements by manipulation of the environment, performer, and task constraints [11]. Informational constraints shape the learner's movements. This is in contrast to imitating prescribed movements by a teacher following demonstration and deconstruction to generate internal representations. Time and practice with conscious deliberation are considered as required elements to generate the correct movements reducing efficiency.

The pre-training survey revealed that novice learners prefer to learn from physical interactions and performing the task rather than from verbal or video instructions. This suggests learning emerges from interactions between the learner, the physical environment and the nature of movements associated with the task performance. This is congruous with the eco-dynamic theory of movement [11, 18], and suggests a novel approach that features these elements for developing competency in these skills.

The post-training evaluation confirmed our hypothesis that learners value hands-on time for learning rather than time spent on cognitive aspects. While contemporary teaching expects the cognitive aspects learned by individuals before practical learning, we posit an integrated approach may have the larger advantage of directly relating the practical aspects of the procedure with theoretical ones, providing for a stronger and sustainable competency link.

LIMITATIONS

There are several limitations to this study. First, all the participants in our study were medical students from the same teaching year in Australia, limiting its generalisability. This restriction was partly due to student availability and the distribution of student teaching blocks. The uniformity in participants reduced the interference from other factors due to age, prior knowledge, and physical ability allowing for a meaningful comparison. Second, life support teaching is usually conducted on mannikins rather than victims of cardiac arrest. This limits the applicability to the clinical environment, and comparisons between approaches may be considered somewhat artificial. Third, skill retention is an important issue in teaching. Our study was limited in studying retention to only one week as students are widely distributed geographically once the term is completed. The time between teaching the theoretical and the practical components has not been specified in cognitive teaching approaches. In our study, this was as short as possible to avoid any deterioration of learning to maximise retention. Fourth, while the cognitive approach is stepped, and sequential many variations exist in its applications. Archer et al. detected no significant difference between two-step, four-step, and five-step approaches to teaching manual defibrillation to first-year medical students [4]. Our study utilised the traditional four-step method, which is claimed to be superior to the two-step "see one-do one" approach [19]. It is unclear if differences may be detected with other approaches. Finally, the ECC represents one task of a large set of CPR procedural tasks with many variations in degrees of size, complexity, cognitive load, and complexity which may limit the generalizability of our findings.

CONCLUSIONS

Our results demonstrate that the CLA is more efficient than the more traditional cognitive approach in teaching CPR skills. The limitations in our study cannot support a broad claim of greater efficiency of CLA without further studies on the efficiency of teaching with other medical procedures incorporating different participants, environments, and tasks. If CLA is more efficient than the cognitive approach this advantage could allow medical educators to teach procedural skills in less time.

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Citation: K. Taraporewalla, P. Barach, J. Lipman, A. Van Zundert, "The Efficiency of the Constraint-Led Approach in Teaching External Chest Compressions to Medical Students", Universal Library of Medical and Health Sciences, 2024; 2(1): 70-77.