Virtual reality and brain anatomy: a randomised trial of e-learning instructional designs

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CONTEXT Computer-aided instruction is used increasingly in medical education and anatomy instruction with limited research evidence to guide its design and deployment.

OBJECTIVES To determine the effects of (a) learner control over the e-learning environment and (b) key views of the brain versus multiple views in the learning of brain surface anatomy.

DESIGN Randomised trial with 2 phases of study.

PARTICIPANTS Volunteer sample of 1st-year psychology students (phase 1, $n = 120$; phase 2, $n = 120$).

INTERVENTIONS Phase 1: computer-based instruction in brain surface anatomy with 4 conditions: (1) learner control/multiple views (LMV); (2) learner control/key views (LKV); (3) programme control/multiple views (PMV); (4) programme control/key views (PKV). Phase 2: 2 conditions: low learner control/key views (PKV) versus no learner control/key views (SKV). All participants performed a pre-test, post-test and test of visuospatial ability.

MAIN OUTCOME MEASURES A 30-item post-test of brain surface anatomy structure identification.

RESULTS The PKV group attained the best post-test score (57.7%) and the PMV group received the worst (42.2%), with the 2 high learner control groups performing in between. For students with low spatial ability, estimated scores are 20% lower for those who saw multiple views during learning. In phase 2, students with the most static condition and no learner control (SKV) performed similarly to those students in the PKV group.

CONCLUSIONS Multiple views may impede learning, particularly for those with relatively poor spatial ability. High degrees of learner control may reduce effectiveness of learning.

KEYWORDS randomized controlled trial; education, distance; neurology/*education; brain/*anatomy; humans; teaching/*methods; computer-assisted instruction.

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INTRODUCTION

Increasingly, computer-aided instructional resources and e-learning are being incorporated into medical education. Commercially available resources such as Primal Anatomy (http://www.anatomy.tv), large multimedia asset libraries such as HEAL (http://www.healcentral.org) and http://www.healthlibrary.ca are used to enhance internet-based resources for medical education. While these resources hold promise, evidence supporting their efficacy for enhancing student learning and understanding is minimal. Several studies have contrasted computer-based learning with alternative formats.[1] As pointed out over a decade ago,[2,3] however, many of these 'media-comparative' studies are of limited value, as they fail to identify and study the critical elements separating the 2 forms of learning.[4] Given this, it is important to avoid having the learner-centred approach to e-learning eclipsed by a technology-centred approach. The latter allows cutting-edge advances in computer technology to drive the development of learning resources; the former

Overview

What is already known on this subject

Online learning is being adopted increasingly for medical education, but experimental evidence has been lacking. Studies of computer-based learning have often compared it to other types of media (e.g. paper-based) rather than attempting to discern which elements of e-learning may be most effective.

What this study adds

Our study suggests that key views of the brain, simply presented, may be the most effective way of using e-learning to teach brain anatomy. Learners with poor spatial ability may be hampered severely by some types of multimedia graphics, highlighting the importance of research into the efficacy of e-learning instructional design for medical education.

Suggestions for further research

Further studies might examine critically other enhancements – animation, motion, etc. – to determine whether they represent real learning benefit.

incorporates evidence from cognitive psychology and educational research in educational design.[1]

One of the key variables in e-learning instructional design relates to the degree of learner control over study materials. In e-learning modules, this can include any or all of the following aspects of a programme of learning: choice of section(s) to complete, the rate of progress and the decision to bypass part of the programme.[5] There is inconsistent evidence regarding the effectiveness of learner control in knowledge acquisition. In part this may relate to how much 'active learning' is taking place and how much previous knowledge the learner has in the subject area.[1] Despite some evidence that individuals learn more when given control over their instruction, most of the existing literature suggests that increased learner control courses are not effective for people with little previous subject matter knowledge or low metacognitive capabilities.[6,7] Additionally, Eva *et al.*[8] demonstrated poor self-assessment in other domains of health science (medical) education, suggesting that most learners are unable to gauge accurately their knowledge deficits and plan their learning accordingly. Consequently, with a high degree of learner control in courses, learners run the risk of skipping over key educational content.

Learning anatomy

Many clinical tasks require an understanding of spatial relationships in anatomy and successful spatial learning may influence performance in subspecialties that rely heavily on anatomy (i.e. radiology, surgery). However, despite its importance in patient care and medical training, the process by which spatial relationships are learned remains unclear. Additionally, medical educators make important decisions about the use of instructional materials (i.e. cadavers, skeletons, plastic models, computer models and atlas illustrations) without this knowledge. These instructional materials vary in terms of their dimensionality [2-dimensional (2D) versus 3D], degree of abstraction (e.g. cadaver or drawing) and the ability to allow for multiple viewing angles. For example, neuroanatomy atlas illustrations used to teach brain surface anatomy typically present 4 views of the brain: superior, inferior, lateral and mid-sagittal. However, a real-life model of the brain can be examined from many more perspectives than just these 4 views. More recently, sophisticated computer simulations such as the Visible Human have become available and can provide a 'virtual reality' (VR) environment. It would seem self-evident that the capacity of the computer to 'get inside' the object under study should significantly enhance instructional efficiency.

Surprisingly, there is evidence to the contrary. Hariri *et al.*[9] found that a dynamic surgical simulator resulted in no improvement in performance over a textbook presentation. In a study examining the learning of wrist bone anatomy,[10] students with high spatial ability learned equally well whether presented with key views or multiple views. Interestingly, students with poor spatial ability were handicapped by the multiple views. Other highly controlled studies support this conclusion, but suggest that there may be an advantage to the presentation of additional views.[11,12]

Why is this the case? When considering the effectiveness of studying an object from multiple different views, it is important to consider how spatial information is represented in the brain. Some evidence suggests that spatial information is remembered as visual (non-verbal) information, and that this visual information is remembered as certain mental viewpoint-specific 2D projections of a real 3D object.[13–17] Consequently, students faced with an oblique projection begin by mentally rotating the object to a standard position, and then extract the critical features. Understandably, students with poorer spatial ability are less able to perform this task.

However, the previous studies raise some questions. The lack of superiority of the multiple views presentation may be related to the fact that the bones of the wrist are not complex enough to benefit from the addition of 3D views. Further, the contrast between the first study, which showed superiority for key views with low spatial ability subjects, and the later studies, showing superiority for multiple views with user control, confounds 2 variables: learner control and a focus on key views with some small variations. The present study, using new, more spatially complex materials attempts to resolve these important issues.

Objective

The overall objective of this study is to examine how presentation of anatomical images using multiple versus key view presentations and differing degrees of learner control influence mastery of brain anatomy.

Specific objectives

- To determine whether study of the key views (KV) (superior, inferior, lateral, anterior) of the brain is as effective as studying multiple views (MV).
- To determine whether more behaviourally active learner control over brain images results in better learning of brain anatomy than more programme-controlled presentation of views.
- To determine if spatial ability influences learning of brain anatomy in e-learning.
- To determine if spatial ability interacts with presentation mode (KV or MV) to influence learning.

METHODS

Design

There were 2 phases of the study. In phase 1, participants were randomised to one of 4 e-learning instructional designs: programme-controlled key views (PKV); learner-controlled key views (LKV) – key views with learner control over which brain image key views they wished to study; programme-controlled multiple views (PMV) – multiple views in a programme-controlled sequence at 30° increments; and learner-controlled multiple views (LMV), where participants could toggle between any of the 24 brain image views they wished to study. In phase 2, in order to delineate further the impact of learner versus programme control, participants were exposed to 1 of 2 e-learning groups: the PKV group from phase 1 versus a more static key views representation (SKV). This latter condition was most like a series of textbook illustrations requiring no activity from the learner. Experimental design was similar to previous studies of carpal anatomy learning.[10,11]

Setting

All participants performed the experiment in an 8-station computer laboratory within our academic health science centre's clinical skills laboratory, with a study supervisor whose interaction with the subjects was scripted through a pre-written protocol.

Participants

For both phases of the experiment, participants were a volunteer sample of 1st-year psychology students from McMaster University's undergraduate psychology programmes (phase 1, $n = 120$; phase 2, $n = 120$).

Interventions

Phase 1

All participants were randomised to one of 4 e-learning instructional designs, as described above. Each instructional phase was exactly 12 minutes in duration, with a total of 27 important surface anatomical structures that the learner would select and view for any given image of the brain. A timer was available to all learners. Participants in the 2 more learner-controlled conditions (LKV and LMV) could determine which images of the brain they wished to study; this variable was predetermined in the 2 more programme-controlled conditions (PKV and PMV).

Key views chosen were anterior, inferior, lateral and superior views of the brain photographed digitally from a high-fidelity plastic model and enhanced for e-learning delivery using image-editing software. Multiple views were created by producing digital images at 30° increments around the model. The e-learning interface was custom-designed using Macromedia Flash by the Visualization Design

Institute at Sheridan College, Oakville, Ontario, Canada. The computer recorded the duration that each view was studied for the learner-controlled conditions.

Phase 2

Participants were exposed to either the PKV condition or a more static, behaviourally inactive SKV condition. Images in the SKV condition were labelled key views (similar to that seen in an anatomical textbook), so that the learner was not required (or able) to select actively an anatomical label. This latter condition represented an extreme version of programme control in order to clarify further the nature of this variable in multimedia learning.

Apart from the instructional intervention, all screens were identical for the participants. In addition to the learning phase, all participants received an identical introduction to the study and provided written informed consent.

The following participant characteristics were collected as potential covariates for later analysis: sex, handedness, comfort with computers, prior neuroanatomy exposure and programme of study (arts versus science streams). Prior to the instructional phase, a pre-test of 16 multiple choice questions requiring recognition of brain surface anatomy structures was administered to all participants. Following the instructional phase, participants undertook a standardised test of spatial ability (mental rotations test, MRT).[18] At the completion, all participants underwent the same post-test designed to assess recognition of the brain surface anatomy structures studied. This 30-item test consisted of images of the brain presented in different orientations with a highlighted structure – half from key views, half from multiple views' images – with the learner selecting a response from a menu of the 27 anatomical structures available. Participants were permitted to work through the questions at their own pace. All responses, and the responses to the spatial ability and demographic questions, were captured in a secure electronic database. At the completion of the study, students were given corrective feedback on their post-test responses.

Measurement

The primary outcome measure was performance on the 30-item post-test, with MRT performance a key covariate. For learner-controlled conditions, the amount of time spent on each view was recorded.

Data analysis

All data were transferred into SPSS for statistical analysis. For phase 1, the primary analysis examined whether post-test performance is related to the 4 instructional conditions. Factorial analysis of variance was conducted with 2 grouping factors (learner versus programme control and key versus multiple views). To examine the effect of spatial ability, we performed analysis of covariance (ANCOVA) with key versus multiple views as the grouping factor and MRT score as the covariate. We also included the covariate-grouping factor interaction term in the model. For phase 2, an analysis of variance (ANOVA) was performed with 1 grouping factor (PKV versus SKV).

Ethics

Approval was obtained from both hospital and university research ethics boards, and all participants provided written informed consent. No identifying information was collected and subject participation was voluntary; participants did receive some course credit for their time.

RESULTS

Phase 1

Participant demographics

Only 2 of the 120 participants failed to complete the study; 1 for personal reasons and 1 for technical reasons. Of the remaining 118 students with complete data, 89 (75%) were female and 29 (25%) were male; 12 (10%) of the participants were left-handed. Only 2 subjects reported feeling uncomfortable with computer technology. Sixty-nine (59%) had never had any previous neuroanatomy exposure; 19 (16%) had some exposure more than 1 year prior to the study; and 30 (25%) students had some neuroanatomy exposure within the past year.

Pre-test

The mean score for the pre-test was 4.6 of 16 [standard deviation (SD) 1.7]. Those students with neuroanatomy exposure within the past year had a mean pre-test score of 5.17 (SD 2.3), which was not significantly different from learners without prior neuroanatomy instruction. There was no significant difference in pre-test scores among the 4 instructional conditions.

Mental rotations test (MRT)

Almost all participants required the full 3 minutes for each phase of the MRT. The mean score for all participants was 12.64, with no significant differences between the instructional groups. There was a significant difference in MRT score between genders with the mean score for males 14.48 (SD 5.7) and females 12.03 (SD 5.4) ($F_{1,117} = 4.4$, $P = 0.038$), consistent with described norms.

Outcome

Mean post-test scores are shown in Table 1. The PKV group received the highest score (57.7%); while the PMV group performed the poorest (42.2%). The two groups with high learner control were intermediate and almost identical, at 48.1% and 48.9%. Analysis of variance revealed a significant main effect of key views versus multiple views (16.0 versus 13.55, $F = 5.18$, $P < 0.05$). Programme control was slightly but not significantly larger than learner control (15.0 versus 14.56) and there was a significant interaction ($F = 4.17$, $P < 0.05$).

Further analysis showed no difference between test items from key views and oblique views. Overall, groups performed slightly, but not significantly better on the oblique views. There was no evidence that the multiple views groups had any advantage over key views groups on the oblique presentations.

Repeating the analysis with spatial ability as a covariate did not change the conclusions. The MRT, while significant, accounted for only about 2% of the variance in post-test performance. However, our previous finding was that individuals with relatively poor spatial ability were considerably handicapped by multiple view presentations.[10] To pursue this in more detail, we re-analysed the data examining the relation between key/multiple views and performance on the MRT. The ANCOVA, including both MRT and MRT ×KV/MV in the model, showed a significant main effect of MRT ($P < 0.05$) and a marginal interaction ($P = 0.08$). The relation between spatial ability and the presentation format is illustrated in Fig. 1, which is a plot of estimated performance on the post-test related to (a) MRT score (ranging from 2 SD below the mean to 2 SD above the mean) and (b) key views or multiple views learning. It is evident that when the images are presented as key views, the impact of MRT score is fairly small (51% versus 55% for extreme groups); however, the impact of MRT on estimated performance in MV is much larger (31% versus 60%). This replicates precisely the finding of the earlier study,[10] which showed a modest advantage of multiple views for learners with high spatial ability, but a serious disadvantage of multiple views (here amounting to nearly 30%) for students with the lowest spatial ability.

Table 1 Mean score on the post-test by learning condition expressed as percentage (standard error)

Learning conditions	*Programme-controlled*	*Learner-controlled*
Key views	57.7 (3.8)	49.0 (3.6)
Multiple views	42.2 (3.5)	48.1 (3.8)

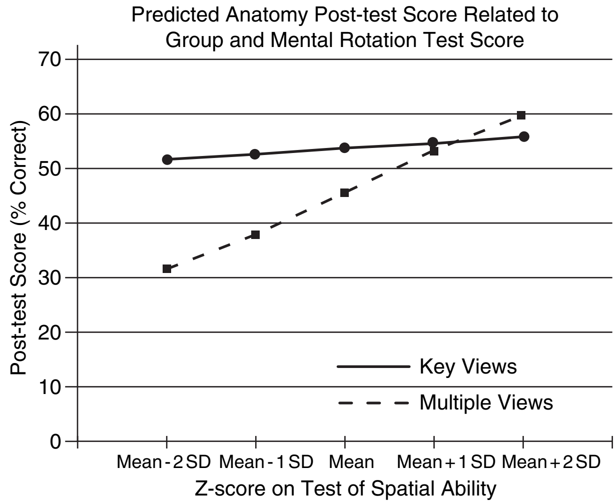

Figure 1 Predicted anatomy post-test score related to group and mental rotation test score

Phase 2

The means of the 2 groups PKV and SKV were not significantly different (22.8 versus 21.3). Thus more active learner involvement, at the level of selecting the anatomical label to highlight, offered no advantage.

DISCUSSION

In summary, these studies demonstrated better performance for learners exposed to more programme-controlled display of key views of the brain. Moreover, the disadvantage of multiple view presentation was greatest for those learners who had relatively low spatial ability, resulting in a reduction in performance of nearly 30%. The second phase of the experiment showed that a behaviourally inactive passive condition was similar to the most successful instructional condition from phase 1.

These findings can be viewed as disquieting. It is presumably a goal of all educational innovations to enhance learning, yet we have shown that the addition of dynamic simulation has a negative impact of learning on those who arguably need it most: students with relatively poor spatial ability. As a finding from a single study this might be dismissed; however, the finding is consistent with earlier studies examining instruction in wrist anatomy.[1,10,19]

There are some methodological and theoretical limitations for this study. Arguably, a more important outcome for medical education would be to look at more sophisticated tests of transfer of learning. Tests of retention, including the recognition of anatomical structures, represent a fairly simple kind of learning, but are arguably a prerequisite for more complex learning outcomes. Secondly, more sophisticated, realistic computer-generated learning materials may have produced different results. Thirdly, this result may not be generalisable, as other structures that are more difficult to visualise than surface anatomical structures might benefit from more sophisticated learning materials. Finally, the use of 1st-year psychology students as participants may not be representative of medical student populations, as prior knowledge and level of academic performance may be different in the two groups.[20–23] Despite the lack of correlation in our study between prior exposure to neuroanatomy instruction and outcome, there is some evidence that new knowledge acquisition may be a very different cognitive process than re-learning or re-activating prior knowledge, and more advanced learners may benefit from different types of presentations than learners new to a topic.[1,5,7]

Our finding that high degrees of learner control hamper learning has been shown in other contexts.[1,5–7,24] As Mayer describes,[1] behavioural activity such as clicking between e-learning screens of brain images is not the same as cognitive activity, which may be stimulated preferentially by the more passive, programme-controlled presentation of materials. In addition, many learners, medical students and professionals included, show evidence of poor metacognitive skills which may lead to the poorer performance in learner-controlled conditions.[8,25] These 2 factors may well have effectively decreased the time on task and resulted in the worse outcomes for those instructional conditions.

Why is it the case that the presentation of multiple views also depressed learning in this and some of our earlier studies on e-learning of carpal bone anatomy?[10–12] The answer may lie, at least in part, in the observation that learners in the LMV group spent most of their time (about 80% of total time) looking at key or near key views. Having to deal with multiple orientations of the brain images may depress learning by exerting undue cognitive load on the learner and decrease the learner's ability to lay down new memories.[1,5,26] Similarly, some literature suggests that learners may have to convert the more unfamiliar, oblique orientations of the brain into more familiar 'key' representations for processing, which would also effectively increase the cognitive load of the task.[13–17]

CONCLUSIONS

This study presents a challenge to frequently held beliefs about the nature of spatial and multimedia learning. It would seem self-evident that learners would derive considerable benefit from the potential of the computer to present visualisations of the structures in multiple orientations. However, these studies have shown that under some circumstances the presentation of complex multimedia instruction under learner control may do more harm than good. Further research into the benefits and adverse effects of e-learning for medical education and training is warranted.

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