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Research Article

Continuous versus step by step training for learning surgical anatomy on an open inguinal hernia model

Abstract

Background: Segmentation of surgical procedures may facilitate learning. The step-by-step framework segments surgical procedures in a standardized manner based on anatomy. The effects of the framework are compared to a continuous approach, on learning anatomy on an inguinal hernia model by pre-novices.

Methods: Students from 10 high schools located in or near Rochester, Minnesota, were randomized into continuous and step-by-step groups. They trained using step-by-step versus continuous video-demonstrations of an open inguinal hernia repair on a simulation model. Anatomical knowledge and cognitive load were assessed.

Results: In total, 220 students participated (156 female; mean age 15 years). In the selection that watched the video-demonstration, the step-by-step group answered 1.9 questions correctly, and the continuous group 2.4, p=0.010. The cognitive load did not differ between the groups.

Conclusions: In pre-novices, anatomy knowledge transfer might be better using continuous rather than step-by-step video-demonstrations.

Abbreviations

CPR: Cardiopulmonary Resuscitation; IBM: International Business Machines

Introduction

To prepare for a surgical procedure, learners may use many resources (journals, books, video, et cetera) including learning from their superiors by watching them perform the surgery in the operating room, known as the master-apprentice model [1]. Due to work hour regulations and decreased exposure time in the operating room, the emphasis today in surgical education is on better preparation before entering the operating room [2,3]. A framework based on anatomical structures has been proposed by our group to segment surgical procedures into steps in a standardized manner [4]. An international expert panel supported the preciseness, usefulness, and applicability of the step-by-step framework. We pondered that the step-by-step framework may also facilitate surgical training for anatomical knowledge using the video-demonstration of a surgical procedure.

The process of learning and the effectiveness of instructional design choices should be understood to optimize the teaching process. The cognitive theory of multimedia learning can explain the learning process from dynamic visualizations such as video and animation [5]. An assumption in this theory is that learners have a limited cognitive capacity available to process new information [6].

The cognitive capacity needed to process new information is known as *cognitive load* [7]. When this new information is presented as a video or animation (*streaming information*), the cognitive load can be high because information that is disappearing from the screen needs to be retained and processed in working memory, or otherwise information that is later presented on the screen cannot be understood (also called *transiency* of information).

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To lower the cognitive load, the segmentation principle in the cognitive theory of multimedia learning can be applied [8]. With the segmentation principle, the video is divided into smaller parts with pauses in between, allowing learners to completely process one segment before moving on to the following segment. Segmentation could also lower the cognitive load by constructing a cognitive schema of the task [9]. The construction of cognitive schemas is especially useful for novices as they do not possess the schemas to comprehend a complex task yet [8].

In the surgical field, the effects of the step-by-step framework on learning surgical anatomy have not been proven. The current study aimed to investigate the effects of an online course based on the step-by-step framework, consisting of a video-demonstration and textual description of the knowledge of the surgical anatomy of a surgical procedure in pre-novices, such as high school students. The primary endpoints are anatomical knowledge and cognitive load.

Materials and Methods

Design

It was a randomized study with two groups: an online course containing continuous video-demonstration and textual description (continuous group) and an online course containing segmented video-demonstration and textual description (step-by-step group). Random assignment to one of the two groups was realized on the school level in which all students of each participating school were included within the same group to prevent contamination. This cluster randomization was chosen as students from the same classes, and teachers cannot be randomized on an individual basis as there is too much risk of contamination. The risk of cluster randomization is an imbalance between the groups, a recruitment bias, such as different teachers, different amounts of attention to the study, etcetera. This problem has been addressed by a large sample size [10]. The randomization was blinded for the researchers.

The open inguinal hernia repair was chosen as a surgical example for the study since this procedure is complicated and execution cannot be performed without adequate anatomical knowledge. One week before the test, the high school students were granted access to their group-specific online course to prepare for the test. During the test day, the students filled in a questionnaire and were examined on their anatomical knowledge using a simulation model representing all relevant anatomical structures. Figure 1 outlines the study design.

Participants

The participants were 220 high school students (64 male and 156 female) from 10 high schools in or near Rochester, Minnesota, in the United States. The participants' average age was 15 years (SD ±2, range 12 to 18) with a median grade of 11 (range 7th to 12th grade).

The study took place within the Mayo Clinic in Rochester, Minnesota, as part of a more extensive seminar involving other medical learning experiences (The "Saving Lives with Gus" seminar offered exposure to CPR, using a defibrillator, tying surgical knots, using an ultrasound machine, et cetera.) Participation was voluntary and all participants consented to the study.

Materials

Online course

One week before the seminar, the students could access an online course where they were instructed to study a surgical procedure (open inguinal hernia repair) and anatomy (male groin). The students had one week to study the course. The course consisted of an introduction and the video-demonstration and textual description of the open inguinal hernia repair including all the anatomical terms. The difference between the two groups was the continuous video-demonstration and textual description versus a step-by-step video-demonstration and textual description of the surgical procedure. The rest of the course, including the information about anatomy, was identical.

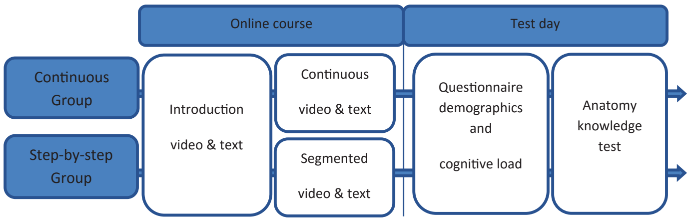

Figure 1: Study design.

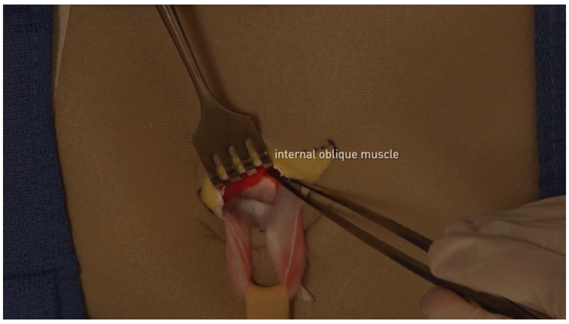

Figure 2: Open inguinal hernia simulation model.

The introduction contained a text and a video of 2:39 minutes, which explained an inguinal hernia. The text also explained a hernia and medical jargon such as medial and lateral. The introduction was similar for both groups.

The video demonstrated surgery on an open inguinal hernia simulation model of a male patient. The simulation model mimicked the abdominal wall as each felt layer corresponded with an abdominal wall layer, for example, Camper's fascia, Scarpa's fascia, external oblique aponeurosis, internal oblique muscle and transversalis fascia. In the video-demonstration, all the encountered anatomical structures were emphasized. These structures were mentioned by the voice-over, shown by highlighting the structure and were named on the screen

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(Figure 2). The simulation model was used to create a realistic environment for the student in order to motivate them.

The continuous group accessed the online course containing the introduction and on a separate page the continuous video-demonstration of the open inguinal hernia repair (10:56 minutes). The continuous textual description was below the video. The step-by-step group reached the online course containing the identical introduction as the continuous group. On a separate page were the step-by-step video-demonstration of the open inguinal hernia repair and textual description. For the step-by-step group, the video was 11:14 minutes in length; six segmented surgical steps, and title frames with the name of the step of 3 seconds before each step. Below the video was the step-by-step textual description in table-form with steps, substeps, and the actions. Each substep, a combination of an anatomical structure and an action, had its explanation [4]. This information was the same as the information for the continuous group but formally structured. Both groups could view the video-demonstration and textual description simultaneously. The videos could be watched as often as wanted and could be paused whenever the participant desired.

Questionnaire

The high school students were asked to fill in a questionnaire regarding their time spent studying the online course and how they perceived their cognitive load during the online course (Appendix A). The questionnaire also inquired if the teacher had discussed the course in class, and if so, how many hours.

The cognitive load during preparation was measured using a shortened rating scale of Leppink [11]. The questionnaire included four statements concerning cognitive load (Table 1). Each statement was scored on a 10-point Likert scale, ranging from 0 "not at all" to 10 "completely".

Anatomy knowledge test

The learning outcomes were assessed using an anatomy knowledge test in which the students had to recognize the correct anatomical structures in the simulation model. During the exam, the high school students received a list of 8 anatomical structure names that had to be linked to the 6 questioned anatomical structures in the simulation model (Table 2). The maximum score was 6 correct answers. The simulation model used during the experiment was identical to the model used in the video-demonstration during the online course.

Statistical analysis

All statistical analyses were done with SPSS (IBM Corp. Released 2016. IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp.). The dependent variables were the number of correct answers on the anatomy knowledge test and the scores on the modified cognitive load questionnaire. The independent variable was the type of online course; continuous or segmented based on the step-by-step framework. The Chi-

Table 1: Shortened cognitive load rating.

	Continuous group	Step-by-step group	Statistical analysis (Mann-Whitney U)	
	Mean±SD	Mean±SD	U	p-value
The content of this activity was very complex.	5.3±2.2	5.4±2.1	5402.5	0.801
In this activity, complex terms were mentioned.	6.1±2.5	6.2±2.4	5387	0.775
I invested a high mental effort in this activity.	6.0±2.5	5.7±2.6	5064.5	0.306
This activity really enhanced my understanding of the content that was covered.	6.5±2.4	6.7±2.6	5104.5	0.350
Total rating cognitive load	6.0±1.9	6.0±1.7	5503	0.984

Table 2: Eight anatomical structures within the open inguinal hernia simulation model.

1. Skin
2. Camper's fascia
3. Scarpa's fascia
4. External oblique aponeurosis
5. Internal oblique muscle
6. Spermatic cord
7. Inguinal ligament
8. Transversalis fascia

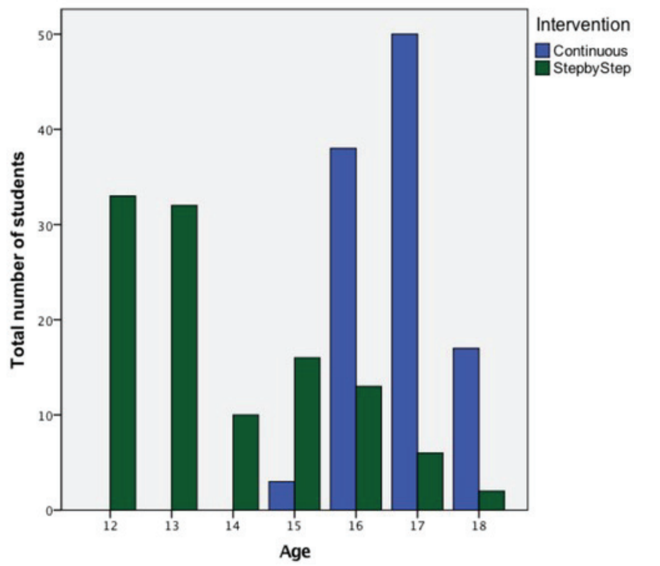

Figure 3: Age distribution.

square test or the Mann Whitney U test, was used to compare the groups. The internal consistency for the cognitive load was determined using Cronbach's α. P-values of less than 0.05 were considered statistically significant.

Results

A total of 220 high school students from ten high schools participated. The continuous group consisted of 108 students with 85 females (78.7%) and an average age of 17 years (range 15-18). The step-by-step group (n=112) consisted of 71 females (63.4%) with an average age of 14 years (range 12-18) (Figure

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Table 3: Preparation.

		Continuous group (n=108)	Step-by-step group (n=112)	*p*-value
Gender	Female (n)	85 (78.7%)	71 (63.4%)	
	Male (n)	23 (21.3%)	41 (36.6%)	0.012^*
Age in years (median; range)		17 (15-18)	13 (12-18)	<0.001†*
Watched introduction video	Yes (n)	86 (79.6%)	105 (93.8%)	0.002^*
Watched video-demonstration	Yes (n)	71 (65.7%)	53 (47.3%)	0.006^*
Study time on website (n)	0 hours	1 (0.9%)	1 (0.9%)	0.734^
	0-1 hour	101 (93.5%)	102 (91.1%)	
	1-2 hour	6 (5.6%)	7 (6.3%)	
	2-3 hour	0 (0%)	1 (0.9%)	
	≧ 4 hours	0 (0%)	1 (0.9%)	
Additional lessons of high school teacher (n)	Yes	21 (19.4%)	24 (21.4%)	0.715^
Explanation time high school teacher (n)	0 hours	88 (81.5%)	90 (80.4%)	0.132^
	0-1 hour	20 (18.5%)	18 (16.1%)	
	1-2 hour	0 (0%)	4 (3.6%)	

^ analyzed using Chi square test; † analyzed using Mann-Whitney U test; * statistically significant.

Table 4: Comparison of the students that watched the video-demonstration versus that did not watch the video-demonstration within the continuous and the step-by-step group.

		Continuous group (n=108)			Step-by-step group (n=112)		
		Watched video-demonstration	Not watched video-demonstration	Statistical analysis	Watched video-demonstration	Not watched video-demonstration	Statistical analysis
Total participants (n)		71	37		53	59	
Gender	Female (n)	54	31	p=0.352^	35	36	p=0.582^
	Male (n)	17	6		18	23	
Age (mean; in years)		17	17	U=1096 p=0.127$^{\varphi}$	14	14	U=1432 p=0.432$^{\varphi}$
Additional lessons of high school teacher	Yes (n)	17	4	p=0.102^	18	6	p=0.002^*
	No (n)	54	33		35	53	
Explanation time high school teacher	0 hours (n)	53	35	p=0.011^*	35	55	p=0.001^*
	0-1 hour (n)	18	2		14	4	
	1-2 hour (n)	0	0		4	0	
Number of correct answers (mean)		2.4±1.0	1.5±1.5	U=788 p<0.001$^{\varphi}$*	2.0±1.3	1.4±1.3	U=1205 p=0.031$^{\varphi}$*

^ analyzed using Chi square test; $^{\varphi}$ analyzed using Mann Whitney U test; * statistically significant

Table 5: Effect of variables on the number of correct answers on the anatomy test.

		All participants (n=220)		Participants watched video-demonstration (n=124)	
		Mean amount of correct answers ± SD	Statistical analysis	Mean amount of correct answers ± SD	Statistical analysis
Intervention	Continuous	2.1±1.2	U=4826 p=0.008$^{\varphi}$*	2.4±1.0	U=1392 p=0.010$^{\varphi}$*
	Step-by-step	1.7±1.3		1.9±1.3	
Age			p=0.017^*		p=0.111^
Gender	Female	1.9±1.2	U=4732 p=0.535$^{\varphi}$	2.2±1.1	U=1556 p=0.993$^{\varphi}$
	Male	1.8±1.5		2.2±1.3	
Watched the video-demonstration	Watched	2.2±1.2	U=3916 p<0.001$^{\varphi}$*	Not applicable	
	Not watched	1.5±1.4			
Additional lesson high school teacher	Yes	2.4±1.2	U=2857 p=0.004$^{\varphi}$*	2.5±1.2	U=1227 p=0.058$^{\varphi}$
	No	1.8±1.3		2.1±1.1	
Time high school teacher spend			p=0.146^		p=0.549^

^analyzed using Chi square test; analyzed using Mann-Whitney U test; * statistically significant.

3). More students in the step-by-step group watched the introduction video regarding the open inguinal hernia repair (p=0.002), while more students in the continuous group watched the video-demonstration (p=0.006). There was no difference in study time on the website, additional lessons of the high school teacher, or explanation time of the high school teacher (Table 3).

In the complete selection (n=220), the continuous group had an average of 2.1 answers correct (±SD 1.2) out of the 6 anatomy knowledge questions compared to 1.7 in the step-by-step group (±SD 1.3), U=4826, p=0.008 (Table 4). Variables that had a significant effect on the number of correct answers on the anatomy knowledge test were watching the video-demonstration (U=3916, p<0.001), age (p=0.017) and additional lessons of the high school teachers (U=2857, p=0.004).

As shown in Table 4, independent of the intervention, the students that watched the video-demonstration answered 2.2 anatomy knowledge test questions correctly in comparison

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to 1.5 correct answers in the students that did not watch the video-demonstration, U=3916, p<0.001. Within the continuous and step-by-step group, the students that watched the video-demonstration scored significantly higher on the anatomy knowledge test than students that did not watch the video, p<0.001 and p=0.031, respectively (Table 5). The gender and age of the students that watched and did not watch the video-demonstration were similar. In the continuous group, more students watched the video-demonstration when the high school teacher spent more time in class discussing the online course (p=0.011). In the step-by-step group, more students watched the video-demonstration when the high school teacher gave additional lessons (p=0.002) and spent more time in class (p=0.001).

Table 5 shows the subanalysis of the students that watched the video-demonstration. Of the 124 participants (56.4%) that watched the video-demonstration of the surgical procedure, the students within the continuous group answered an average of 2.4 questions correctly, and the students in the step-by-step group answered 1.9 questions correctly, U=1392, p=0.010. In this sub-selection, age (p=0.111) and additional lessons of high school teachers (U=1227, p=0.058) were non-confounding variables.

On the different statements of the cognitive load (internal consistency of Cronbach's alfa=0.707) and the total rating of the cognitive load, no significant differences were found between the continuous and the step-by-step group (Table 1).

Discussion

In this study, the effects of a video-demonstration of a surgical procedure based on the step-by-step framework on anatomy knowledge and cognitive load were compared to a continuous video-demonstration. High school students studied a surgical procedure with an emphasis on anatomical structures and were tested on their anatomical knowledge. The continuous group answered slightly more questions correct on the anatomy knowledge test compared to the step-by-step group. The cognitive load was similar for the continuous group and the step-by-step group.

The continuous group was on average older than the step by step group, which was a confounding variable. In the sub-selection of the students that watched the video-demonstration, age was, however, no confounding variable. A more critical factor for answering more correct answers was the preparation by watching the demonstration video. Our results suggest that the transfer of anatomical knowledge in pre-novices may be better when information is presented continuously.

Based on previous studies, the expectation was that the step-by-step group would score higher on the anatomy knowledge test and lower on the cognitive load [12-14]. Moreno reported that the segmentation group outperformed the continuous group and had a lower cognitive load [14]. In both experiments of Moreno, they included pre-service teachers (average age 25 years old) in an introductory educational psychology course in their last semester of the teacher education program. Moreno selected participants with knowledge in the field they were tested in, contrary to our students that did not know the open inguinal hernia repair. Our participants were also younger compared to Moreno's participants. In a study with elementary school students (age 9 to 11), studying the causes of day and night, the segmented group outperformed the continuous group [15].

Our high school students studied a surgical procedure with its relevant anatomy, which might be more complex to comprehend for high school students compared to the causes of day and night. The students in both groups had a low number of correct answers in the anatomy knowledge test, indicating they might have been too novice and had too little prior knowledge to be able to learn the open inguinal hernia repair and its anatomy adequately. They were likely unfamiliar with the medical jargon used in the video-demonstration and textual description. Exposing students to information that is too complex for their level of expertise, risks overloading their cognitive abilities and impairs learning [5,16,17]. Further research comparing step-by-step to continuous video-demonstration should be performed in participants with more medical knowledge, such as medical students, surgical residents or surgeons.

The data suggested a similar experienced cognitive load in both groups. This was, however, not measured immediately after viewing the course, but during the test day. Furthermore, the assessment included the entire online course and not the video-demonstration exclusively, which could also explain the same cognitive load in both groups [11].

We expected that some high school teachers would discuss the online course in class. In the continuous and the step-by-step group, the number and the duration of additional lessons were similar. As high school teachers are no experts in open inguinal hernia repair, they likely could only either stimulate the students to do the online course or could watch the video-demonstration in class. Within the sub-selection of students that watched the video-demonstration, there were no effects of the high school teacher's additional lessons on the number of correct answers on the anatomy knowledge test.

In the step-by-step group, we built-in a pause of 3 seconds after each segment. All participants could pause and re-watch the video-demonstration themselves. Indeed, in the continuous group, this perhaps led learners to create their own segmentation. We could not monitor how many times the students paused or watched the video-demonstration. In case the continuous group students watched or paused the video-demonstration more times compared to the step-by-step group, the segmentation effect of the step-by-step group may have been diminished [12].

The cluster randomization occurred by school in order to avoid students sharing access to the continuous and step-by-step video-demonstrations. Unfortunately, this led to a significant difference in the age distribution between the groups. In the complete selection, older age resulted in significantly more answers correct in the anatomy knowledge test. Within

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the selection that watched the video-demonstration, age did not affect the mean correct answers of the anatomy knowledge test. Before cluster randomization, the differences per high school should have been assessed.

Conclusion

In summary, we found that the continuous group scored slightly higher on the anatomy knowledge test compared to the segmented step-by-step group. The subjects in this study might have been too novice as both groups answered a low number of anatomical questions correct. Further research on online video-based course on inguinal hernia repair should test more experienced learners to investigate the hypothesis that a step-by-step framework facilitates learning by optimizing the use of the cognitive capacity and subsequently, the learning process.

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