USER ACCEPTANCE OF A HAPTIC INTERFACE FOR LEARNING ANATOMY

Soonja Yeom[1], Derek Choi-Lundberg[2], Andrew Fluck[3] and Arthur Sale[1]
[1]School of Computing and Information Systems, University of Tasmania, Australia
Private Bag 100 Hobart, Tasmania, Australia
[2]School of Medicine, University of Tasmania, Australia, Private Bag 34 Hobart, Tasmania, Australia
[3]School of Education, University of Tasmania, Australia, Locked Bag 1307 Launceston, Tasmania, Australia

ABSTRACT

Visualizing the structure and relationships in three dimensions (3D) of organs is a challenge for students of anatomy. To provide an alternative way of learning anatomy engaging multiple senses, we are developing a force-feedback (haptic) interface for manipulation of 3D virtual organs, using design research methodology, with iterations of system implementation, formative evaluation, and cyclic enhancements. In the present study, we aimed to determine the user acceptance of the haptic interface for exploring anatomical structures and relationships. Undergraduate computing (n=10) and medical (n=35) students from the University of Tasmania, Australia, who volunteered to try two iterations of the system (n=18 and 27 in two separate user tests) reported on anonymous questionnaire with quantitative and qualitative questions that the system was easy to use, useful for learning, and neither physically nor mentally stressful. We conclude that many medical students would accept a haptic interface for manipulating 3D virtual organs as an aid to learning anatomy. Further development of the system will involve development of learning and assessment modules, and we plan to evaluate the system's usefulness in promoting learning of anatomy.

KEYWORDS

Anatomy, haptic interface, technology-enhanced learning, higher education, medical education

1. INTRODUCTION

Efforts to improve learning experiences with technology have been actively pursued for decades (Reiser, 2001). Different teaching strategies and learning resources vary in effectiveness for learners with different learning styles (Murphy et al., 2004, Dobson, 2009); thus, offering a variety of learning options is pedagogically sound. This article describes the initial stages of development and evaluation of a system for exploring three-dimensional (3D) anatomical structure and relationships of human organs with haptic feedback.

As students of human biology may have only limited time to learn from real human organs or realistic 3D physical (eg, plastic) models, such a system provides an additional option for exploring 3D anatomical structures, making use of new technological opportunities to enhance learning experiences through activating multiple sensory systems of the learner. Students have reported difficulty in learning anatomy from 2D resources such as textbook diagrams (Yeom, 2011). Providing a 3D model with haptic feedback reduces the gap between a learning system and reality. When information is presented in a multisensory format, it improves learning and memory ability (Shams and Seitz, 2008). A display device and a controlling device are the main computer peripherals required for this system. This study investigated the acceptance of a haptic system with 3D anatomical models for learning anatomy by undergraduate computing and medical students at the University of Tasmania (UTAS).

3D simulations with interaction in anatomy, radiological imaging, and surgery is an active research area (Behringer et al., 2003, Chien, 2010, Dieperink, 2006, Nicholson et al., 2006, Sakellariou et al., 2009, Tan et al., 2012, Temkin et al., 2006, Yushkevich et al., 2006, Liao et al., 2010). For example, learning from a 3D computer model and standard two-dimensional (2D) images of laryngeal anatomy did not differ, but learners preferred the 3D model (Tan et al., 2012). In contrast, Nicholson et al. (2006) found learning outcomes were improved with 3D computer models of the ear compared to traditional 2D images, possibly due to greater interactivity and complexity of the 3D computer models vs the 2D images. Computer-generated 3D models may be particularly effective in providing visualization of anatomy that is hard to represent through traditional 2D images (Sakellariou et al., 2009). User responses to virtual reality (VR) with a haptic interface were "positive and the majority of users found the VR system more engaging, interesting and easy to use and more efficient in elucidating spatial inter-relationships of structures" (Sakellariou et al., 2009). However it is unclear whether the positive results were due to 3D models produced in VR, the haptic interface, or a combination of both. The effectiveness of a haptic interface may not be easy to measure due to the complexity of the system, with interactivity, quality of the system, and learning outcome goals important additional variables (San Diego et al., 2012).

As educational research incorporating haptic technology for learning human anatomy in health fields is currently mostly limited to advanced, post-graduate trainees, our research aims to determine if a haptic interface can assist undergraduate medical students in learning anatomy. Our overarching research question is to determine whether learning anatomy in a 3D system with a force-feedback palpable (haptic) control will enhance anatomy learning and transfer of knowledge into realistic settings. As a work-in-progress, research sub-questions are to investigate if the haptic interface will lead to more effective learning, whether users accept a haptic interface to learn anatomy, and what factors affect learning and user acceptance. This paper focuses on evaluating user acceptance of the haptic interface.

2. METHODOLOGY

We used the design research approach, with iterations of system implementation, formative evaluation and cyclic enhancements to develop our haptic system (Bannan-Ritland, 2003; Collins et al., 2004; McKenney, 2001 and Reeves, 2006). To date, the system has been through two phases of development and user tests.

2.1 Interface and Interaction

The interface domain in this study comprises 3D modeling and 3D interface space with the Phantom Omni haptic device (Figure 1), which provides six degrees of freedom: three for position (x,y,z) and one each for pitch, yaw and roll (rotation in the forward vertical, horizontal and transverse planes). Force feedback gives different amounts of resistance to an input depending on the state of the virtual operation.

Figure 1. Haptic device (Phantom Omni) used in the system and user tests

The system supports functions such as moving selected organs, zooming, and rotating. Particular parts of an organ can be selected to display its name (Figure 2), and these labels can be turned on or off.

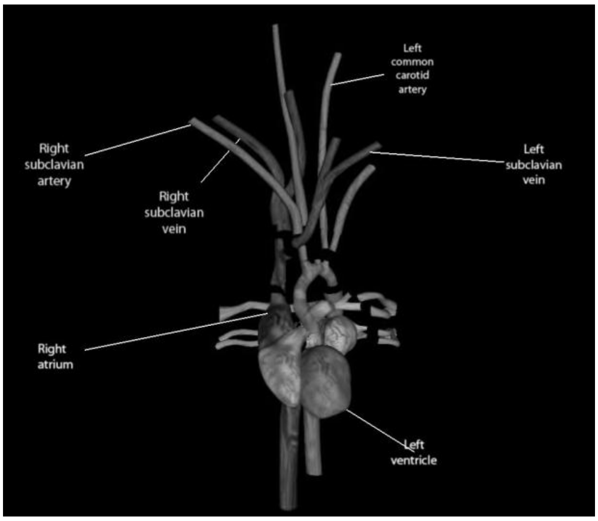

Figure 2. Screenshot of organs displayed in user test 2. Several labels have been turned on

The user receives tactile feedback, the force of which depends upon the part pressed. For example, different levels of surface deformation were set: the lung is 'spongy' (Figure 3), while the liver is firm. In Figure 3, the lung surface is being deformed, and the user is experiencing haptic feedback.

Figure 3. Screenshot of the lungs displayed with surface deformation in user test 1

The organs displayed in user test 1 included the lung, liver, and heart. For user test two, the organs displayed were the heart with its four chambers, and numerous blood vessels.

2.2 Development Environment

The computer system used in user test 1 was an Intel ® Core ™ Duo CPU @ 2GHz, RAM 2GB. An upgraded system was used in user test 2, which provided more sensitive feedback to the user. Its specification was Intel® Core ™ i7-2600 CPU @ 3.4GHz, RAM 16GB.

2.3 Formative Evaluation

To investigate user acceptance of the haptic interface, we recruited first to third year undergraduate medical students and computing students at UTAS to try the system. For user test 1, an email invitation was sent to all (n=230) second and third year medical students. In addition, computing students engaged in activities in a computer lab were invited to test the system, which was set up in an office. For user test 2, all first year medical students (n=115) were invited to test the system during a practical laboratory class.

Demographic information and prior experience with computers and haptic devices was gathered from participants prior to each test via a short questionnaire. After a brief introduction to using the system, each user was free to explore it. The lead researcher and a research assistant observed the users, to observe how they learned to use the interface and any difficulties they encountered. After exploring the system, participants were asked to complete a questionnaire with both visual analogue scale (VAS) questions and an open response comment box on their experiences with the system.

Results of quantitative questions are presented as mean, standard deviation (SD), and standard error of the mean (SEM). T-tests were used to compare results from user tests 1 and 2, with significance level conservatively adjusted to $\alpha = 0.01$ using the Bonferroni correction for multiple comparisons (type I family-wise error rate of $\bar{\alpha} = 0.05$ divided by 5, the number of comparisons). Quantitative analysis was performed in Excel and SPSS. Qualitative analysis of open response comments was through coding and identifying themes (Braun and Clarke, 2006).

3. RESULTS

3.1 User Test 1 Settings and Demographics of Participants

We emailed all year 2 and 3 Bachelor of Medicine, Bachelor of Surgery (MBBS) students at UTAS (n=230), inviting them to participate in our research project by trying the haptic system and completing a questionnaire. The system was set up in a vacant tutorial room at the School of Medicine campus, three times for two hours each, when at least some of the students did not have classes. In addition, some computing students at UTAS were invited to participate (n=20). The system was set up in an office at the School of Computing and Information Systems for two days.

In total, 18 students, 15 males and 3 females, tried the system and completed the questionnaire, including eight medical students (3.5% response rate) and ten computing students (50% response rate). The average age of all participants was 23, and four reported previous experience with haptic devices, but none with the Phantom Omni haptic device.

3.2 User Test 2 Setting and Demographics of Participants

Sample size calculations ($n = 2*[(z_\alpha - z_\beta)\sigma/(\mu_1-\mu_2)]^2$), based on an estimate of standard deviation (σ) of 22 derived from the average of the observed standard deviations on the five VAS questions relating to user acceptance in the first user test, and a desire to detect a difference in mean scores ($\mu_1-\mu_2$) of 20 on the 100-point VAS with β=0.20 (power = 0.80, z_β=-0.84), yielded required sample sizes of n=19 at α=0.05 (z_α=1.96) and n=29 at α=0.01 (z_α=2.575). We emailed all year 1 MBBS students at UTAS (n=115), inviting them to participate in our research project by trying the system and completing a questionnaire. The system was set up at two practical laboratory sessions, each two hours long with half the class each. Twenty-seven students (23% response rate), 16 males and 11 females, tried the system, but only 25 participants completed the questionnaire, with two participants each not answering one question. More students wanted to try the system than were able to, and many students watched other students using the system. The average age of all participants was 19, and one reported previous experience with haptic devices, described as a mobile phone.

3.3 User Acceptance of the Haptic System

Participants were asked to complete a questionnaire immediately after using the system, which included VAS responses (scale of 0 to 100) and an open response comment box. The design of the questionnaire was based on the Technology Acceptance Model (TAM). According to the model, acceptability of a system is determined by two main factors, perceived usefulness and perceived ease of use (Chuttur, 2009). On average, participants rated the interface useful, easy to use, indicated that they performed well with the interface, and reported low levels of mental and physical stress (Table 1).

Table 1. Comparison of questionnaire responses in user tests 1 and 2

Question	User Test	n	Mean	SD	SEM	t	p
Did you perform well with the interface? (0=very poor to 100=very good)	1	18	71	19	4.5	1.02	.32
	2	24	63	22	4.5		
Was the interface useful? (0=totally useless to 100=very useful	1	18	81	15	3.5	1.87	.07
	2	24	69	17	3.5		
Was it easy to use? (0=very difficult to 100=very easy)	1	18	73	18	4.2	2.13	.04
	2	25	58	20	4.0		
Did you become mentally stressed? (0=not at all to 100=very stressed)	1	18	22	30	7.1	-.44	.66
	2	25	32	27	5.4		
Did you become physically stressed? (0=not at all to 100=very stressed)	1	18	21	29	6.8	1.22	.23
	2	25	17	19	3.8		

Observing the participants using the haptic device during the first user test, we noted that when the cursor was moved too far in the z-axis, users found it hard to bring the cursor back. This was mitigated by the faster computer in the second test. The status of developed prototype was the main difference between two user tests. The user test 1 version included only three organs (heart, lungs, liver), and provided basic interaction with 3D models and haptic feedback. The user test 2 version had 28 objects (heart chambers and blood vessels), and increased functionality including clicking to make labels appear. There were some speed issues with version 2 when the users tried to do more complex activities such as moving smaller objects.

The questionnaire responses show that ease of use and perceived usefulness of the haptic interface decreased somewhat in the second test compared to the first, but these were not statistically significant at $p = 0.01$ (adjusted for multiple comparisons). In both user tests, most participants were using the haptic interface well after a few minutes. Questionnaire responses from the second user test indicated most participants would like to use the system as an aid to learning when fully developed, with an average value of 75 out of 100 (n=21 respondents to this question, SD=17, SEM=3.8; 0=not at all to 100=very likely). Responses to this question correlated positively with the questions on usefulness ($r^2=0.56$), ease of use ($r^2=0.31$), and performing well ($r^2=0.14$); however, there was no correlation with physical stress ($r^2<0.01$), and a weak negative correlation with mental stress ($r^2=0.07$).

Qualitative analysis of written comments on any aspect of the system involved coding the responses across both user tests, with 19 participants providing written comments. Seven participants requested additional functionality, relating to greater anatomical detail, more options to manipulate organs, or additional physiology or pathology content. Seven participants described system interface problems, relating to difficulty with placing the cursor, slow or jittery response, or the cursor getting stuck. In contrast, five participants praised the haptic feedback or other functionality, such as the ability to rotate organs. For example, one wrote: “I felt that the interface was appropriate for the task, with a high level of fine control permitted. I was impressed with the texture and density feedback test, there was a definite difference between the lung and liver in terms of feedback through the haptic interface.” One participant wrote they didn’t learn anything, another questioned usefulness for learning, and one described it as “fun”. In contrast, two participants described the system as a useful learning tool, and two others wrote they would like to try it again when further developed.

4. DISCUSSION

Our main finding was that the majority of undergraduate computing and medical students who participated in this research study were favorable towards a haptic interface for exploring the structure and relationships of virtual 3D organs (Table 1). Our observations of the participants during the user tests suggest that students can rapidly learn to use the features of the system (moving organs, rotation, zooming, pressing organs). This was confirmed in questionnaire responses that most users found the system easy to use. This concurs with earlier work showing the 'naturalness' of the haptic interface, and the ease with which users adapt to it (Massie and Salisbury, 1994, Sankaranarayanan et al., 2003). The intuitiveness and ease of using a system like this should minimize extraneous cognitive load while learning from the system. However, open response feedback from the questionnaire indicates that further work is needed to smooth responsiveness of the cursor to movement of the haptic device; greater processor speed would assist. Many students would also like additional functionality to increase the potential to learn from the system. Most participants indicated they would like to use the system as an aid to learning when it is fully developed, suggesting intention to use this system. In agreement with the technology acceptance model (Chuttur, 2009), behavioural intention to use the system correlated strongly with perceived usefulness ('was the interface useful?', r^2=0.56) and perceived ease of use ('was it easy to use?', r^2=0.31).

The majority of participants in this study were young males. There were no obvious gender differences in accepting the new interface, with both males and females expressing enthusiasm. The smaller number of female volunteers may have been because fewer females were interested in trying a new technology system, or, in the second user test conducted during a regularly scheduled class (laboratory practical session), females may have been more focused on their learning tasks than males. We did not have a large enough number of participants to enable comparing responses by participant age. Anecdotally, one mature-age student showed frustration and stopped using the system. The current generation of 18-20 year old undergraduate students are 'digital natives' who have used technology since they were 5 or 6 years old (Prensky, 2001), confirmed in our questionnaire demographic data. In contrast, some older students may be less comfortable with new technology.

The greater interest (response rate) in the second test compared to the first may have been due to students seeing the haptic device, and watching others trying the device and expressing enthusiasm. In addition, the anatomical structures displayed (heart and blood vessels, Figure 2) were related to the learning objectives of the laboratory practical session (relating to introductory anatomy of several organ systems, including the cardiovascular system) at which the system was set up.

A limitation of this study is potential self-selection bias in the samples of students that tested the system. In the first user test, computing students and year 2 and 3 medical students were invited to try the system via email; there was a very low response rate (3.5%) from the medical students. In the second test, the system was set up in a laboratory practical class for first year medical students, and a higher, but still low response rate (23%) was obtained. In both cases, the students electing to participate in the research and try the system may have had a positive bias towards accepting new technology. Thus, the high level of user acceptance, and low self-reported levels of stress, may differ from the general undergraduate student population.

Although the user acceptance was not statistically significantly different between the first and second user tests, there were trends for decreased acceptance levels. Sample size calculations at power of 0.80 (80% chance of detecting an actual difference) yielded n = 19 or 29 at α=0.05 or 0.01, respectively. Our actual numbers of respondents to the questions were 18 and 24-25 in user tests 1 and 2, respectively, indicating we had somewhat less chance of detecting an actual difference between our two user tests. The trends towards decreased acceptance may have been due to different sample populations. In the first test, computing students and second and third year medical students were invited to participate. In the second test, we selected the group of students more likely to use the system in its present level of anatomical complexity, that is, first year medical students. It is possible that computing students, in particular, may have had a higher level of acceptance of the new technology.

5. CONCLUSION

We conclude that undergraduate medical students accepted a haptic interface to explore the structure and anatomical relationships of virtual 3D organs. However, the low response rate and positive self-selection may have resulted in a more positive response than the population. Additionally, positive responses may have been due to a novelty effect or that they were being observed trying the system. Further development of our system will provide another learning resource that engages multiple sensory systems for use by undergraduate medical students. However, a factor limiting wider availability of this system is the requirement for the computer peripheral, the haptic device. The next phase of the research is to develop learning activities including formative assessment opportunities, and testing materials to measure the users' learning achievement with the system compared to traditional learning resources.

ACKNOWLEDGEMENT

We thank the students that participated in the tests, and acknowledge the support of UTAS through a teaching development grant. This study was approved by the Human Research Ethics Committee at UTAS (ethics approval number H0011743).

REFERENCES

Bannan-Ritland, B., 2003. The Role of Design in Research: The Integrative Learning Design Framework. *Educational Researcher,* Vol. 32, No. 1, pp. 21-24.

Behringer, R. et al, 2007. Some Usability Issues of Augmented and Mixed Reality for e-Health Applications in the Medical Domain. *HCI and Usability for Medicine and Health Care Lecture Notes in Computer Science,* Vol. 4799, pp. 255-266.

Braun, V. and Clarke, V., 2006. Using Thematic Analysis in Psychology. *Qualitative Research in Psychology*, Vol. 3, No. 2, pp. 77-101.

Chien, C. et al, 2010. An Interactive Augmented Reality System for Learning Anatomy Structure. *International MultiConference of Engineers and Computer Scientists.* Hong Kong, pp. 370-375.

Chuttur, M., 2009. Overview of the Technology Acceptance Model: Origins, Developments and Future Directions. *Sprouts: Working papers on Information Systems,* Vol. 9, No. 37 http://sprouts.Aisnet.org/9-37

Collins, A. et al, 2004. Design Research: Theoretical and Methodological Issues. *Journal of the Learning Sciences,* Vol. 13**,** No. 1, pp. 15-42.

Dieperink, B., 2006. *The Effect of Retroactive Interference on Anatomical Learning Using a Virtual Learning Environment.* Thesis, University of Twente. http://essay.utwente.nl/58744/

Dobson, J., 2009. Learning Style Preferences and Course Performance in an Undergraduate Physiology Class. *Advancement in Physiology Education,* Vol. 33**,** No. 4, pp. 308-314.

Dunser, A. et al, 2008. A Survey of Evaluation Techniques Used in Augmented Reality Studies. HITlab, Christchurch, NZ.

Liao, H. et al, 2010. 3-D Augmented Reality for MRI-Guided Surgery Using Integral Videography Autostereoscopic Image Overlay. *IEEE Transactions on Biomedical Engineering,* Vol. 57**,** No. 6, pp. 1476-1486.

Massie, T. and Salisbury, J., 1994. The PHANTOM Haptic Interface: A Device for Probing Virtual Objects. *Proceedings of the American Society of Mechnical Engineers, Winter Annual Meeting*. *Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems.* https://alliance.seas.upenn.edu/~medesign/wiki/uploads/Courses/Massie94-DSC-Phantom.pdf

Mckenney, S., 2001. *Computer-based Support for Science Education Materials Developers in Africa: Exploring Potentials.* PhD Thesis, University of Twente.

Murphy, R. et al, 2004. Student Learning Preferences and Teaching Implications. *Journal of Dental Education,* Vol. 68**,** No. 8, pp. 859-66.

Nicholson, D. et al, 2006. Can Virtual Reality Improve Anatomy Education? A Randomised Controlled Study of a Computer Generated 3D Anatomical Ear Model. *Medical Education*, Vol. 40**,** No. 11, pp. 1081-1087.

Prensky, M., 2001. Digital Native, Digital Immigrants Part 1. *On the Horizon*, Vol. 9, No. 5, pp. 1-6.

Reeves, T., 2006. *Design Research from a Technology Perspective.* Routledge, London,England.

Reiser, R., 2001. A History of Instructional Design and Technology: Part I: A History of Instructional Media. *Educational Technology Research & Development,* Vol. 49**,** No. 1, pp. 53-64.

Sakellariou, S. et al, 2009. Design and Implementation of Augmented Reality Environment for Complex Anatomy Training: Inguinal Canal Case Study. *In:* Shumaker, R.. (ed.) *Virtual and Mixed Reality.* Springer-Verlag. LNCS 5622, pp. 605-614.

San Diego, J. et al, 2012. Researching Haptics in Higher Education: The Complexity of Developing Haptics Virtual Learning Systems and Evaluating Its Impact on Students' Learning. *Computers & Education,* Vol. 59**,** No. 1, pp. 156-166.

Sankaranarayanan, G. et al, 2003. Role of Haptics in Teaching Structural Molecular Biology. *Proceedings of the 11th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems*. http://www.hitl.washington.edu/publications/r-2003-16/r-2003-16.pdf

Shams, L. and Seitz, A., 2008. Benefits of Multisensory Learning. *Trends in Cognitive Science,* Vol. 12, No. 11, pp. 411-417.

Tan, S. et al, 2012. Role of a Computer-generated Three-dimensional Laryngeal Model in Anatomy Teaching for Advanced Learners. *Journal of Laryngology and Otology,* Vol. 126**,** No. 4, pp. 395-401.

Temkin, B. et al, 2006. An Interactive Three-dimensional Virtual Body Structures System for Anatomical Training Over the Internet. *Clinical Anatomy,* Vol. 19**,** No. 3, pp. 267-74.

Yeom, S., 2011. Augmented Reality for Learning Anatomy. *Proceedings of ASCILITE.* Hobart, Australia, pp. 1377-1383.

Yushkevich, P. et al, 2006. User-guided 3D Active Contour Segmentation of Anatomical Structures: Significantly Improved Efficiency and Reliability. *NeuroImage,* Vol. 31**,** No. 3, pp. 1116-1128.