The Virtual Haptic Back for Palpatory Training

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ABSTRACT

This paper discusses the Ohio University Virtual Haptic Back (VHB) project, including objectives, implementation, and initial evaluations. Haptics is the science of human tactile sensation and a haptic interface provides force and touch feedback to the user from virtual reality. Our multimodal VHB simulation combines high-fidelity computer graphics with haptic feedback and aural feedback to augment training in palpatory diagnosis in osteopathic medicine, plus related training applications in physical therapy, massage therapy, chiropractic therapy, and other tactile fields. We use the PHANToM haptic interface to provide position interactions by the trainee, with accompanying force feedback to simulate the back of a live human subject in real-time. Our simulation is intended to add a measurable, repeatable component of science to the art of palpatory diagnosis. Based on our experiences in the lab to date, we believe that haptics-augmented computer models have great potential for improving training in the future, for various tactile applications. Our main project goals are to: 1. Provide a novel tool for palpatory diagnosis training; and 2. Improve the state-of-the-art in haptics and graphics applied to virtual anatomy.

Categories & Subject Descriptors: Computer Applications & Life and Medical Sciences

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1. INTRODUCTION

Haptics, the science of touch, is being applied in virtual reality environments to increase realism. An example of this is virtual reality computer games that use a force-reflecting joystick.

Haptics has been applied recently to education, most notably in medical education. In the Stanford Visible Female project (Heinrichs, et al., 2000), a 3D stereoscopic visualization of the female pelvis has been developed from numerous slices of 2D pelvis data. Further, haptic feedback was enabled via the PHANToM haptic interface, allowing the user to interact with and feel the virtual model. The Interventional Cardiology Training Simulator (Shaffer et al., 1999) links technical simulation with specific medical education content. A virtual reality-based simulator prototype for the diagnosis of prostate cancer has been developed using the PHANToM haptic interface (Burdea et al., 1999). An earlier tumor palpation VR simulation was developed by Langrana (1997). The Immersion Corp. (www.immersion.com) has developed haptic interfaces for injection training and sinus surgery simulation. Delingette (1998) is working on realism in modeling human tissue for medical purposes. The GROPE Project (Brooks et al., 1990) has developed over 30 years a 6D haptic/VR simulation of molecular docking. The SPIDAR haptic interface has been adapted to serve as "the next generation education system" (Cai et al., 1997), although the authors do not elaborate on the type of education intended. The Center for Human Simulation at the University of Colorado (Denver) has developed a haptic surgical training simulation, with sub-mm resolution, using the Visible Human Database (Reinig et al., on-line paper).

A group at the University of Ioannina in Greece is involved with virtual learning environments including a Power Glove with tactile feedback to "build a theoretical model for virtual learning environments, expanding constructivism and combining it with experiential learning" (Mikropoulos and Nikolou, 1996). A research group at the Ohio Supercomputing Center has applied haptics in virtual environments to improve tractor safety by training young rural drivers (Stredney et al., 1998); their results show haptics increases training effectiveness. Haptics has been applied to make virtual environments accessible to blind persons (Jansson et al., 1999). Affordable haptic interfaces have been implemented to augment the teaching and learning of high school physics (Williams et al., 2001). This literature review demonstrates the significant interest in the field of haptics and graphics for biomedical applications; our work is unique because of its osteopathic medicine focus and emphasis on palpatory training. For an early project overview, please see Williams et al. (2003).

The Virtual Haptic Back (VHB) project is an interdisciplinary collaboration between two Ohio University colleges: Engineering and osteopathic medicine. Its purpose is to develop a realistic haptic/graphical model of the human back that can be used for palpation in medical training, as a step toward a more comprehensive haptic modeling of the human body. The VHB will add a component of science into the learning of the art

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of palpatory diagnosis. It has the potential to be the flight simulator equivalent for learning palpatory diagnosis for osteopathic medicine, physical therapy, massage therapy, chiropractic therapy and related fields.

This paper presents motivation, overview, and details for our VHB model. We then present a summary of evaluations to date, initial evaluation results, plus future evaluation plans and a discussion of the potential role of haptics in training.

2. VHB OBJECTIVES AND OVERVIEW

The purpose of the VHB project is to develop a series of computer-based, haptic simulations of the human body to assist students in the learning of palpatory techniques.

From the very beginnings of medicine, palpation (diagnosis through touch) has been an important part of the diagnostic process, for detection of organ enlargement, tumors, herniations, tissue swelling, and of abnormalities in the movements of heart, lungs, intestines, muscles, bones, and joints. Palpation has been an additionally significant part of osteopathic medical practice, because of its emphasis on somatic dysfunction and viscerosomatic reflexes. Palpation is an effective, sensitive, and economical way to diagnose many musculoskeletal (somatic) dysfunctions, including those that arise from visceral abnormalities via viscerosomatic reflexes. Unfortunately, the diagnosis of dysfunction by means of palpation is difficult to learn for three reasons: Palpation requires a highly trained sense of touch; medical students generally practice on each other, thus the subjects are often young and healthy; palpation on a human subject may change conditions, hence successive students may not be presented the same case to feel. Virtual reality with haptic feedback shows promise for overcoming these obstacles in palpatory training. Each of these difficulties can be addressed by the VHB simulator. Haptics provides the opportunity for practice to develop the sense of touch on simulated somatic dysfunction of graded intensity, presented in a reproducible way. Our simulator also provides a means for an instructor to keep track of and rate the progress of each trainee.

3. VHB PRODUCT

The VHB is under development to simulate the palpatory feel of the normal and the dysfunctional human back. A high-fidelity graphical model of the human back (Figure 1) is coupled with dual PHANToM 3.0 haptic interfaces (Figure 2, www.senseable.com) to allow user interaction. In Figure 1, L and R indicate the left and right finger cursors, respectively, which the user can use to navigate and feel the back model. The back can be displayed transparent as in Figures 1 and 2 or opaque.

3.1 VHB Model Development

The VHB model shown in Figures 1 and 2 has been developed over the past three years, with continual improvements and refinements. The back of a volunteer subject (adult male of average size) was measured using a 3D digitizer. An offline graphical representation of the smoothed digitizer data was the first step in our graphical development.

In the initial real-time interactive model version *v*0, the feel consisted of linear springs of varying spring stiffnesses, normal to the surface of each graphical polygon. A more complex haptic model *v*1 was then developed wherein human skin, fleshy material, and underlying skeletal structure was included. The idea behind this model is to allow the user to feel different layers of haptic feedback (i.e. palpate through the fleshy material to feel the ribs and vertebrae beneath the surface). Also, each vertebra was given realistic rotational freedoms.

An improved back model, *v*2, shared the same attributes as *v*1, but the graphics and haptics properties were improved. Also, the back model data irregularities were smoothed, and major skeletal landmarks were associated with it for increased realism, including the acromion process above and the posterior superior iliac spine below.

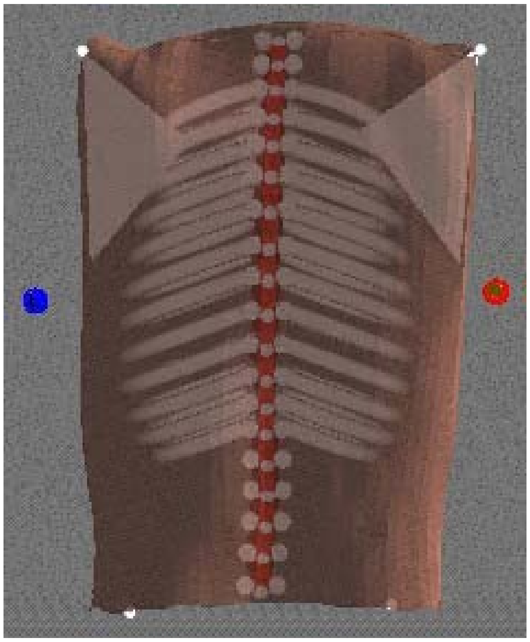


Figure 1. VHB Model

Figure 2. 2 PHANToM 3.0s for Dual-Handed Palpation

The current VHB, *v*3, is shown in Figures 1-4. This model, an extension of *v*2, has two new features. First, movable haptic ribs have been added. Second, two PHANToM 3.0 haptic interfaces are implemented for dual-handed palpation (earlier models allowed only one PHANToM 1.0).

Figure 3 shows an image of the human back on a monitor with the underlying vertebral column and stylized scapulae made visible. The image of the vertebral column was obtained by digitizing a model vertebral column with a 3D scanner. The buttons across the top of the screen include:

a. trans – toggles on or off the image of the underlying skeletal elements.

b. test – runs a sequence which includes subtests of abnormal vertebral stiffness and abnormal vertebral position at three levels of difficulty for each. The vertebra chosen to be dysfunctional is varied randomly. The user indicates his/her choice by pressing a foot switch while “touching” with a finger the vertebra selected. During the test, the time to correct identification and number of errors are recorded automatically. For identification of abnormally rotated vertebrae, the image of underlying vertebrae is not displayed.

c. pretest – runs a sequence designed to familiarize the user with the VHB.

d. angle – a drop-down menu that permits manual selection of a vertebra (T6 illustrated here) to be rotated and the degree of its abnormal rotation.

e. stiff – a drop-down menu that permits manual selection of a vertebra to be abnormally stiff to rotation and the degree of its abnormal stiffness.

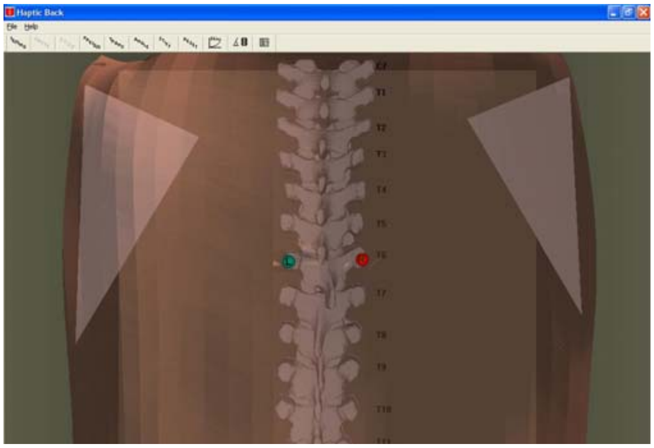


Figure 3. VHB Image with Vertebral Column and Scapulae

Figure 4 shows the VHB model in use for teaching in the osteopathic Manipulative medicine (OMM) Laboratory at Ohio University. An osteopathic Doctor palpates a human subject’s back while a team member demonstrates a similar examination using the VHB.

For more information, please visit our VHB website:

http://www.ent.ohiou.edu/~bobw/html/VHB.html

3.2 Hardware

The PHANToM 3.0 haptic interfaces (Figure 2) by SenseAble Technologies, Inc. uses position information input by the user to determine what forces to relay back to the user via its three motors. A flow diagram for the PHANToM is pictured in Figure5. The human finger moves the PHANToM to desired X, Y, Z Cartesian locations (sensed internally via joint encoders $\theta_1, \theta_2, \theta_3$); this Cartesian input is sent to a virtual computer model. The haptic/graphical software determines what Cartesian force vector F_X, F_Y, F_Z the human should feel and the PHANToM generates this force at the human finger (accomplished internally via joint torques τ_1, τ_2, τ_3).

Figure 4. VHB in use in the OMM Laboratory

Figure 5 PHANToM Flow Diagram

The two PHANToM 3.0 haptic interfaces shown in Figure 2 have nominal resolution of 0.02 *mm*, a workspace of 39x54x75 *cm*, and a maximum exertable force of 22 *N*. These PHANToMs only read positions and exert translational forces (no orientations can be read nor moments exerted currently). A passive gimbal connects the user’s finger to the tip of the PHANToM.

The current VHB simulation with two PHANToMs runs on a 2.8 GHz, dual Pentium Xeon processor PC NT workstation, with 1 GB RAM and a NVIDA Quadro4 900XGL, 128 MB graphics card.

3.3 Software

SensAble Technologies Inc. provides a General Haptics Open Software Toolkit (GHOST$^{®}$ SDK). It is a C++ object oriented toolkit that represents the haptic environment as a hierarchical collection of geometric objects and spatial effects. The Ghost$^{®}$ SDK uses OpenGL and 3D graphics. The 1000 *Hz* servo loop performs the following functions:

1. Updates the PHANToM node position in the scene.
2. Updates the dynamic state of all dynamic objects.
3. Detects collisions in the scene.
4. Sends the resultant force back to the PHANToM.

3.4 Haptics Model

The haptics feedback in the VHB is the result of a combination of different models. The vertebra and bony landmarks were created with SensAble Technologies GHOST software. Their haptics are modeled by a spring-damper system. The motors in the PHANToM limit how solid these objects will feel. The spinous ligament is created as a mesh object, again using the GHOST software. The stiffness of the mesh is set slightly lower than that of the vertebra. The feel of the mesh is also modeled by a spring-damper system. The skin is made up of two parts. The first is a mesh similar to the spinous ligament. Once a certain force threshold is exceeded, the user will push through this mesh into a second force region. This part of the skin uses a surface model. The feel of the skin in this region is determined by an exponential function of the distance from the surface of the skin to the position of the user below the skin surface. The model is layered because the vertebrae, spinous ligament and bony landmarks are located within the skin force field. As these objects are being touched, the second skin force is pushing the user away from them.

The values for spring stiffnesses for the skin and bone models, plus the rotational stiffnesses for the vertebrae were not measured from a live human subject. Rather, they were set by the development team according to subjective feel. We have been updating these values based on expert feedback for increased realism.

3.5 Features

The VHB is being developed as a device for use in teaching medical palpatory skills. The operator feels resistance as the finger touches the simulated skin. As the finger is pressed into the skin, the vertebral spines or transverse processes can be felt as additional resistance sensed by the palpating finger. An image of the back being palpated appears on a computer screen along with a cursor that specifies location of the palpating finger. As the finger compresses the skin, the skin can be seen on the screen to dimple. The graphics can be set to reveal the underlying bone or not, so that the palpation can be done with or without the aid of seeing the underlying vertebrae on the screen (the real world does not allow this choice!).

The VHB, *v*1 included only vertebral spinous processes C6 through L1; these were fixed so the user could palpate each, but there was no relative motion. The VHB, *v*2 improved upon this, including vertebral spinous processes C2, C6, and C7, T1 through T12, and L1 through L5. Version 2 skips cervical vertebrae C3 through C5. Individual vertebrae T1 through T12 can be rotated as the operator presses on a transverse process, as shown in Figure 3 (seventh down from the top, where the L and R cursors are). The resistance to rotation can be varied for each of these vertebrae independently so as to simulate restricted vertebral motion. The initial position of each of these vertebrae can also be set independently via a pull-down menu in order to simulate vertebrae out of position. The current VHB, *v*3 shares the same attributes, with the addition of movable haptic ribs. In addition, the user can rotate each vertebra independently with three degrees of freedom in a realistic manner. In the future we will develop the capability for changes in stiffness and rotation for groups of vertebrae so that we can simulate Type II somatic dysfunction in addition to the Type I (individual vertebrae) somatic dysfunctions currently enabled.

The interspinous ligaments joining the spinous processes are palpated as objects with less intrinsic stiffness (more give) than the spinous processes. Transverse processes can also be palpated lateral to the spinous processes and deeper. These features allow instructors to program various somatic dysfunctions, using pull-down menus. Students can then be asked to detect these abnormalities by palpation.

The system is still under development and will be expanded in the future to include improved ribs, continuous haptic model improvements, and soft tissue changes, such as muscles in spasm and regions of local edema. We are currently working on an improved collision detection algorithm using a finger with realistic dimension, rather than the single point is use in *v*3. With the current single point, the finger can slip between ribs and other model features, so our new algorithm will increase realism.

Sound feedback is employed in the simulation to provide immediate feedback to the trainee during palpatory diagnosis practice sessions. When the trainee has identified the spinous process that is out of place, for instance, pressing a foot button will provide aural feedback indicating if the identified one is correct.

We have also implemented a playback feature wherein an expert's motions during a simulated VHB diagnosis can be saved and replayed later for trainees using the PHANToM haptic interface. In this way the steps taken by an experienced practitioner of manual medicine can serve as a guide to a learner. Figure 6 shows two position trajectory curves, the red one representing the expert's recorded positions and the green one showing the path traced by the PHANToM upon playback to a trainee.

The closeness exhibited in Figure 6 between the expert's motions and the playback experienced by the trainee indicates that we may use this developed feature in our work with small position errors. For more information on our playback feature, including initial evaluation results, please see Srivastava et al. (2003).

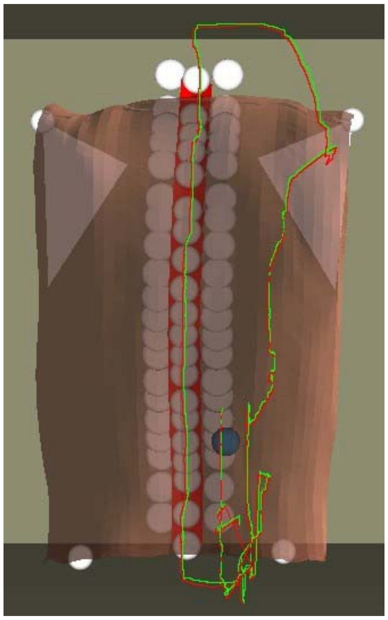


Figure 6. Playback **and** Recorded **Paths**

4. EVALUATION PLAN

This section presents our initial VHB evaluations, plus plans for continuous evaluation as the project progresses. This section concludes with a brief discussion on the potential of haptics-augmented graphical images in training applications.

Our initial VHB evaluations have taken two forms. First, from the start we have sought expert osteopathic Doctors' advice in improving the realism of our simulation. Many of their comments have been implemented, leading to the current simulation, *v*3. This type of feedback will be continuously sought and acted upon as the VHB evolves. In our first formal evaluation, a group of physical therapy graduate students and a control group of engineering students were asked to practice with and rate the effectiveness of the VHB with regard to the quality and realism of graphics and haptics. The current simulation also reflects the results of this initial evaluation.

The current instantiation of the VHB, *v*3, is shown Figure 1 (transparent, showing the underlying skeletal structure; this transparency can be turned off). We have plans for four consecutive, continuous evaluations of the VHB model, using osteopathic medical students at Ohio University, for two years each. A control group for each of the four evaluations will be general (non-osteopathic students with no palpatory experience). Our first two-year evaluation cycle is nearing completion and we present some initial data from this in the next section.

The initial hypothesis we are testing is:

"Training in the Osteopathic Manipulative Medicine Laboratory improves the students' performance with the Virtual Haptic Back."

Future training evaluation using the VHB will involve somatic dysfunction. The goal is to provide realistic somatic dysfunction for the trainee to identify through palpation with the virtual model; this can be done in a repeatable manner, with as much practice as the trainee desires.

A long-term hypothesis to be tested is:

"*The Virtual Haptic Back provides an objective means for testing palpatory skills.*"

Currently, there are no objective, repeatable methods for measuring success and tracking improvements in learning palpatory diagnoses.

Finally, our preliminary laboratory experiences indicate a great potential future for haptics-augmented virtual reality simulations in training applications. Though our work is relatively narrowly focused on palpatory training for medical and related fields, we can see the potential for training in general tactile tasks. We say: "*Feeling is believing!*" Combining realistic, real-time haptic feedback with high-quality real-time interactive computer graphics and aural feedback will be a powerful tool in future training applications in many fields.

5. INITIAL EVALUATION DATA

This section presents some data from our initial VHB evaluation trials with multiple human subjects; we focus on the learning effect, to better design experiments in the future.

Figure 7a shows the time to correct identification of randomly-assigned abnormally stiff vertebrae (motion testing), and Figure 7b shows the associated number of incorrect responses before correct identification of the abnormally stiff vertebrae. This data is for the same N=36 subjects, exposed to repeat VHB usage once per quarter for four quarters (skipping summer 2003).

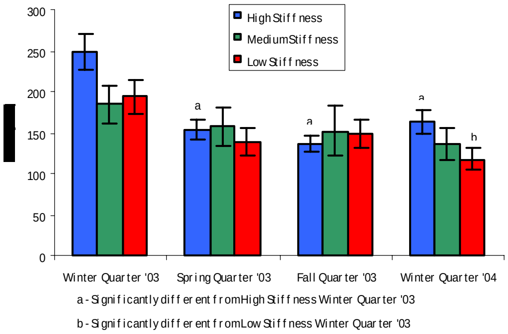
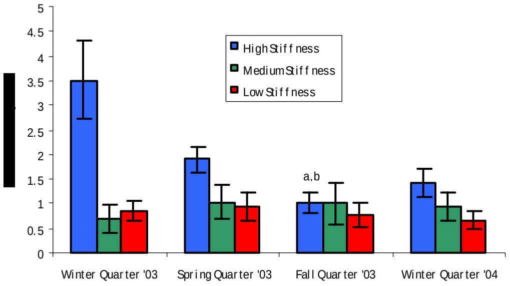


Figure 7a. Identification Time, Quarterly, Vertebrae Stiffness



a - Significantly different from High Stiffness Winter Quarter

b - Significantly different from High Stiffness Spring Quarter

Figure 7b. Incorrect Responses, Quarterly, Vertebrae Stiffness

Some evidence of learning between the first two trials is seen in Figure 7a, especially in the “high stiffness” test, which is always the first of the subtrials run in each session. Using a repeated measures ANOVA test with $P<0.05$, ‘a’ indicates a significant difference from the first high stiffness trial, Winter Quarter 03, and b indicates a significant difference from the first low stiffness trial, Winter Quarter 03.

Also, some evidence is seen of learning between the first two or three trials in Figure 7b, but only in the “high stiffness” subtest, again, the first done in each session. Again using a repeated measures ANOVA test with $P<0.05$, ‘a’ indicates a significant difference from the first high stiffness trial, Winter Quarter 03, and b indicates a significant difference from the second high stiffness trial, Spring Quarter 03.

No learning trend appeared over the four quarterly sessions in the subtests in which the task was identification of the abnormally rotated vertebrae (data not shown).

Figures 8a and 8b are similar to the tests shown in Figures 7a and 7b, except that this is more preliminary data (N=3), for the learning effect over six trials in the course of one week (rather than quarterly, i.e. the trials are much closer together over time than in Figures 7a and 7b).

Figure 8a shows the time to correct identification of randomly-assigned abnormally stiff vertebrae (motion testing), and Figure 8b shows the time to correct identification of randomly-assigned abnormally rotated vertebrae (done with vertebrae not visible).

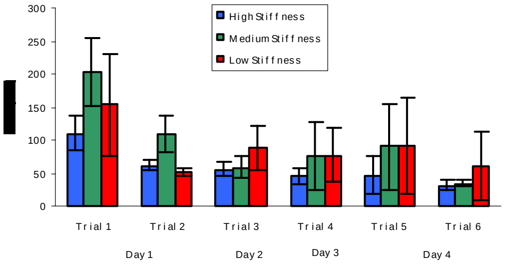


Figure 8a. Identification Time, One Week, Vertebrae Stiffness

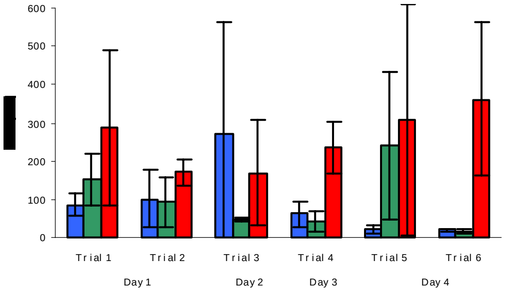


Figure 8b. Identification Time, One Week, Vertebrae Rotation

In Figure 8a, a trend suggests a learning effect between trials 1 and 2. As to the number of incorrect responses (not shown), subjects averaged fewer than one, and no trial-dependence with respect to incorrect responses was evident.

In Figure 8b, the time to identification of abnormally rotated vertebrae task reveals more variability and appears to be more difficult, especially with the vertebrae with a slight (low) degree of abnormal rotation. No learning effect is evident in Figure 8b.

Overall, the data presented suggest that one or two sessions with the VHB is sufficient for getting past the learning phase, whether the trials are separated by quarters (three months) or days in one week. This will be taken into account in the design of future studies to evaluate the usefulness of the VHB as a teaching and testing tool for musculoskeletal palpatory diagnosis.

6. CONCLUSION

We present an overview of the Virtual Haptic Back (VHB) project at Ohio University. This project is under development to augment tactile training in osteopathic medicine, physical therapy, massage therapy, chiropractic therapy, and related fields. Our simulation involves a high-quality computer graphics model implemented with two haptic interfaces. The user interacts with the simulation via the haptic interfaces in real-time, moving the tips of the two PHANToMs to navigate around the simulated live human back, while feeling appropriate realistic haptic feedback. We have a layered haptic model wherein the palpatory trainee can feel the skin, plus underlying tissue, skeletal structure, and ligaments. Pull-down menus are used to establish simulated somatic dysfunction, setting different initial positions and relative stiffnesses for the various spinous processes. The model can be viewed either opaque, as in the real world, or transparent for easier interaction during early practice. Sound feedback is included to assist the trainee and a playback mode has been developed to demonstrate to the trainee an expert’s approach to the same palpatory diagnosis problem. We are currently developing less complex palpatory modules to teach and test simpler palpatory diagnoses tasks as well. The VHB model adds a measurable, repeatable component of science to the art of palpatory diagnosis.

Our multimodal simulation approach includes graphics, haptics, and aural feedback. This paper describes the VHB simulation, discusses our initial evaluations and future evaluation plans, and presents a discussion of the potential of haptics-augmented training systems. Early evaluation results indicate a good potential for our tool in palpatory diagnosis training. This work is a first step in our large future goal, ‘Virtual Haptic Anatomy’, which will deal with the entire virtual human body, with realistic haptic sensations, both inside and out.

7. ACKNOWLEDGEMENTS

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