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Virtual reality objects improve learning efficiency and retention of diagnostic ability in fetal ultrasound

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KEYWORDS: fetal anomalies; fetal brain; prenatal diagnosis; teaching; ultrasound; virtual reality

ABSTRACT

Objective *Virtual reality (VR) objects of fetal ultrasound volumes have been proposed for teaching and learning diagnostic ultrasound. The aim of this study was to determine if VR objects improve learning efficiency and retention of diagnostic ability in fetal ultrasound.*

Methods *Medical students and junior doctors were taught normal and abnormal sonographic fetal brain anatomy using conventional means (video lectures and review articles; control group) or additionally with selected VR objects from a novel fetal brain atlas (Pocket Brain, http://pb.fetal.ch; study group). Knowledge, speed of recognition and retention of diagnostic ability were tested in multiple-choice questionnaires 1 and 4 months after teaching, and the results were compared between those taught using conventional means only and those taught using VR objects.*

Results *Participants taught using VR objects answered significantly more questions correctly and solved the tests quicker than those taught using conventional methods only, both 1 and 4 months after teaching.*

Conclusion *The use of VR objects in teaching fetal ultrasound significantly improves learning efficiency and knowledge retention. Copyright © 2018 ISUOG. Published by John Wiley & Sons Ltd.*

INTRODUCTION

Ultrasound is the main tool for prenatal diagnosis. Specific protocols have been developed for ultrasound screening and diagnosis[1]; however, the performance of diagnostic ultrasound is highly operator-dependent. Increasingly sophisticated equipment and extended protocols widen the gap between the theoretically possible diagnostic capabilities and the skills of examiners[2]. Ultrasound education involves direct tuition by a teacher, supervised image acquisition and application of practical skills and observation of normal and pathological educational cases. Some aspects can be achieved by self-study using digital teaching material[2,3].

Ultrasound imaging data are well suited to transformation into digital learning objects[4]. Virtual reality (VR) objects offer a new way of simulation-based ultrasound training[5,6]. Pocket Brain is a web-based learning tool that uses highly instructive brain imaging data from normal and structurally abnormal fetuses, captured using volume ultrasound and presented as VR objects, which are scroll-through movies with a fixed orientation to enable simple and convenient use[7]. In this study, we evaluated the effect of teaching using Pocket Brain on the learning of junior doctors and medical students with regard to fetal cerebral malformations. The main objective was to study whether the use of VR objects improves learning efficiency and knowledge retention, using multiple-choice questions in standardized tests on fetal brain anomalies. Secondary objectives were to analyze how this effect differs over time by testing the participants twice, 3 months apart, to examine a possible influence on test-solving speed and to investigate whether VR objects can help with diagnostically challenging anomalies.

METHODS

This study was performed between May and December 2016. Participants were junior doctors or medical master students, without prior specific ultrasound teaching, recruited from medical schools and various university and non-university teaching hospitals (listed in the acknowledgments) through personal contact or the respective departmental educators. The study was conducted entirely online, using a web-based learning platform (Moodle, Moodle Pty Ltd, Perth, Australia) that contained all teaching and test materials.

In the random allocation of participants to the control and study groups, raffle tickets indicating assignment of participants to teaching using conventional methods only

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or additionally with VR objects were folded to hide the assignment and shuffled. These were then handed out to participants on enrollment.

After confirmation of participation, registration and log-in, participants completed a 2-h learning session, with or without VR objects, according to their group allocation. In both groups, each participant received a total of 2 h teaching. Test completion and time taken were recorded per participant, using the website's tools.

In the control group, teaching consisted of a 1-h video lecture on the fetal brain and its malformations as well as individual reading of an accompanying guideline[1] and a review article[8] for 1 h (Figure 1). In the study group, participants were additionally exposed to selected VR objects in Pocket Brain (http://pb.fetal.ch), a freely available novel online atlas and teaching system that uses VR objects of normal and abnormal fetal brain volumes[7]. The teaching and testing objectives are detailed in Appendix S1. The complete teaching material and testing environment were made freely accessible after completion of the study, access to which can be gained through contacting the corresponding author. Diagnostic abilities were tested in both groups using an online multiple-choice questionnaire (MCQ) 1 and 4 months after teaching (Figure 1). The MCQ consisted of 20 questions about the fetal brain and its anomalies. Eight questions tested factual knowledge that had been presented in the lectures and articles provided, and 12 questions required recognition of fetal brain malformations on ultrasound images. Only participants completing both tests were included in the analysis.

One question (MCQ item 17) concerned visual recognition of agenesis of the corpus callosum, which has been suggested as a particularly difficult and therefore discriminating question[9]. The results of the groups regarding MCQ item 17 were compared separately and as part of the entire test results.

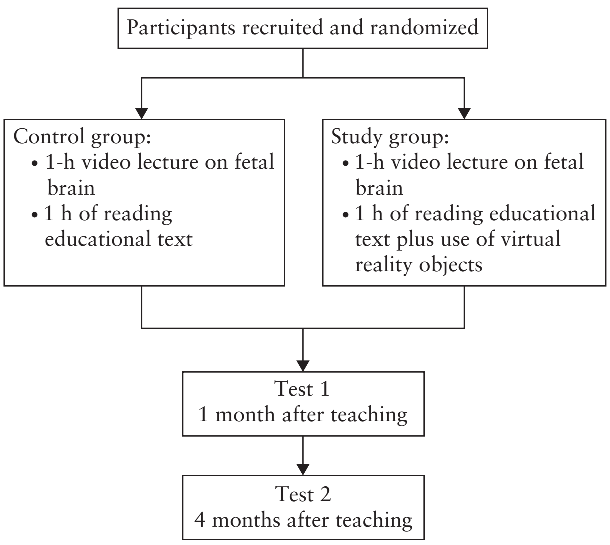

Figure 1 Recruitment, randomization, teaching and testing of participants.

The statistical program R (R. Gentleman *et al.*, Statistics Department of the University of Auckland, New Zealand), version 3.4.1, was used for statistical analysis. To detect a significant difference in test score at a significance level of 5%, the power calculation, performed using G*Power (version 3.1, Heinrich Heine University, Düsseldorf), showed a required sample size of 84 (42 per group). Normal distribution was tested using the Shapiro–Wilk test. Levene's test was used to assess homogeneity of variance. For variables with homogeneity of variance and normal distribution of the residuals, one-way ANOVA was used (indicating mean values) with Cohen's *d*-test for effect size. Non-normally distributed variables were tested using the Mann–Whitney *U*-test (indicating median values) and *Z*-values for effect size *r* were calculated[10]. Fisher's exact test was used for comparison of MCQ item 17 score.

RESULTS

Of the participants initially recruited from 13 hospitals in two countries (Switzerland and Germany), 51 completed both tests, with 30 in the control group and 21 in the study group.

The study group answered more questions correctly than did controls, both 1 and 4 months after teaching; this difference was greater after 4 months (Table 1 and Figure 2). Cohen's *d*-test for both tests showed a strong effect (1.05 and 1.32 after 1 and 4 months, respectively).

The study group correctly answered the test questions quicker than did the control group, both 1 month (13.2 min *vs* 15.9 min; $Z = 6.2148$; $P < 0.001$; effect size $r = 0.87$, i.e. a strong effect) and 4 months (10.3 min *vs* 13.5 min; $Z = 6.2155$; $P < 0.001$; effect size $r = 0.53$, i.e. a strong effect) after teaching.

The ability to recognize agenesis of the corpus callosum (MCQ item 17) has been proposed as a discriminating

Table 1 Scores of medical students and junior doctors in 20-item multiple-choice questionnaire on fetal brain ultrasound, 1 and 4 months after teaching using conventional methods only (controls) or additionally with virtual reality objects (study group)

Participants/time after teaching	*Controls (n = 30)*	*Study group (n = 21)*	P
All			
1 month	11.9 (10–14)*	14.9 (12–17)*	< 0.001†
4 months	10.6 (7–13)*	15.1 (14–17)*	< 0.001†
Medical students			
1 month	11.2 (10–13)*	12.0 (11–12)*	0.52†
4 months	9 (7–12)	14 (10–15)	< 0.001‡
Junior doctors			
1 month	14 (13–15)	16.5 (13.5–18)	< 0.001‡
4 months	12.6 (8–15)*	15.8 (14–17)*	0.07†

Data are presented as median (interquartile range (IQR)). *Mean and SD calculated for normally distributed variables and converted into median[12] and IQR[13] for uniformity. †One-way ANOVA. ‡Mann–Whitney *U*-test.

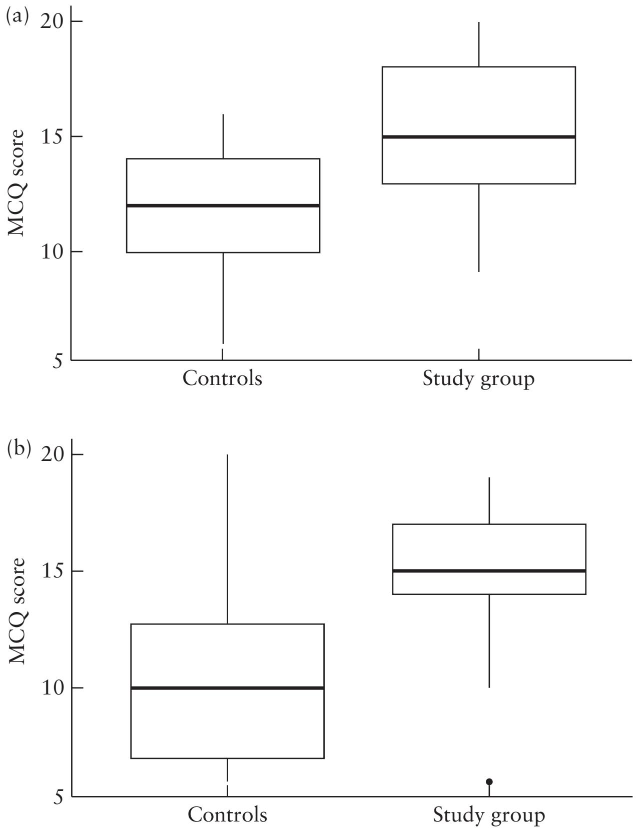

Figure 2 Scores in 20-item multiple-choice questionnaire (MCQ) on fetal brain ultrasound of participants taught using conventional means only (controls) and those taught additionally using virtual reality objects (study group), 1 month (a) and 4 months (b) after teaching. Boxes are median and interquartile range, and whiskers are range.

factor for applied specific knowledge[9]. The study group scored better on MCQ item 17 compared with controls, both 1 and 4 months after teaching (71% and 67% *vs* 55% and 57%, respectively), but these differences were not statistically significant ($P = 0.25$ and $P = 0.57$, respectively).

Three-quarters of the participants in both groups were female. Women scored on average the same as did men, 1 month (13.1 points, SD 3.21 *vs* 13.1 points, SD 3.12; $P = 0.96$) and 4 months (12.3 points, SD 4.14 *vs* 12.9 points, SD 4.01; $P = 0.62$) after teaching (Figure S1).

Not all registered participants completed the teaching and both tests. After the second test, there were 21 (70%) medical students and nine (30%) junior doctors in the control group and five (24%) students and 16 (76%) junior doctors in the VR objects group. To assess the effect of the uneven distribution of medical students between the two groups, subanalyses were performed in both groups considering students and junior residents separately. Overall, junior doctors scored higher, however, junior doctors and medical students in the study group performed better than controls (Table 1 and Figure S2).

DISCUSSION

The use of ultrasound is highly operator-dependent and the development of increasingly sophisticated equipment magnifies the potential for diagnostic error. Due to a lack of training, there is a widening gap between the sophistication of the most advanced machines and techniques and the skills of those expected to use them and interpret the images[2]. Clinical experience and direct observation and training in specialized ultrasound units predict trainees' confidence in performing diagnostic obstetric ultrasound examinations independently, but concerns exist about the adequacy of current ultrasound training programs. Simulation-based training may improve learning efficiency and knowledge retention[11]. VR objects have been proposed as teaching and self-study tools[3,4,6,11].

This study assessed whether VR objects improve teaching success in a clinically-relevant context, i.e. teaching junior doctors and medical students to recognize fetal brain anomalies on ultrasound. The results show that the use of VR objects improves learning significantly and in a sustained way. The experimental group had self-study exposure to VR objects for as little as 1 h, yet they answered more questions correctly than the control group. Knowledge retention was also better after teaching using VR objects. These findings are consistent with other results on learning behavior that show beneficial effects of visual learning[8].

We recruited students and junior doctors to this study because conventional simulation-based ultrasound training works more effectively on novice trainees than on experienced volunteers[14]. We explicitly limited access of the study group to the VR objects to a relatively short period of time to avoid uncontrolled additional self-study. At the end of the study, this web-based tool was made universally available and can theoretically be updated and enhanced to repeat and augment the learning process, and to further consolidate individual knowledge and abilities.

Another advantage of using web-based VR objects was the availability of the resource at any time of the day. While this allowed the participants to select their best individual conditions for the learning session and the tests, it might have been a confounder since time and physical location at the time of the tests were not standardized. Theoretically, external auxiliary tools might have been used by participants during the tests, but the conditions were identical for both groups.

Limitations of our study are the moderate number of participants who completed both tests and the uneven distribution of junior doctors and medical students in the two groups due to dropouts. In future studies, to avoid this uneven distribution, participants could first be divided into junior doctors and students and then allocated randomly.

The effect size was larger than expected, yielding significant differences between the groups despite the sample size being smaller than our power calculation required. Overestimating the utility of VR objects is unlikely as we included only motivated participants (final-year medical students and junior doctors) who approached us voluntarily, having been alerted to the possibility of participation, with subsequent randomization. Focusing on a very specific topic (fetal brain abnormalities), specific test questions (testing only information presented previously to both groups) and allotting time equally during teaching and the tests reduced potential error in the judgment of test efficacy.

In conclusion, for the first time, we have demonstrated the utility of VR objects for improvement of diagnostic ability and knowledge retention in prenatal diagnosis. Based on our results and on current research on the theory of learning and the various possibilities in the digital age, we propose to make ultrasound training as visual as possible. VR objects provide an ideal tool for this; they can be combined easily with additional learning resources such as online lectures and conventional scripts or textbooks. The VR objects used in this study as well as the teaching and testing environment are freely available, can be used by others and could be adapted to cover other aspects of diagnostic imaging. Further studies with more participants and with teaching in organs other than the fetal brain should be performed.

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SUPPORTING INFORMATION ON THE INTERNET

The following supporting information may be found in the online version of this article:

Appendix S1 Specific teaching and testing objectives of lectures, teaching articles and Pocket Brain

Figure S1 Scores of participants in 20-item multiple-choice questionnaire on fetal brain ultrasound, 1 month and 4 months after teaching, according to gender of participant.

Figure S2 Scores of participants in 20-item multiple-choice questionnaire on fetal brain ultrasound, 1 month and 4 months after teaching, according to prior education.