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Finding the "Sweet Spot": The Challenge of Balancing Task Complexity and Skill Level in Simulation

Marie-Eve LeBel[1]*, Saad Chahine[2] Ara Tekian[3] and Sayra Cristancho[2]

[1]Division of Orthopaedic Surgery, Western University, London, Ontario, Canada

[2]Centre for Education, Research & Innovation, Western University, London, Ontario, Canada

[3]Department of Medical Education, University of Illinois at Chicago, Chicago, Illinois, USA

***Corresponding author: Marie-Eve LeBel,** Email: mlebel4@uwo.ca

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Abstract

Introduction: Surgical simulation is becoming increasingly incorporated in surgical training curricula yet there is still debate on how to tailor its design to the trainee's skill level. The contextualization (or absence thereof) of orthopaedic surgical skills during learning/assessment using simulation has not been extensively studied. We explored the fine-tuning of task complexity to trainees' skill level in simulated arthroscopic surgical tasks.

Methods: Junior medical students without prior experience with surgery/arthroscopy were recruited. Using a prospective two-arm randomization, this pilot study focused on learning basic arthroscopic skills on a simulated physical leg/knee joint, using real arthroscopic instruments. Participants were placed either in the *decontextualized* or *contextualized* practice groups. An observational assessment checklist was developed and used at pre/post-tests during the first session. Follow-up retention testing was administered one month later.

Results: Twenty students participated and were randomized to the decontextualized practice (n=7) or contextualized practice (n=13). All participants improved their skills at post-test and skills maintenance was seen during retention testing. However, no difference was found between decontextualized and contextualized groups.

Discussion: The "skill level-task complexity" balancing act can be challenging and should be reviewed for appropriate fine-tuning of orthopaedic simulation scenarios. There might be a limited need for fine contextual details when novice learners acquire new basic skills. We reflected on current practices in orthopaedic surgical simulation and drew attention on a few conceptual frameworks that can be considered when designing surgical simulation curricula in order to reach a "sweet spot" during basic skills learning.

Keywords: Contextualization; Simulation; Surgical skills; Minimally invasive surgery; Orthopaedics; Arthroscopic training

Introduction

Simulation training can assist surgical motor skill development [1-3]. However, most surgical simulation approaches use context-free activities for training basic surgical skills [2,4]. This may prevent trainees from engaging with the surgical world's reality (i.e., environment where the patient is seen, presented patient information, physical findings, pre-operative investigations, intraoperative findings, etc.), thereby missing important data that the surgeons should consider when learning and operating [2,5]. As DeBourgh and Atherton suggest [6,7], contextualization facilitates flexibility, heightened skills of discrimination and discretion, and the ability to select among options the most appropriate method for the situation. Learning is a function of the activity and context in which it occurs: learning in different contexts will provide learners with different experiences, knowledge, information about the environment, skills, ways to control their stress level, etc.

Aside from the contextualization during training, two conceptual frameworks can assist us, trainers, to enhance the quality of the surgical training: the Challenge Point Framework (CPF) [8] and the Zone of Proximal Development (ZPD) [9] framework. These frameworks assist in determining the proper amount of information and feedback to provide to trainees and align these with their own skills. Our goals should aim for reaching the "optimal learning point" where our trainees are able to eventually become independent surgeons.

The contextualization (or absence thereof) of surgical skills during learning and assessment using simulation is largely assumed and has not been extensively/adequately studied. We define "contextualization" in our study setting as the use of different contexts (scenarios) in a learning environment (physical knee simulator) to influence the learning experience. These scenarios are a combination of a short vignette and changes made to the simulator or simulation training sessions during practice and assessment. We define "task complexity" as a group of characteristics specific for a task in a specific setting. Task complexity is influenced by one's personal experience, the task-person's interaction and the objective characteristics of the task [10]. Task complexity and contextualization are different concepts, but they are surely linked to a certain extent as specific scenarios might add complexity to the task. For example, a clerk who sees a patient in a noisy emergency trauma room will most likely have a different experience than if he/she sees the same patient with the same clinical problem in a quiet examination room. The clerk in the trauma room will have to deal with nurses, paramedics, noise, a stressful environment and be precise/concise in information gathering, etc. The clerk in the examination room will most likely be more relaxed and potentially be able to retrieve more information about the reason for consultation and also about the general/social situation of the patient. Ultimately, the difference in the clinical scenarios exemplified here will add some degree to complexity to the required tasks. The tasks themselves might not be that much more challenging, but the whole context will make them more difficult to achieve, therefore by extension, more complex. In opposition, different scenarios might also not affect the task complexity. For example, scenarios presenting 1) a 72-year-old woman with hip pain in a family practitioner's office versus 2) a 22-year-old man with hip pain in an orthopaedic surgeon's office will require similar physical examination tasks, but the 72-year old woman might only be more difficult to mobilize to complete the examination.

The purpose of this project was to determine how task contextualization/task complexity impacted the surgical trainees' performance during basic knee arthroscopy on a physical simulator. This is guided by the claims from the medical education research literature that the design of simulation-based training should be a context-guided activity supported on sound principles of how people learn while engaging in a dynamic context [11]. More specifically, what if a single simulated training session provides different contexts to learn/practice new skills: how would this influence the learning experience, learning outcomes and surgical performance? Can the manipulation of different contextual features impact skills' learning in minimally invasive surgery? For instance, in orthopaedics, can features such as the presence or absence of cartilaginous surfaces/surfaces that are damaged or not impact skill's learning? These are the questions we anticipated our paper would address. We hypothesized that training novices in basic arthroscopic skills using a contextualized approach would result in better performance with simulated case scenarios in knee arthroscopy. We also anticipated that changing only one variable (the presence/absence cartilage surfaces) within our simulator would not affect the complexity of the arthroscopic tasks.

Methods

Preliminary work [11,12] provided the definition of a set of basic arthroscopic skills that we used to test a conditional conjecture: *training novices in basic arthroscopic surgery, using a contextualized approach with simulated case scenarios and simulated conditions, will result in better simulation-based performance in knee arthroscopic surgery than a decontextualized approach.* All previously defined basic arthroscopic skills are "generic", meaning that they are transferrable from one joint to the other, and that they are performed regularly during any arthroscopy of any joint.

Participants

Junior medical students (first/second years) at Western University in London, Canada were invited to participate, using a purposive sampling [13]. In addition, snowball sampling [14] was used in selecting participants who were part of a homogeneous group of medical students potentially interested in a surgical career but without previous surgical experience. Medical students were chosen over orthopaedic residents to obtain a larger sample size and to ensure they really had no prior exposure to scoping procedures. Learning arthroscopy is very challenging for any novice, even for those with good anatomy knowledge. First-year orthopaedic residents are, indeed, no better than medical students when learning arthroscopy. Exclusion criteria were: previous exposure in observing and/or participating in a scoping procedure (general surgery, orthopaedics, urology, gynecology). Ethics board approval was received through Western University.

Study design

This prospective, randomized, two-arm pilot study focused on learning basic arthroscopic skills on a custom-built simulated physical leg and knee joint, using real arthroscopic instruments [15]. Baseline knowledge disparities were addressed by providing all participants with a standardized video explaining and displaying the normal knee anatomy, the different instruments to use (arthroscope, probe, grasper and shaver) and the different basic arthroscopic skills to perform on the simulator.

The basic arthroscopic skills we focused on included "visualization, triangulation of instruments, debridement (shaving/burring) of surfaces (bone or cartilage), probing and grasping/cutting". The visualization task was evaluated throughout the entire testing time (for example, by keeping the action centered on the monitor, orienting the arthroscope upside up). Triangulation task was evaluated through positioning of the instruments during the entire testing (placing instruments tip to tip, no overshooting). Probing was tested during palpation of specific landmarks around the knee (undersurface of patella, middle of trochlea, medial and lateral femoral condyles, medial and lateral menisci and medial and lateral tibial plateaus). Every landmark was marked with a 2 mm dot made with a permanent marker. Grasping and cutting involved the removal of a loose body and performance of a partial meniscectomy.

Following the standardized introduction, participants were randomly assigned for simulation training to one of two conditions: either decontextualized practice or contextualized practice. The "decontextualized practice" required performance of a series of basic arthroscopic skills on a knee without cartilage surfaces, with intact menisci and no clinical scenario provided. The "contextualized practice" focused on the same set of basic skills, but done in two conditions for testing the impact of differing clinical scenarios and simulator's features: 1) clinical scenario of a 22-year-old patient presenting for knee pain following a knee injury, simulated knee with intact cartilage surfaces and menisci, or 2) clinical scenario of an 82-year-old patient presenting for knee pain following a knee injury, simulated knee with severely damaged cartilage surfaces and intact menisci.

Testing session one

Following the standardized introduction, all participants took a pre-test on the simulator [15] and were provided "the old patient" clinical scenario (contextualized pre-test). The participants were then randomly assigned for simulation training to either contextualized practice or decontextualized practice. Based on previous studies, the practice time for this project lasted a maximum of 30 minutes [16]. Performance was measured for all participants immediately after the simulation practice, using the same simulator features with "the old patient" clinical scenario (contextualized post-test).

Testing session two

Retention was measured on the same contextualized knee one month after the post-test.

Performance Assessment

A checklist was developed to measure skills identified in our previous work [11,15]. The checklist evaluated trainees' performance related to: visualization, triangulation, debridement, probing and grasping/cutting. Participants received a score of "1" for correct performance, "0" for incorrect and "N/A" for not attempted. In creating total sum scores, the N/As were not included. Skills that were "not attempted" were deemed as problematic as if they were done incorrectly because if certain skills are not done, then certain parts of a procedure could have deleterious effects on the patients, either acutely or long-term. For that reason, the "incorrect performance" and "not attempted" categories were grouped together [17]. Participants performance was measured at three time points: 1) Pre-test, 2) Post-Test, 3) One month after post-test (retention). No assistance or feedback was provided: participants were instructed to complete the tasks independently at all times.

Results

A total of 21 participants were recruited and enrolled: 10 females and 11 males. One participant did not complete the study. All but one were right-handed dominant; one participant had extensive experience with video-gaming. Seven participants were randomized to the decontextualized practice and 13 participants were randomized to the contextualized practice: "young patient scenario"/intact cartilage, n= 7; "old patient scenario"/damaged cartilage, n=6. Overall internal

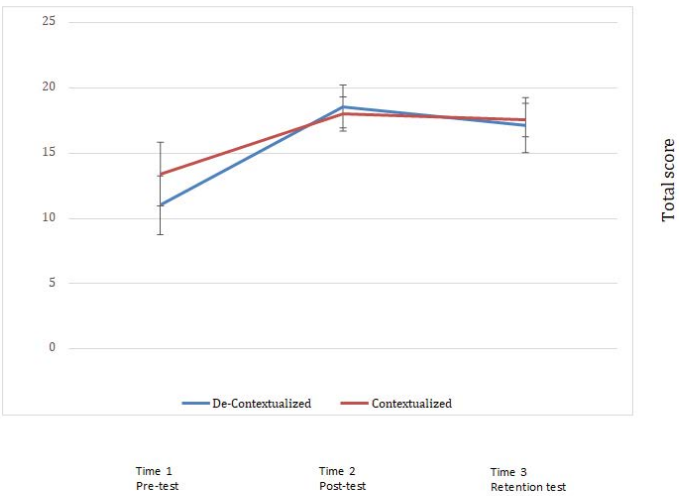

Figure 1: Total score are 3 time points.

Note: Error bars represent a 95% CI.

consistency of the checklist items was moderate and adequate for subsequent analysis based on Cronbach's alpha for each time point (Pre-test=0.77, Post-test=0.62, Retention test=0.61) [18].

The average total scores for participants improved in the decontextualized groups (pre-test *M*=11, *SD*=3.06, post-test *M*=18.6, *SD*=2.23, retention *M*=17.1, *SD*=2.85) and the contextualized group (pre-test *M*=13.4, *SD*=4.5, post-test M=18, SD=2.4, retention *M*=17.5, *SD*=2.4). To evaluate the change of performance over time, we compared the total scores using a repeated measures ANOVA. Greenhouse-Geisser correction was applied (ε=0.66) as Mauchly's test ($\chi^2(2)$=12.66, p=0.00) showed a violation in sphericity. Overall, the ANOVA was significant: F(1.39,18.61)=27.38, p=0.00. Follow-up pair wise comparisons showed a significant difference (p=0.00) between pre-test and post-test, and pre-test and retention test. However, there was no statistical significance between time at post-test and retention. Further follow-up analysis showed no significant difference between the decontextualized and contextualized groups.

Discussion

As expected with any practice, performance improvements were significant from pre-test to post-test. Additionally, sustained performance was observed, as skill performance reduction at retention testing was not significant. Against our initial conjecture, contextualization of the knee was not overtly relevant. Based on this finding, we believe we provided some initial indication that baring the task complexity, varying practice conditions or delivery format (type of simulations used, stressful/non-stressful environment, opportunity for practice, etc.) are potentially ineffective for novice learners [8]. Studies are needed with larger sample size to see if differences exist with advanced learners, and to compare novices and experts with varying conditions.

While we initially believed that contextualized scenarios and accompanying features of a simulated knee would show performance differences, the differences were irrelevant for our novice trainees, essentially missing the point of optimal learning and maximized performance from the CPF and ZPD frameworks. The scenarios presented here were either a young patient with intact joint surfaces or an older patient with damaged joint surfaces versus a decontextualized condition with no scenario and no cartilage surfaces. The contexts (scenarios) of the simulated surgeries required changes within the simulator that certainly affected to a certain degree the complexity of the required tasks. We expected that changing only one variable (the cartilage surfaces only and not the menisci) would not affect the task difficulty too much, but it did for a few participants. This resulted in technical challenges for four participants as some cartilage fragments became too loose and prevented them to obtain proper visualization. Theoretically, the notion of balancing task complexity and skill level aligns with the Challenge Point Framework (CPF) [8]. In CPF, different levels of contextualization may influence more or less the trainees' performance depending on their skill level: a large amount of contextual information may not be necessary for novice learners, but with improved skill level, more contextualization may be required. But disproportionate information (contextualized complex scenario and/or increased technical difficulty) may be detrimental for improving performance over time in both novice and advanced learners [8].

From the developmental psychology perspective, Vygotsky's "Zone of Proximal Development (ZPD)" also supports the task complexity/ skill level balancing as initial assisted performance progresses towards increased independence and responsibility levels [19]. Both CPF and ZPD advocate for an optimal point in learning with proper tailoring of assistance and guidance to execute the integrated tasks smoothly [19]. Given this perspective, feedback mechanisms should most likely be considered when using a contextualized approach to training to positively impact the outcome and avoid development of bad habits (such as inappropriate use of instruments) [20] when learning new surgical skills [19]. In this study, no feedback was provided to only focus on the participants' own personal skills and abilities with no bias from any form of feedback. We needed to know what the participants could do by themselves to eventually understand how to help them move into their Zone of Proximal Development. On the other hand, we are aware that providing some feedback and guidance, like in real life, might have helped the participants getting closer to a point of optimal learning.

The subdivision of the contextualized group into 2 subgroups ("young" and "old" patient scenarios) might have prevented the gathering of more meaningful data and limited the completion of generalizable and significant statistical analysis. The absence of significant difference between the groups could also be related to the participants' lack of previous knowledge/exposure to normal arthroscopic knee anatomy, contributing to the technical difficulties of this testing across the groups. Those difficulties could be secondary to the inability to recognize normal anatomical landmarks or to reduced visibility and intra-articular disorientation. The short duration of the training or lack of sensitivity of the checklist could also explain the negative results. Even though we were not able to draw strong conclusions, this study allowed us to reflect on current practices in basic arthroscopic simulation and drew attention on a few conceptual frameworks that should probably be used when designing surgical simulation curricula [8,19].

While our results are initial information, future work will involve replication of this study with a larger number of randomized participants to further support the Contextualization and Zone of Proximal Development frameworks, and compare novices with intermediate and advanced trainees.

Conclusion

Basic orthopaedic arthroscopy skills' training is challenging to teach and learn, and effective approaches are lacking. To allow our trainees to maximize their learning experience, tailored surgical training curricula with either CPF or ZPD in mind are required for each individual training level. Finally from a teaching perspective, in order to improve the effectiveness of learning, influencing variables need to be taken into consideration: the right amount of information, based on skill level of the individual, practice conditions, task difficulty and feedback.

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