Multi-Session VR Medical Training - The HOPS Simulator

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Virtual reality medical simulators offer the potential to provide a training environment for a novice doctor to practice skills without risk to patients. However, these simulators must be shown to provide learning before they are used in a medical training environment. This paper describes the first stage of an experiment to assess the effectiveness of the Glasgow Horse Ovary Palpation Simulator for training novice veterinary students. The performance on the simulator of a group of participants has been measured over multiple training sessions. The results show that over 4 training sessions, participants improved in their accuracy in diagnosis on the simulator while reducing the time required to make the diagnosis.

Keywords: haptic interaction, force feedback, virtual reality training, medical simulation

1 Introduction

There are inherent problems in training medical personnel. Serious ethical considerations must be addressed, particularly in providing training for procedures where a mistake can lead to permanent injury or can prove fatal for the patient. Traditional methods of training - such as would be provided by anatomy labs - do not provide the flexibility or realism required for training. The apprenticeship approach is most often used in both human and veterinary medicine. The student will watch many procedures performed by an experienced doctor or veterinarian before performing the procedure themselves under the expert's supervision. There is an obvious risk to the patient in this instance.

Virtual Reality (VR) simulations are increasingly being researched for use as a training tool in medicine. They have the potential to provide a safe, controllable environment for novice doctors to learn, allowing them to make mistakes without consequences to the patient. It is also possible to integrate both the anatomy and physiology, which is not possible in an anatomy lab. A wide range of reusable rare conditions and complications can be modelled and presented to a user when required. VR training also offers the possibility of providing a standardised performance rating for any user which is not possible with traditional teaching methods. Currently, a doctor's ability to perform a procedure is most often based on the number of times he/she has performed it. This may provide an inaccurate measure. By assigning tissue properties to the virtual model, and monitoring the user's actions and forces used, it is possible to objectively rate his/her performance on metrics such as tissue damage. Only through appropriate presentation of this performance feedback can users adjust their behaviour to improve performance. VR simulators are now widely thought to offer the potential of providing a new medical training paradigm. As such, commercial as well as research systems are being developed worldwide. For a simulator to become an accepted training tool, however, it is necessary to show that it improves performance for the task it is modelling.

1.1 Computer Haptics Overview

Computer haptics refers to interaction with a computer through the user's sense of touch. When interacting with a virtual environment such as a medical simulator using a haptic device, users can feel their interaction with the virtual objects. Current haptic devices can be separated into two categories: tactile and force feedback. Tactile technologies (such as a Braille device) stimulate the skin to generate the sense of contact with an object. Force feedback devices stimulate the kinaesthetic system, restricting the motion of users by applying forces to the fingers, hand or body.

An example of a high-resolution force feedback device is the PHANToM from SensAble Technologies (Massie and Salisbury, 1994). The PHANToM allows a user to interact with a virtual environment through a single point. The user can move freely in 6 degrees of freedom (X, Y, Z, roll, pitch, and yaw). The device can also provide 3 degrees of high-resolution force feedback to resist or assist motion in the X, Y and Z dimensions. By using the standard GHOST toolkit, geometric and VRML objects can be incorporated into a PHANToM environment to provide the touchable model. For each of these models, stiffness, friction and damping properties can be set to provide a variety of different feels.

1.2 Medical Simulation Overview

Virtual medical simulations are becoming more common, and as the fidelity increases, they are expected to become more widely accepted as a training aid. Flight simulations are often used as an analogy in that they provide training in a multi-dimensional, safety-critical task. Although not widely accepted for many years, improved technology has lead to more realistic simulations that have proved useful in developing, maintaining and assessing pilot skill. They have been successfully used to simulate a wide range of conditions and emergencies, while reducing the learning curve for trainee pilots by providing a safe, controllable learning environment (Rolfe and Staples, 1986).

Simulation training is not a new idea in human and veterinary medicine. Students gain experience in certain techniques through use of plastic or rubber models, but these often lack realism and provide no useful feedback to the trainee. Surgical skills can also be improved in the anatomy labs that are incorporated into the medicine and veterinary medicine courses. Again, there are problems however since cadavers are a scarce resource, and are not generally reusable. Living tissue can also have noticeably different haptic properties than cadaver tissue (Higgins et al., 1997). VR medical simulators have the potential to present anatomical and physiological information to the user simultaneously on reusable models. Simulations currently developed can be divided into those that provide training for minimally invasive surgery (MIS), surgery, or palpation procedures. MIS simulators are by far the most common (Bro-Nielsen et al., 1999, Kühnapfel et al., 1999, McCarthy et al., 1999, Sherman et al., 1999). In an MIS procedure, surgeons view their interaction with the patient through a monitor, and hence, it lends itself to a virtual simulation. The Preop endoscopic simulator (Bro-Nielsen et al., 1999) developed by HT Medical Systems is one example of a system combining a force feedback MIS training system with anatomical and physiological models. Other systems exist to simulate other MIS procedures such as arthroscopy or laparoscopy. SKATS (Arthur et al., 1999) and VE-KATS (Sherman et al., 1999) present knee arthroscopy training systems.

Surgery simulations cover a wide range of techniques using different surgical instruments. Cathsim (Barker, 1999) is an example of a commercially available training system for venipuncture. Users of Cathsim can practice inserting a needle into a virtual vein with different scenarios available. Berkley et al. (Berkley et al., 1999) present a simulation for training in wound suturing with real time deformable tissue to increase the fidelity of the simulation. Simulation for cutting procedures in particular present problems as models need to be dynamically adjustable, to allow incisions. Delp et al. (Delp et al., 1997) have developed tissue cutting and bleeding models for this purpose.

The development of a palpation simulation presents different problems than a surgery simulation. During surgery, a medical practitioner interacts with the patient through surgical instruments, so the quality of haptic feedback from the tissue to the surgeon is degraded. Palpation, however, involves the medic interacting directly with skin or tissue. The development of palpation simulators tends to be less common, although palpation is an important technique for the diagnosis of many conditions. Two recent examples come from the Human Machine Interface Laboratory at the CAIP Center at Rutgers University. They have developed a simulation using the Rutgers Master II for training in palpation for the detection of sub-surface tumours using experimentally based force-deflection curves (Dinsmore et al., 1997). They also present a prostate simulator developed using the PHANToM, which can model several different prostate conditions.

One of the most important aspects of a virtual training system is that a user can be given a standard performance rating for the procedure performed. Determining the performance in a medical procedure is difficult however, since it can be a complex, multi-dimensional task with many different outcomes - not just success or failure. Metrics will depend on the training task performed. Gorman et al. (Gorman et al., 1998) suggests the following metrics for a task involving driving a simulated needle through a target overlaying a blood vessel: time on task, accuracy, peak force applied, tissue damage, surface damage, and angle error. However, they note the difficulty in calculating tissue or surface damage accurately. For a palpation simulator where the user may wish to examine the whole of an object for specific shape or surface properties, accuracy and angle error may not be so relevant. Particularly in training for diagnosis, metrics can be very high level. For example, in Glasgow University's Horse Ovary Palpation Simulator (HOPS) (Crossan et al., 2000), users palpate the ovaries for a follicle to diagnose the stage of ovulation of the horse. The users might be asked "Does a follicle exist on either ovary, and if so, what size is the follicle". Systems exist to allow user performance to be stored over many training sessions (Bro-Nielsen et al., 1999), such that any trends of improvement or otherwise can be noted. This could eventually lead to an objective method of certification of medical trainees (Higgins et al., 1997). O'Toole et al. (O'Toole et al., 1997) present a study suggesting that experienced surgeons perform better than novice surgeons on the metrics defined on their surgery simulator.

2 Horse Ovary Palpation

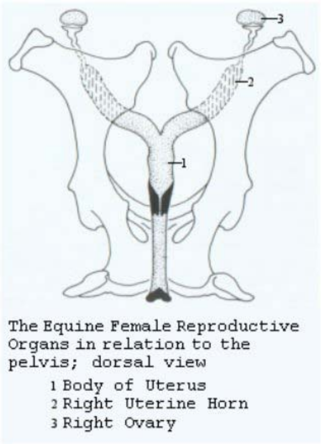

Figure 1. Dorsal view (from above) of the reproductive system of a non-pregnant mare.

During an ovary examination, the vet inserts a gloved hand into the pelvic area of the horse through the rectum. The vet must search through the pelvic region of the horse for the uterus. The ovaries are attached to the uterus, and each can be found by following either the left or right uterine horn. This is difficult since the vet must perform this search through touch alone. It usually requires several attempts before an inexperienced student can locate an ovary. Once located, the vet will cup the ovary with one or more fingers, and palpate it using his/her thumb. In particular they will look for any abnormalities in the shape or surface properties of the ovary, and through experience, will be able diagnose different conditions through touch alone. For the purposes of the Glasgow University simulator, follicles of different sizes can be placed at different positions on the ovary models. A follicle is a roughly spherical fluid filled sac that grows on the surface of an ovary. Some of this sac exists under the surface. It will typically grow from a small size to a few centimetres in diameter. As the follicle grows, it will also tend to move towards the centre of the ovary. Depending on the size, position and feel of the follicle a vet can diagnose the stage of ovulation of the horse. There may be many follicles on each ovary, but only one follicle will eventually ovulate. Other surface features may exist on the ovary surface. A corpus luteum feels similar to a follicle and may therefore be mistaken for one. Unlike a follicle however, it is ridged around the edge. Ovarian cysts or tumour may also exist, but are less common. Below are given some typical descriptions of the common objects involved.

An ovary is a hard fibrous object. It may feel similar to many objects in the abdomen and is therefore difficult to identify. A corpus luteum is object on an ovary's surface that may feel similar to a follicle. However, unlike a follicle, it has a thick walled with a ridge. A follicle is a thin walled, soft partially submerged object on an ovary's surface. Horse veterinarians were closely involved when developing the shape and haptic properties for the virtual ovaries.

The core skills involved in this procedure are location and identification of the ovaries, and recognition of surface features on the ovaries. Ultrasound scanning is now often used to identify the surface features. However, the Glasgow University Veterinary School still considers palpation as an important technique for students to learn.

Students are expected to participate in training outwith the Glasgow veterinary course. Approximately five percent of all students will get placements in an equine practice. This is one of the most useful ways of gaining experience in equine welfare. However, particularly for an invasive procedure such as ovary palpation, a student may still not get a chance to examine a horse. A veterinarian is often paid for the time spent performing examinations, and clients may be unwilling to pay for the time it would take to teach a novice. A horse owner is also unlikely to allow an inexperienced student to examine his/her horse, as there is the possibility of causing injury.

3 Multi-Session Training Study

A previous study has shown that over one training session, participants trained using the HOPS simulator perform no worse on specimen ovaries than participants trained using traditional methods (Crossan et al., 2000). In this case, performance was based on the correct location and sizing of a follicle on the specimen ovaries. This study also showed that there was a low percentage of correct identification in both cases (~11% correct), which suggests current methods of teaching can be improved upon. This experiment will build on the previous work with the HOPS simulator by examining the effect on performance of multiple training sessions.

3.1 Hypotheses

3.1.1 Hypothesis 1

The independent variable for hypothesis 1 is the quantity of haptic training that the participants receive. The dependent variable is the performance level on the virtual ovaries. Performance is defined by the number of follicles that have been placed correctly on an ovary, and the correct sizing of these follicles.

The performance level of the participants on the simulator will significantly improve with an increasing number of training sessions.

3.1.2 Hypothesis 2

The independent variable for hypothesis 2 is the quantity of haptic training that the participants receive. The dependent variable is the time taken to complete the examination of the ovaries. The time required to complete the task will significantly decrease as the participant receives more simulator training.

3.1.3 Hypothesis 3

The independent variable for hypothesis 3 is the quantity of haptic training that the participants receive. The dependent variables are individual workload, confidence and overall workload when examining the virtual ovaries.

The measured individual workload factors when examining the virtual ovaries will significantly decrease as the participants receive more simulator training. Participants' overall workload will significantly decrease while confidence will significantly increase.

3.2 Participants

One group of participants was involved in the experiment. The group consisted of second year veterinary students at Glasgow University Veterinary School who have learned the theory of ovary palpation from lectures, but have no practical experience of in-vivo ovary palpation through university teaching. There were eight participants - seven female and one male. All were regular computer users, but none had any previous exposure to the PHANToM.

3.3 Experimental Set-up

Participants interacted with the HOPS environment using a PHANToM 1.5 from SensAble Technologies with the standard thimble attachment. The simulation was run on a 700 MHz dual-processor PC. The equipment for the experiment was set up as shown in Figure 2. The participants wore headphones to mask noises produced by the PHANToM motors.

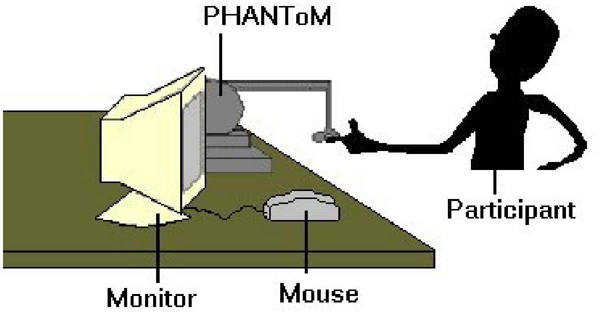

Figure 2. The experimental set-up used. Participants interacted through the PHANToM. Ovary models and PHANToM interactions were not displayed to the user on-screen, while the mouse was used to start and stop examinations

3.4 Design

3.4.1 Training

As participants had no previous exposure to the PHANToM, they took part in an initial training session immediately before the first haptic training session. This training stage was designed to familiarise users with interacting with a three dimensional environment using the PHANToM. They were each presented for five minutes with a standard environment supplied by SensAble Technologies that allowed participants to interact with moveable boxes. Participants could both feel their interactions through the PHANToM, and see their interactions on the screen. The participants were then presented with an environment containing a haptic only representation of two spheres. In this condition, they could not see the spheres or the PHANToM cursor on the screen.

Initially the size of the spheres varied. Each participant was asked to state whether the left or right sphere was larger or they were equal size using touch alone. A random selection of each of these cases was presented to participants to explore until they reach an appropriate level of performance. There was no time limit for the exploration, but participants proceeded after answering five cases correctly.

A similar training session was provided for training in softness discrimination using the PHANToM. The same environment containing two spheres was used although the size of the spheres remained constant while their softness was varied. Participants stated whether the left or right sphere was softer, or whether they were of equal softness. Once again there was no time limit, and the participant proceeded after answering five cases correctly.

These training stages were only presented to the user before the first experimental session. They were designed to provide some initial familiarisation of the PHANToM as well as training in size and softness discrimination, and locating objects though touch alone. These skills were important for the experimental task.

In addition to the above training, users were presented with a visual and haptic representation of the HOPS environment (shown in Figure 3) before each experimental session. The participants were asked to explore the plain environment - no surface features - for five minutes.

3.4.2 Task

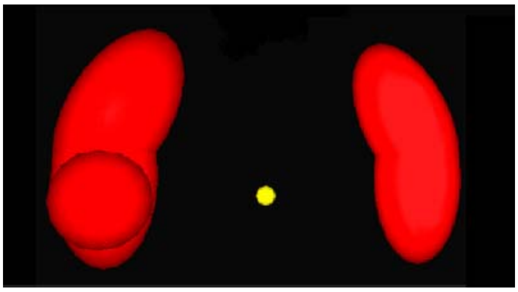

Figure 3. The Horse Ovary Palpation Simulator. This environment consists of a left and right ovary. On the bottom half of the left ovary, a spherical follicle can be seen. The user's cursor is shown as the sphere in the centre.

All participants were presented with the same thirty-two ovary cases over the four training session, but in counterbalanced orders. There were four orders of presentation with two participants being presented with each ordering. In one experimental session, participants were each presented with eight ovary cases. Also, in each experimental session, the total number of follicles in all cases was kept constant at seventeen. For each case, participants were told that there were zero, one or more follicles present on either ovary and were allowed five minutes to explore the environment while identifying all follicles. Identification involved positioning the follicle on the left or right ovary, the front or back of the ovary, and top or bottom half of the ovary. Once identified, participants were asked the size of the follicle. They were told that the follicles would either be 2cm, 3cm or 3.5cm in diameter. Participants started and stopped each case using the mouse. If a case was explored for five minutes, he/she was alerted that his/her time for examining the current case was finished and was allowed to proceed to the next case.

Time measurements were taken for each case. As timing information would be affected by the number of follicles found in a case, there were equal numbers of cases of equal complexity in each experimental session. Therefore, there were two one-follicle cases, three two-follicle cases and three three-follicle cases presented in each session.

Participants were asked to complete a NASA TLX workload evaluation form after each experimental session had ended. Four such experimental sessions spaced a week apart were performed by each participant. Participants were not told if their answers were correct or incorrect at any time during the experiment. This was to ensure that measured confidence values were not affected by results, and that all training was as a result of time spent using the simulator.

3.5 Results

Correctness data for positioning the follicles is shown in Figure 4. Results were analysed using GLM ANOVA tests. Increasing the number of training sessions was found to have a significant effect when comparing mean accuracy in placing follicles on the ovaries over the four training sessions (F=4.27, p<0.02). *Post-hoc* analysis using Tukey tests show a significant difference in performance in session 1 and session 3 (p<0.04) and session 1 and session 4 (p<0.03). Although a slight performance increase can be seen in Figure 4 between sessions 3 and 4, this difference is not significant.

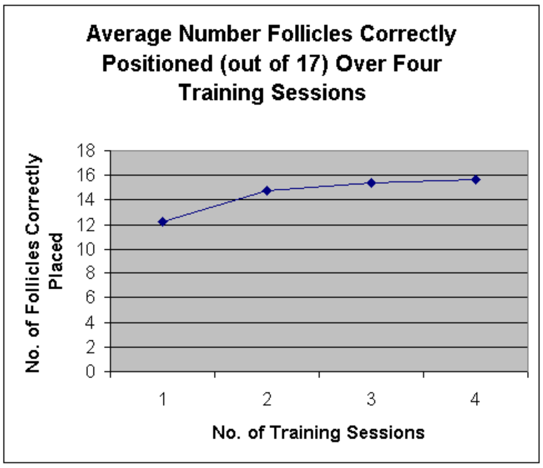

Figure 4. Average number of correctly positioned follicles for all participants over four training sessions. There were 17 follicles in each session.

Similar analysis was carried out on follicles that were correctly positioned and sized over the four training sessions. The results over four training sessions are shown in Figure 5. GLM ANOVA analysis shows a significant performance difference as training progresses (F=7.28, p<0.021). *Post-hoc* analysis using a Tukey test revealed that there were significant differences between performance in sessions 1 and 3 (p<0.003), sessions 1 and 4 (p<0.02) and sessions 2 and 3 (p<0.04). Although a slightly decrease in performance can be seen in Figure 5 between sessions 3 and 4, this difference is not significant.

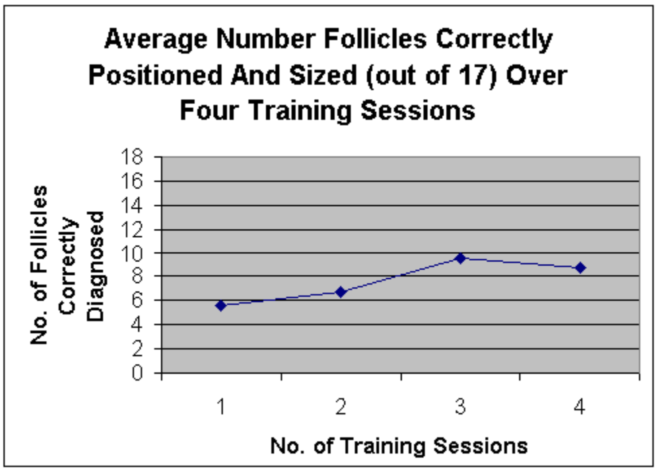

Figure 5. Average number of correctly positioned and sized follicles for all participants over four training sessions. There were 17 follicles in each session.

The results of the timing data are shown in Figure 6. Timing data was again analysed using a GLM ANOVA test. The results show a significant decrease in time taken to complete the task as training progressed (F=10.64, $p<0.001$). A *post-hoc* Tukey test revealed a significant decrease in time taken for the task during sessions 1 and 2 ($p<0.05$), 1 and 3 ($p<0.03$), 1 and 4 ($p<0.001$), and 2 and 4 ($p<0.05$). Again, although time taken to complete the task decreases between sessions 3 and 4, this difference is not significant.

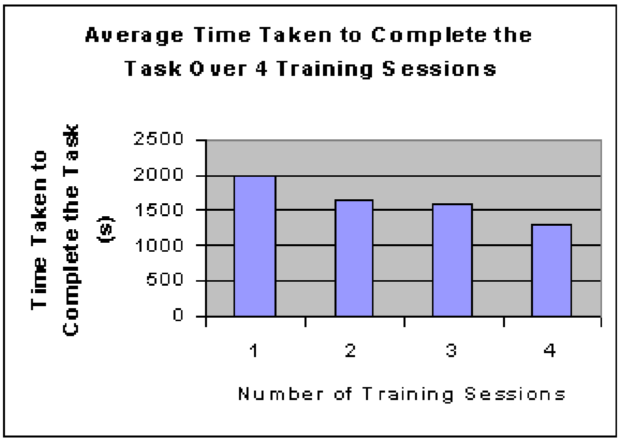

Figure 6. Mean time to complete task over all training session for all participants to complete the task

The results gathered from workload analysis are shown in Figure 7. It is important to note that for 'Performance Achieved' and 'Confidence Level', lower score indicates better perceived performance or confidence.

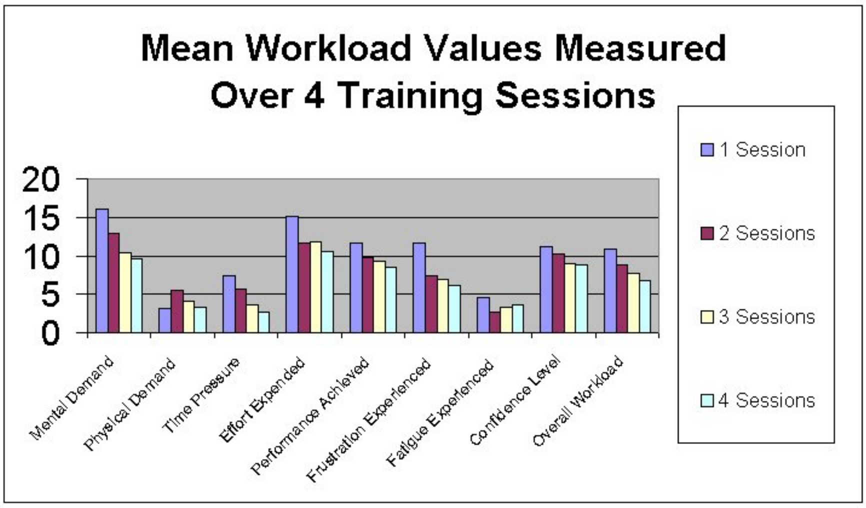

Figure 7. Average Workload for All Participants Shown Over 4 Training Sessions. Performance Achieved and Confidence Level are such that a lower value indicates better perceived performance or confidence.

A GLM ANOVA suggests that there is no significant decrease due to participants completing multiple training session (F=2.38, p=0.098). GLM ANOVAS on the individual factors suggest that the only workload factor significantly affected by multiple sessions is 'Mental Demand' (F=3.80, p<0.03). The *post-hoc* Tukey test showed a significant decrease in 'Mental Demand' is shown between sessions 1 and 4 (p<0.03).

4 Discussion

Hypothesis 1 has been supported by the results. As the number of experimental sessions increased, a significant increase in performance was also noted when examining both correctly positioned, and correctly positioned and sized follicles. For correctly positioned follicles, this difference was significant between sessions 1 and 3, and 1 and 4. The fact that no significant performance difference was shown between sessions 2, 3, and 4 suggests that the training benefits of multiple sessions in placing follicles may be levelling off after two or three sessions. Results suggest that sizing the follicles proved a more difficult that required more training. Significant performance differences were noted between session 1 and all other sessions as well as between sessions 2 and 3. This suggests that participants were still learning, and improving performance during the third training session. There is a slight decrease in performance between sessions 3 and 4, but this is not significant. This may indicate that the performance improvements due to time spent on the simulator had levelled off by the fourth session.

Hypothesis 2 has also been supported by the results. Significant decreases in time were shown between sessions 1 and all other sessions, and session 2 and 4. This difference is emphasised by the fact that examination times were capped at five minutes for each case. The majority of examinations not completed in five minutes occurred in the first week. Again, there was no significant time difference noted between sessions 3 and 4. This may suggest that participants would not become much faster with more training. The timing data combined with the performance data shows that as participants received more training, they were able to complete the task in less time without having a detrimental affect on performance.

Hypothesis 3 was not supported by the data. There was no significant mean workload differences noted throughout the four training sessions. Although no significant decrease was noted, there was a general downward trend noted which may become significant after more training sessions. Similarly, although there was a general increase in confidence noted throughout the training sessions, these increases are not significant. The increase suggests however that a significant result may be possible with more training sessions. For each of the individual workload factors, only 'Mental Demand' showed a significant decrease throughout the training sessions. The perceived 'Mental Demand' for session 4 was significantly less than the perceived 'Mental Demand' for session 1. This may correspond to the fact that the participants were performing better at this stage, and taking less time to complete an examination.

5 Future Work and Conclusions

The results described above are the first stage in an experiment to assess the usefulness of HOPS as a training tool for veterinary students. The results show that as participants received more training on the simulator, their performance in diagnosing the condition of the ovaries improved, while time taken to make the diagnosis and overall workload for the task decreased. The next stage of the experiment will measure how closely these improvements translate to improvement in performance in the real life ovary examination procedure. The experiment will involve 2 groups: the same group of participants who performed the experiment described above, and a group of participants who have similar background knowledge but have had no haptic training. The performance of each group will be measured on the same set of specimen ovaries as used in student anatomy laboratories. The hypotheses tested will be that the group who have received haptic training will diagnose follicles on the ovaries more accurately, while taking significantly less time. It is hypothesised the haptic training group will show higher confidence levels and lower overall workload than the no training group.

These results have provided an encouraging basis for the future experiment described. They have demonstrated that learning takes place in the HOPS simulator environment over several training sessions. The next stage of the experiment will demonstrate whether or not these improvements carry through to the real life procedure.

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