

# The Virtual Haptic Back Versions

August 2006, Dr. Bob and Bob C

This document presents a summary of the evolution of our Virtual Haptic Back (VHB) model. We present our subsequent model improvements to answer suggestions by expert palpators (teaching and practicing DOs; for more detail see Physicians' comments above), plus the version numbers for our continuously-evolving VHB software. Realism is driving all of our developments. This research, implementation, and evaluation work is now funded by the Osteopathic Heritage Foundation and was initially supported by the Ohio University 1804 Research Program.

## Virtual Haptic Back, *Version 0*; Spring 2001

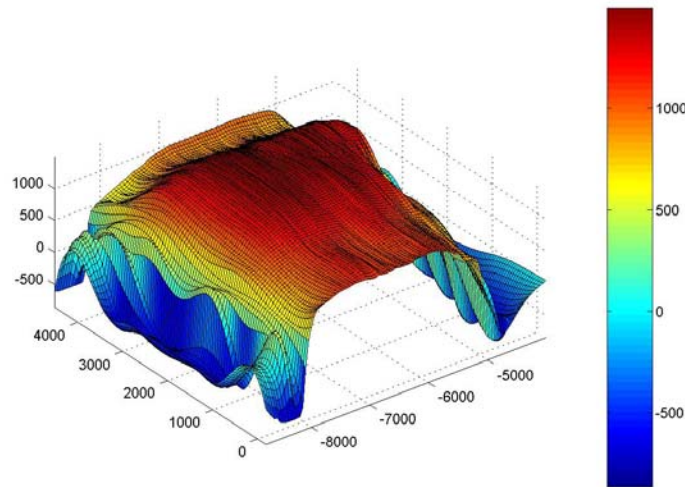
The initial Virtual Haptic Model, *version 0*, consists of raw-data and smoothed VHB models, as shown in Figures 1. The back of a volunteer subject (Dr. Howell, adult male of average size) was measured using the Metrecom Skeletal Analysis System (SAS, Figure 2). The back was created by scanning 9 rows at 15hz on the back. The number of points in each row is about 100. The model is a mesh only model. A single PHANToM haptic interface (Figure 3) is used for palpator interaction and haptic feedback. In this initial real-time interactive VHB model, *version 0*, the feel consists of linear springs of varying spring stiffnesses, normal to the surface of each graphical polygon. In *version 0*, we model only the skin surface, with no underlying tissue or skeletal structure. No objects could be felt under the skin.



Figure 1a. Raw VHB Model, v0



Figure 1b. Smoothed VHB Model, v0



**Figure 1c. Smoothed VHB Model in Matlab, v0**



**Figure 2. SAS**



**Figure 3. PHANToM Haptic Interface**

Experiment 0 was conducted with the VHB, *version 0*, during Spring 2001. Associated with Experiment 0, three DOs (Drs. Chila, Eland, Muntean) and one RN (with massage therapy background) used the VHB, *version 0*, and gave specific comments for improvement. The experts suggested programming muscle tissue and skeleton graphically and haptically beneath the skin. Since the digitizing of a skeleton is not trivial, two of the DOs independently suggested programming different sized spheres to represent the spinous and transverse processes of the human spine. This eliminates the programming of parts of the skeleton that the palpator cannot ordinarily feel. This type of haptic modeling would enable the programming of different types of somatic dysfunction, including different stiffness and/or rotation of individual vertebra (Type I) or groups of vertebrae (Type II). Another suggestion to aid in palpation training is to turn off the graphical clues for different types of dysfunction, thus testing the student's ability to diagnose by feel. All of these comments have been implemented.

Dr. Muntean also suggested that it is better to have the DO standing and the virtual patient standing or lying face-down. This relative positioning of the DO and patient has not yet been implemented (currently the DO is sitting, while the virtual patient is standing). Dr. Muntean also mentioned that visceral organ manipulation could also be programmed in virtual patients, in addition to back/spine diagnoses; MDs as well as DOs routinely use that type of palpatory diagnosis. Dr. Muntean also pointed out the difference between kinesthetic (motion-based, deep sensors) and tactile (cutaneous and subcutaneous sensors) modes in the human haptic system. Dr. Muntean also recommended programming virtual dysfunction due to muscle tension (spongy and tense muscles). Dr. Muntean also

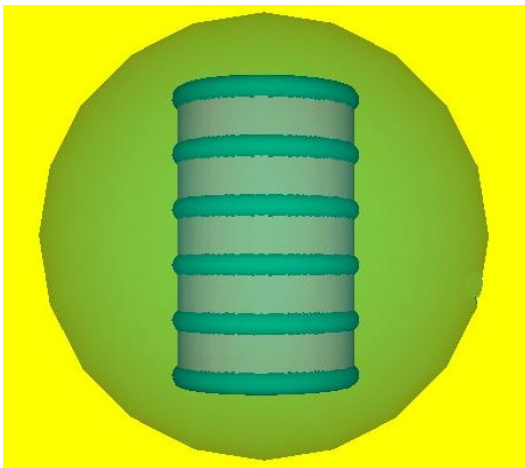
suggested that the approach of the palpator's finger (or thumb) should be parallel to the virtual back surface, rather than normal (pointing into the back) as we had been doing (the VHB can be used either way). He also requested a large computer screen, to allow real-size scaling of the virtual back.

All DOs mentioned that they tend to use both hands, and most of their fingers and thumbs while palpating real patients. Therefore, the single index finger of the right hand enabled by the VHB, *version 0*, is not sufficient.

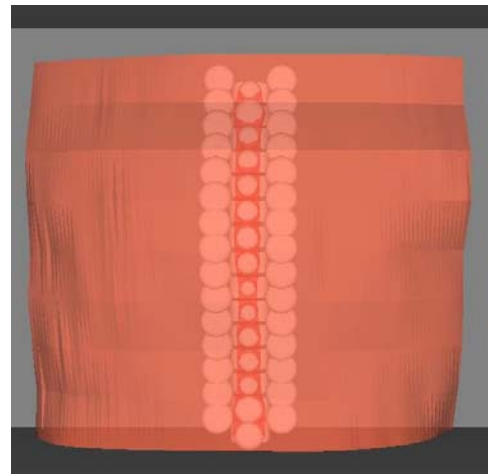
## Virtual Haptic Back, *Version 1*; Fall 2001

As shown in Figure 4, a more complex proof-of-concept haptic model was developed wherein a cylinder with torus-shaped ribs simulating bones is encased in a spherical force-field simulating fleshy material. The force from the sphere is radially directed. 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 beneath the surface).

Figure 5 shows the first interactive VHB model, *version 1*, to include this layered feature, plus a simple model of the human spine wherein vertebrae can be felt under the skin. Dr. Chila suggested that the interspinous ligaments should be modeled, with realistic size and feel (*version 1* includes this feature). *Version 1* also allows vertebral rotation only about the primary *Y* axis of the virtual human spine, suggested by Dr. Eland. This *v1* is the first force field version of back; data from *v0* was edited to create a skin force field. The spinous and transverse processes are modeled by spheres. The haptic skin field is linear. The modeled vertebrae are C6, C7, T1-T12, and L1. The vertebrae are artificially placed (their positions were not measured).



**Figure 4. Layered Haptic Model**



**Figure 5. VHB, *v1***

## Virtual Haptic Back, Version 2; Summer 2002

An improved back model, *version 2*, is shown in Figure 6a. This VHB model shares the same attributes as *version 1*, but the graphics and haptics properties have been improved. Also, a new back data set was measured (same subject, Dr. Howell, average-sized adult male), including the major skeletal landmarks for increased realism. The circles located laterally represent the acromion process above and the posterior superior iliac spine below. This time 33 columns were scanned with about 150 points in each column, so this back has better resolution than the previous versions. The modeled vertebrae are C2, C6, C7, T1-T12, and L1-L5. The positions of each vertebra as well as the corners of the scapulae and positions of each PSIS were also digitized by the Metrecom. The haptic skin force is still linear and the processes are still spheres.

A playback feature was developed for *version 2* wherein a student can follow the motions of an expert and feel what the expert felt during the course of a simulated palpation examination using the VHB model. Initially we implemented a P controller for position playback, while simultaneously enabling the haptic model (or, recording the force interaction of the expert palpator). This initial attempt is not adequate because it is impossible to simultaneously play back positions and force with 100% fidelity since the same PHANToM motors torques are used for position playback and the haptic playback. Therefore, we implemented a two-mode playback approach: In Mode 1 the student finger in the PHANToM thimble is passive while a PD position controller plays back the expert's motions without haptic feedback (Figure 6b). In the second mode the student must actively move the PHANToM to recreate an expert's motions (by following a highlighted ball on the screen; a bar graph assists with Z depth errors); in this mode the student can feel the haptic model since the torques are not required to recreate the position playback (Figure 6c).

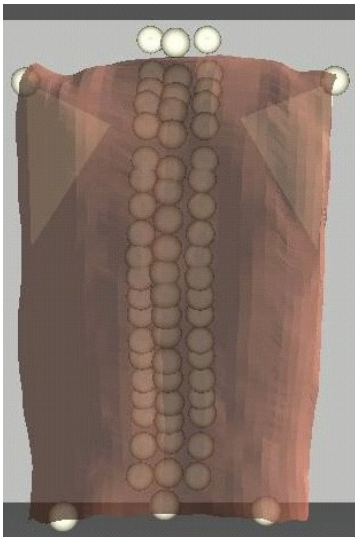


Figure 6a. VHB, v2

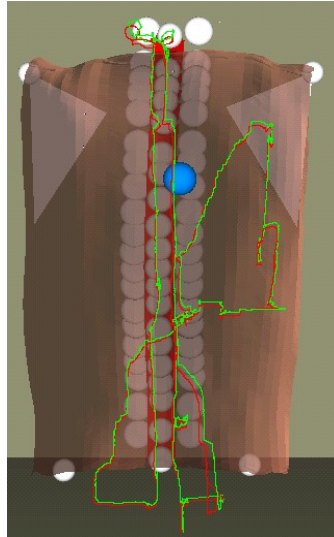


Figure 6b. Mode 1 Playback

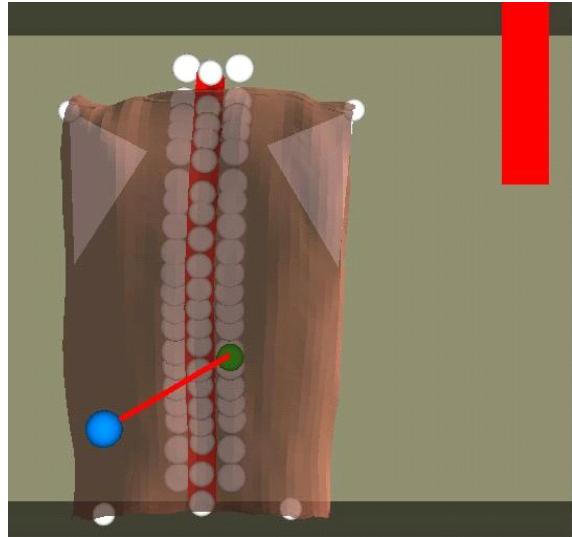
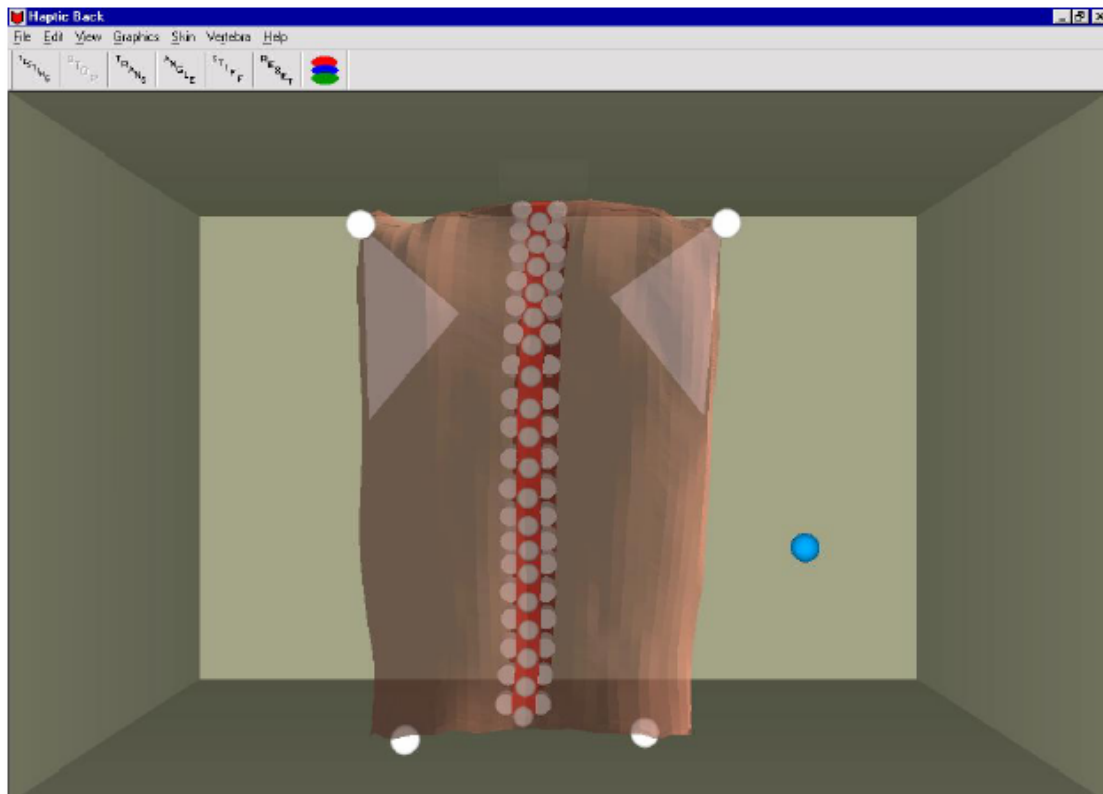


Figure 6c. Mode 2 Playback

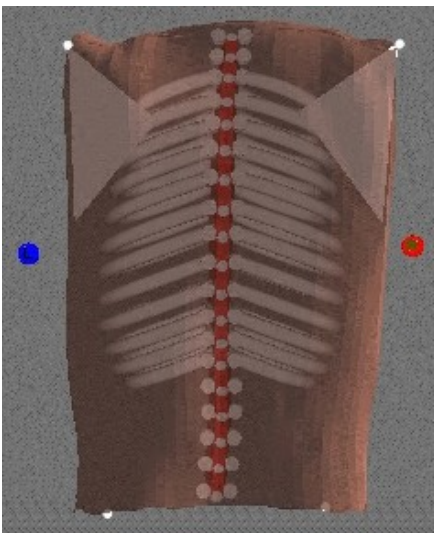


**Figure 6d. VHB, v2, Testing Model for Experiment I, Winter 2003**

The v2 testing model, used in the first two-year round of VHB evaluation with cohorts of Osteopathic and control subjects (Experiment I), is shown in Figure 6d. It has an exponential haptic skin field. The vertebrae positions have been altered to get them evenly spaced and in a straight vertical line. There is a spinous ligament. The transverse processes are cylinders and the spinous processes are spheres. The vertebrae modeled are C6, C7, T1-T12, and L1-L5. Testing is over T1-T12 only. Each vertebra can rotate about any axis ( $X$ ,  $Y$ , or  $Z$ ). This model is not life-sized. Testing was done on the desktop PHANToM 1.0 in Stocker Center. The model of Figure 6d, including the same computer and PHANToM was used for two years of testing on the same student groups, Winter 2003 – Spring 2004.

## Virtual Haptic Back, *Version 3*; Winter 2003

The VHB, *version 3*, is shown in Figure 7. This model, an extension of *v2*, includes all the features of *v2*, with the following three new features. First, movable haptic ribs have been added (they spring back after the palpation force is removed). Second, each individual vertebra moves with five degrees-of-freedom for increased realism. The palpator can rotate a vertebra in roll, pitch, and yaw, plus translate the vertebrae in *X* (horizontal) and *Z* (normal to back). Realistic stiffnesses for a healthy human are programmed, as guided by expert D.O. palpators. Third, for the first time, two PHANToM haptic interfaces are implemented for dual-handed palpation (L and R cursors represent the virtual left and right finger positions in Figure 7; the left and right PHANToM haptic interfaces are pictured in Figure 8). The new PHANToMs are the largest size, PHANToM Premium 3.0s, instead of the small PHANToM Premium 1.0 of Figure 3. This version is not a testing version. Each rib is a torus. The model is not life sized.



**Figure 7. VHB, *v3***



**Figure 8. PHANToMs for Dual-Handed Palpation**

During Summer 2003, Dr. Janet Burns suggested that the nominal VHB model scale should be 1:1. That is, not only should the graphics image appear life-size, but the spacing of the palpator's fingers via the two PHANToMs should map to an equal distance (and equal rotations) in the VHB model. This problem is more noticeable with two PHANToMs than with only one.

## Virtual Haptic Back, Version 4; Summer 2003

The VHB, *version 4*, is shown in Figure 9a. This model, an extension of *v3* with two PHANToMs, has two new features. First, the nominal graphical scaling is 1:1, including the spacing of the palpator's fingers. The PHANToMs must be calibrated in the provided supports for best results. The graphics can then be scaled in or out from this nominal, but the haptics scaling does not change. This is equivalent to the palpator moving their head closer to or further from the virtual back image. Second, a realistic human vertebra was digitized in 3D using the Picza pin-contact digitizer (Figure 9b). The same vertebra is used for all. The vertebra model is rough, to avoid an excessive number of graphical polygons which slows down the system. The haptics model for each vertebra has not changed, i.e. it is still composed of spheres as the DOs suggested.

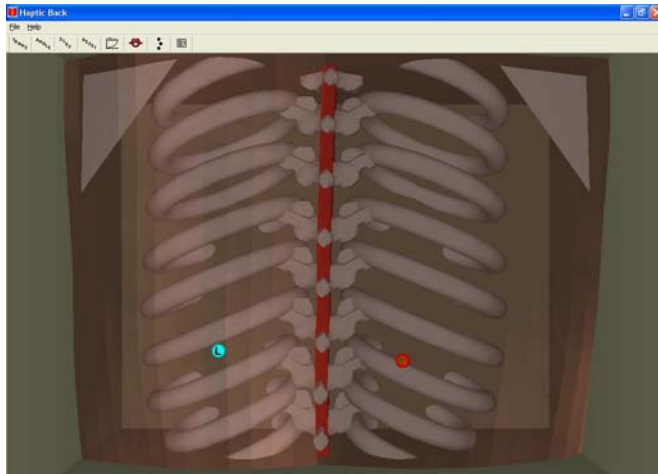


Figure 9a. VHB, v4

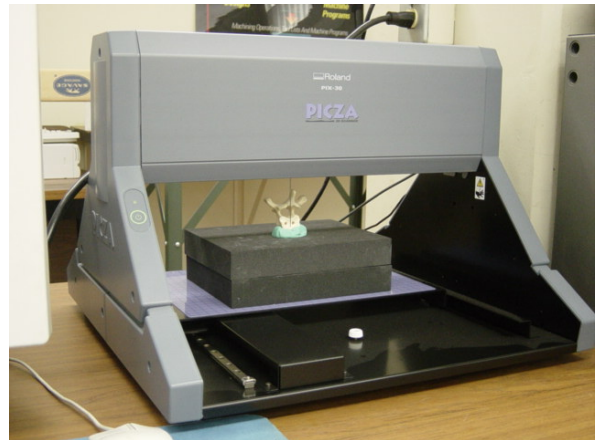


Figure 9b. Picza 3D Digitizer with Vertebra

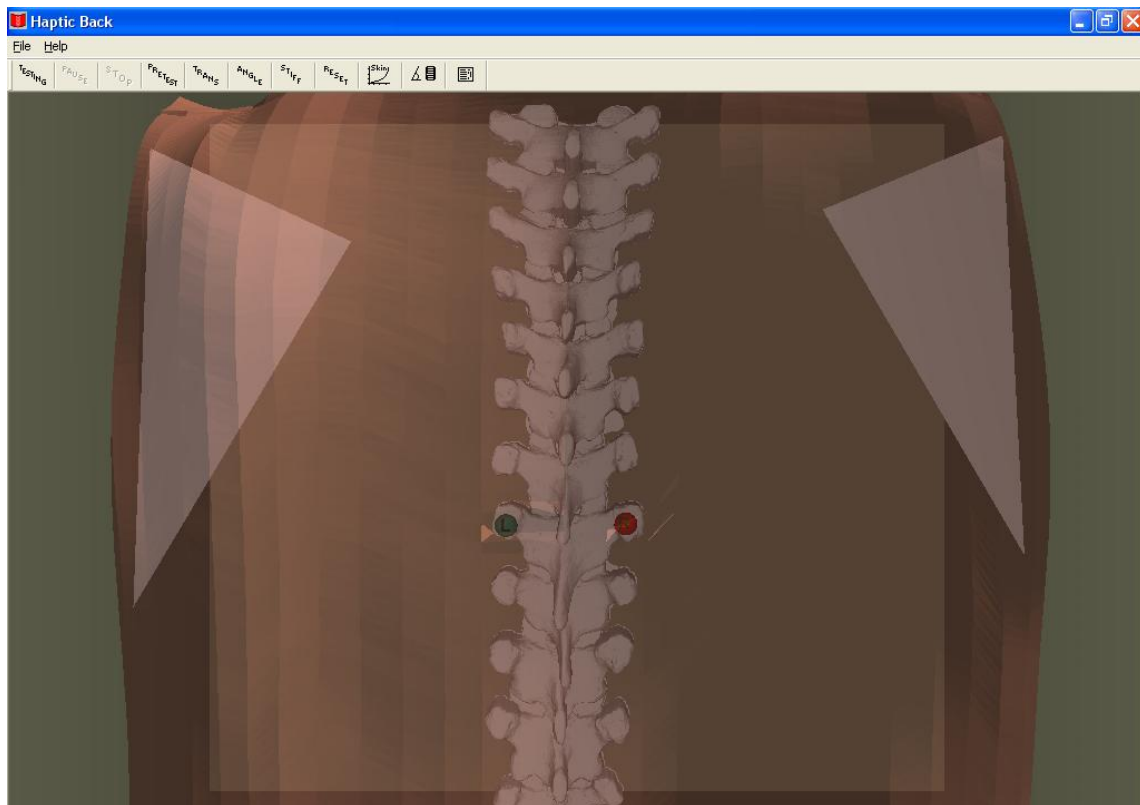
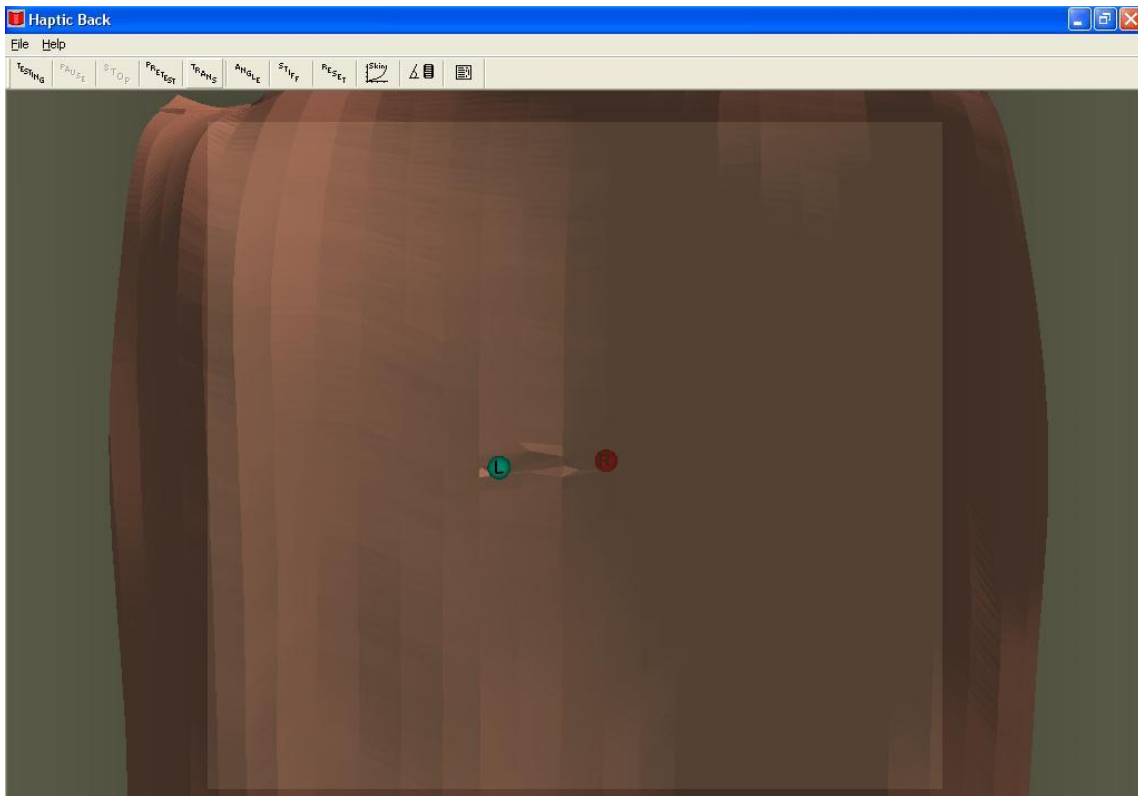


Figure 9c. VHB, v4 transparent, Testing Model for Experiment II, Fall 2003



**Figure 9d. VHB, v4 opaque, Testing Model for Experiment II, Fall 2003**

The v4 testing model, used in the second two-year round of VHB evaluation with cohorts of Osteopathic and control subjects (Experiment II), is shown in Figures 9c and 9d. Note again in Figures 9c and 9d the L and R cursors represent the virtual left and right finger positions, defined by the locations of the tips of the left and right PHANTOM haptic interfaces, respectively. The testing v4 has the same features as previous VHB models, but the interspinous ligament was removed due to the complex shape of each vertebra. Also, the ribs were removed since they are not involved in the testing protocol. This VHB model is life-sized. Vertebrae were scanned as explained above (Figure 9b) and are life sized. The exponential haptic skin model is from previous versions, scaled up to be life-sized. Visible vertebrae are haptic at the processes only; the haptic field at each process is elliptical in shape. It would take too much processor time to be able to feel all the parts of each vertebra; also, the D.O.s feel this would be overkill, i.e. not required for good human back simulation and palpatory training. The vertebrae modeled are C7, and T1-T11. Testing is done on T1-T10 only. C7 and T11 are present so the subject has something to compare with above and below each possible testing vertebra.

In Figures 9c and 9d, the buttons across the top of the screen include:

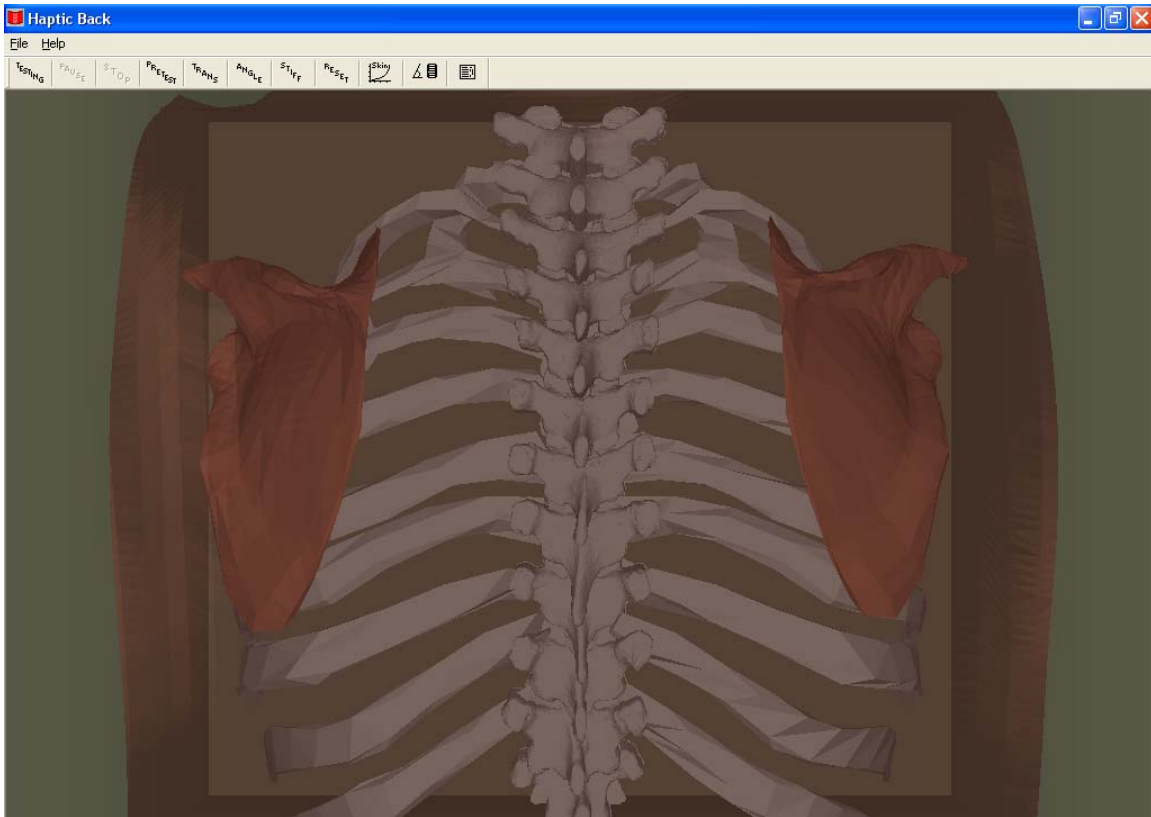
- a. trans – toggles on or off the image of the underlying skeletal elements.
- b. test – runs a sequence which includes subtests of abnormal vertebral stiffness and abnormal vertebral position at three levels of difficulty for each. The vertebra chosen to be dysfunctional is varied randomly. The user 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 9e shows the VHB model in use for teaching in the Osteopathic Manipulative Medicine (OMM) Laboratory at Ohio University. Dr. Burns palpates a human subject's back (Ji Wei) while Bob C demonstrates a similar examination using the VHB.



**Figure 9e. VHB in use in the Laboratory**



**Figure 9f. VHB, v4b**

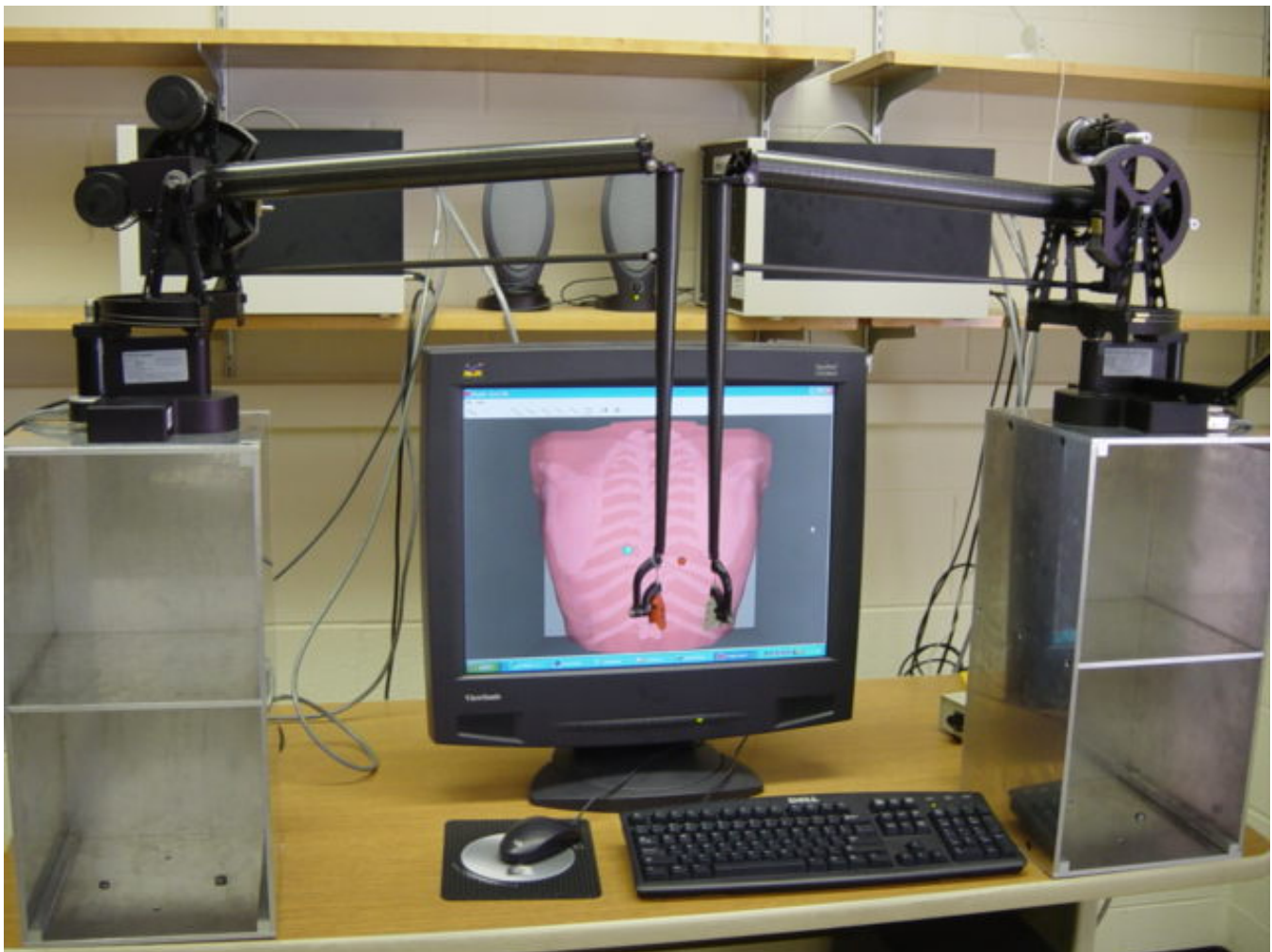
Figure 9f shows VHB *version 4b*. This is the same as v4, but realistic looking ribs and scapulae have been scanned and added. The ribs and scapulae are low resolution for limiting processor loading, and can be felt haptically. This is not a testing version, yet.

## **Virtual Haptic Back, Version 5; Summer 2004**

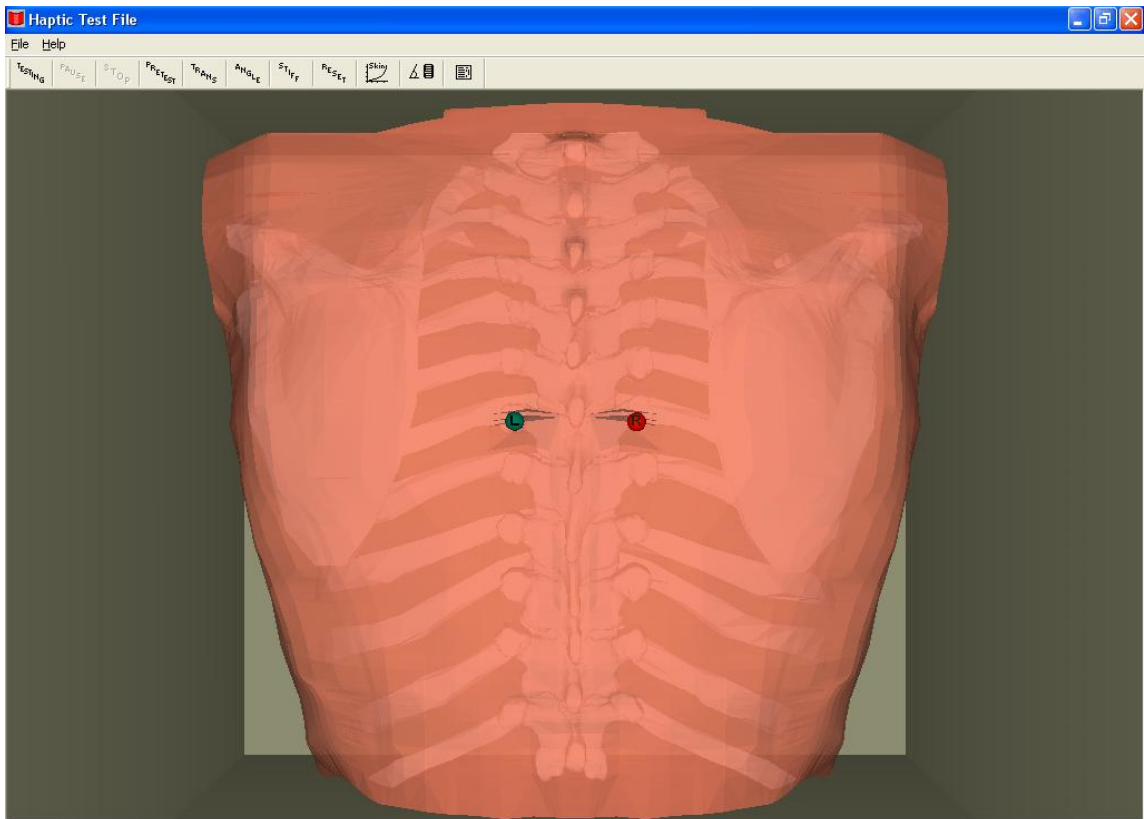
VHB v4 is mature and relatively life-like and easy to use, as rated by our student evaluators (see Experiment I and Experiment II write-ups). Two major problems still exist: the virtual fingers can puncture the skin and slip between vertebrae in a most unrealistic manner; also, there is no skin friction model and so palpators can easily slip off features in the VHB when they would not do so in the real world. The former problem of slipping between vertebrae is being addressed with an improved collision detection algorithm wherein the virtual finger for collision determination will be given realistic 3D size (to replace the GHOST-built-in single-point-based collision detection routine in use in all previous VHB versions). The latter problem of skin friction could be addressed by modifying VHB v4; however, we are trying an entire new approach as explained below.

During Spring and Summer 2004, a new paradigm has been developed for VHB modeling. A surface-only model is being implemented in lieu of the existing layered modeling approach. That is, in the new surface model approach, there are no underlying structures as in previous versions; instead, the haptics model is made at the skin surface to indicate the vertebrae, etc. This is a fundamentally different approach compared to VHB v0-v4; it is being implemented to allow easy skin friction modeling and we wish to see what other benefits this approach may yield.

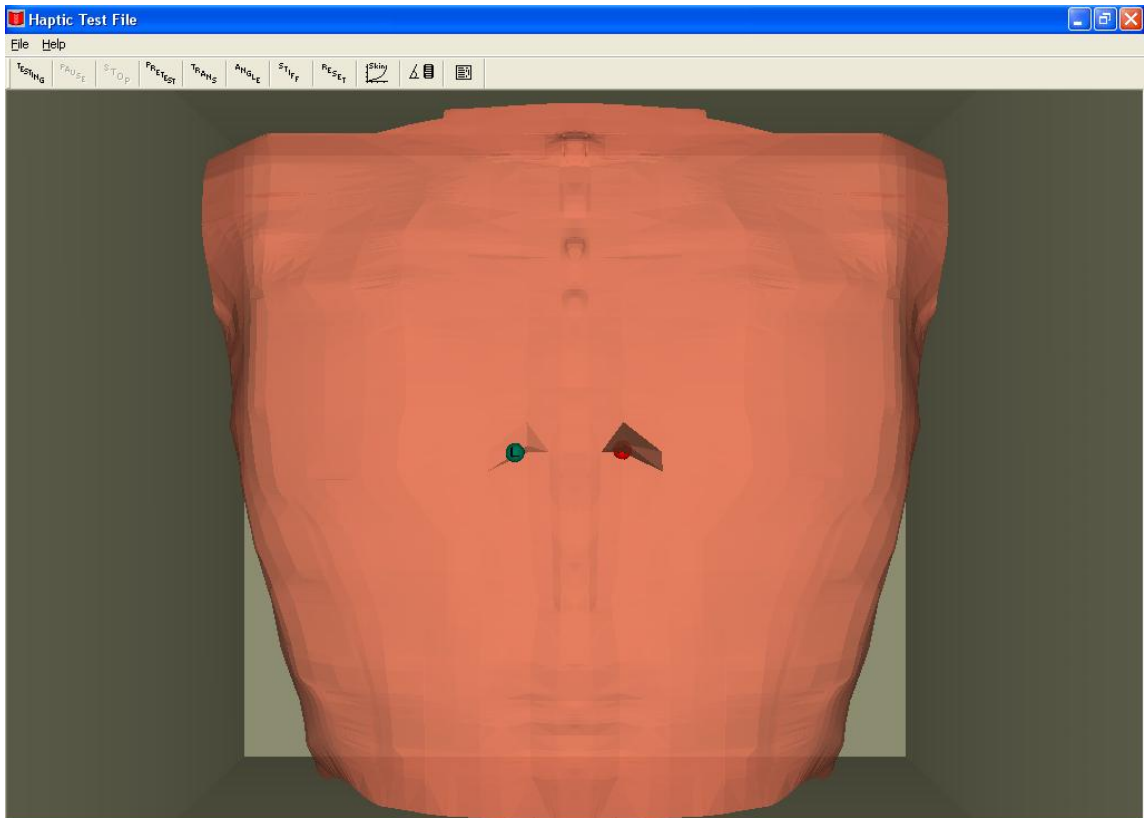
The initial VHB surface model, *version 5*, is shown in Figure 10a. While the haptic modeling is now focused only on the surface rather than in a layered manner as previously, we still include skeletal graphics to user orientation (can be made transparent as in Figure 10b or opaque as in Figure 10c).



**Figure 10a. VHB Surface Model, v5**



**Figure 10b. VHB, v5 transparent, Testing Model for Experiment III, Fall 2004**



**Figure 10c. VHB, v5 opaque, Testing Model for Experiment III, Fall 2004**

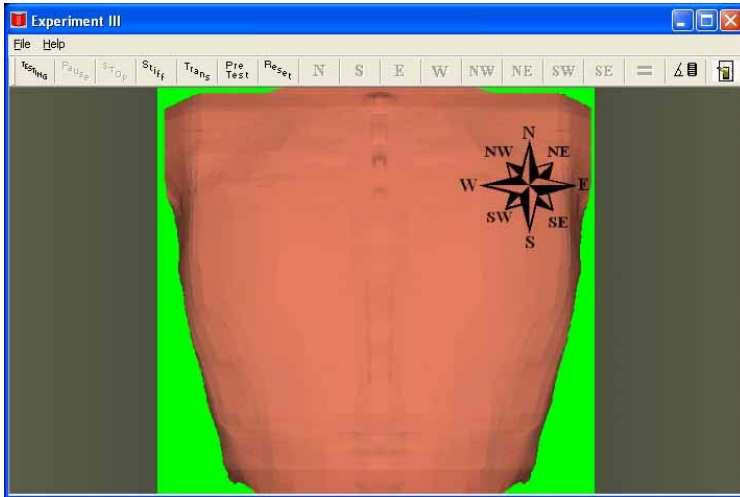
Both Drs. Burns and Eland agree that the surface model may have a more holistic and realistic quality than the VHB models v0-v4. These layered models are good for local modeling where single vertebrae are stiffer and/or out of alignment, but the surface model is more natural for the regional motion model. There are two schools of thought in the Osteopathic world along these lines. We will continue developments in each model type, improving the realism of each as we go, and we hope that our work in VR may help the Osteopathic discussion as to which model is preferable.

One change was made to the VHB v5 for Experiment V: the virtual patient was made to lie prone while the palpator stands (rather than standing in front of a seated palpator). Also, the somatic dysfunctions were made more subtle, harder to feel and find. As these changes were rather cosmetic, no new full version number is assigned – it is still fundamentally the surface model of version v5. Therefore, we call it the VHB v5.1.

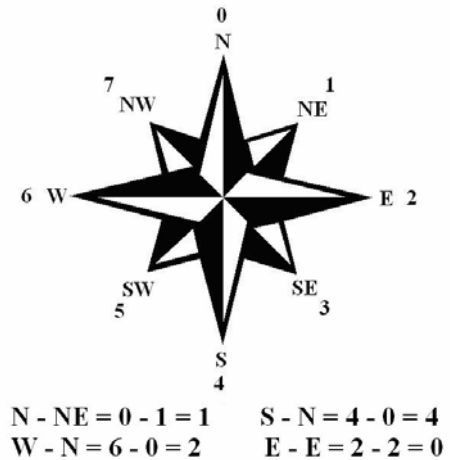
In addition to the large, complex, virtual haptic back model, we have developed simpler tactile modules to exercise and test human subjects' palpatory skills. On the recommendations of our expert palpator co-investigators, we have completed initial development of two haptic training modules: a fascial drag test and a haptic bump size discrimination test. We will further develop and evaluate these and additional haptic training modules suggested by our expert palpators, for focused haptic training purposes, independent of specific human anatomy. These two haptic modules are explained in the following two sections.

**Fascial Drag Module, VHB Version 5; Fall 2004**

The object of the fascial drag module is to simulate the realistic feeling in human anatomy that the tissue you are pressing normal to the surface is also pulling your finger in a certain direction along the surface. Figure 11a simulates a small 3D surface of human skin. For testing, the direction of this fascial drag is randomly assigned to be one of the compass rose directions shown. The magnitude of the drag force is also randomly chosen, from subtle to more obvious. The subject must identify the direction of the fascial drag by feel only (no graphical cues).



**Figure 11a. Fascial Drag Haptic Module**



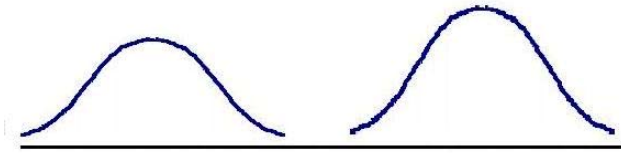
**Figure 11b. Fascial Drag Number Assignment**

In order to analyze the data, the direction of the fascial drag force needed to be converted into a number, as shown in Figure 11b. The difference between the actual direction of the force and the direction picked by the subject was used in the data analysis.

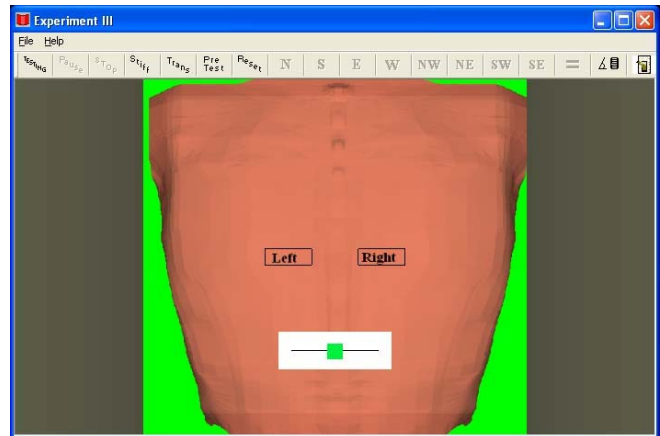
For the fascial drag test, the variables recorded are the difference with correct direction, the time to identification (both left and right fingers), and the average force used for both left and right fingers. Both PHANToM 3.0 haptic interfaces are thus used in evaluation, but one at a time.

## Haptic Bump Module, VHB Version 5; Fall 2004

The object of the bump test module is to match the height of two Gaussian-shaped bumps (see Figure 12a) on a flat surface by feel only (no graphical cues). The height of the right bump must be matched by the user to the left bump (whose height is randomly set by computer, from subtle to more obvious) by adjusting the slider (green square in Figure 12b) at the bottom of the screen. The subject cannot see the bumps graphically, otherwise it would be easier to match their size. The bumps are located within the boxes labeled Left and Right (Figure 12b). This is a one-dimensional test, i.e. not only are the bumps on a flat surface (top view in Figure 12b), but they have the same height normal to this flat surface along the vertical Left and Right box directions. We are currently able to test size discrimination to the sub-mm level.

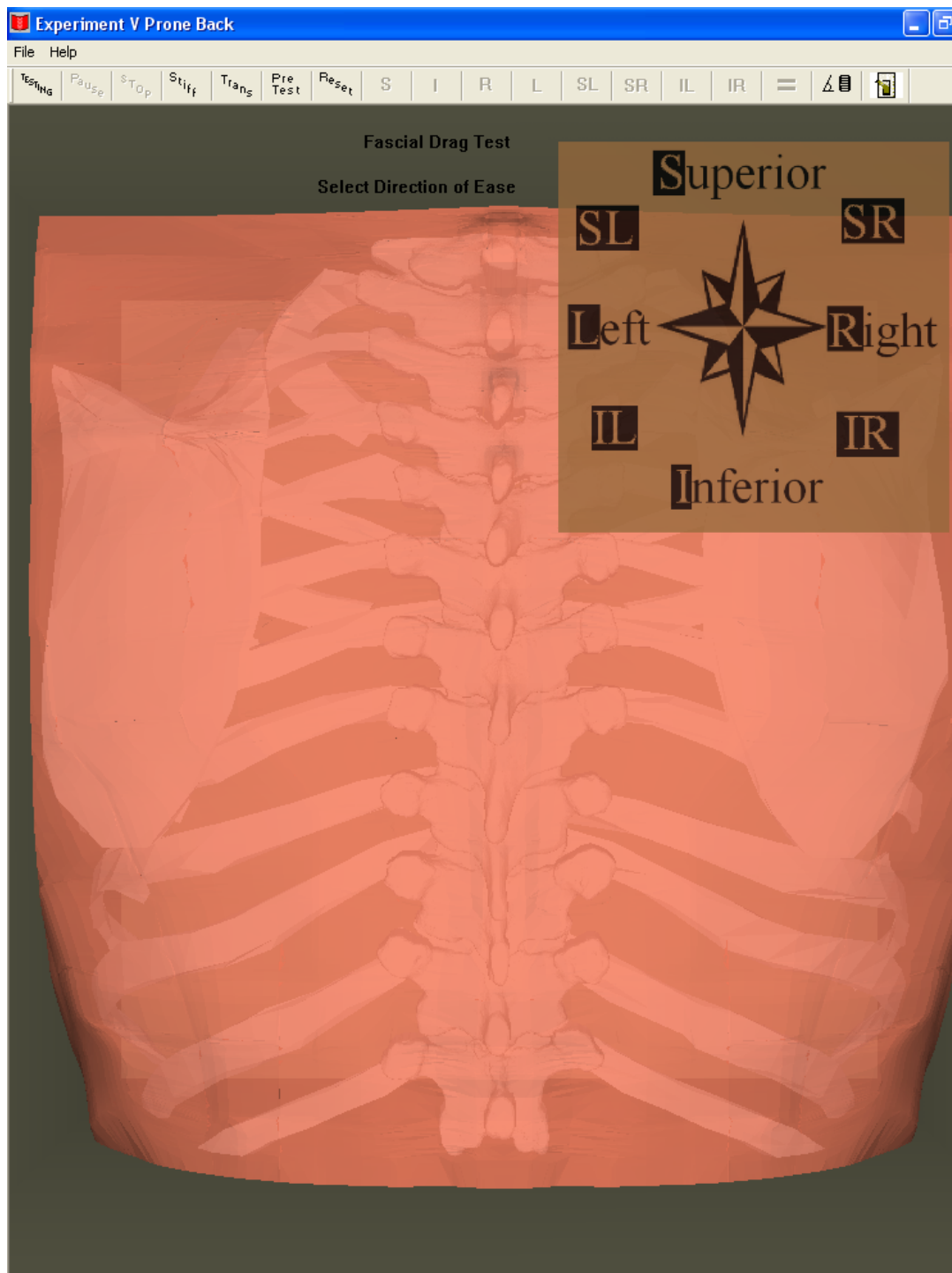


**Figure 12a. Gaussian Bumps**



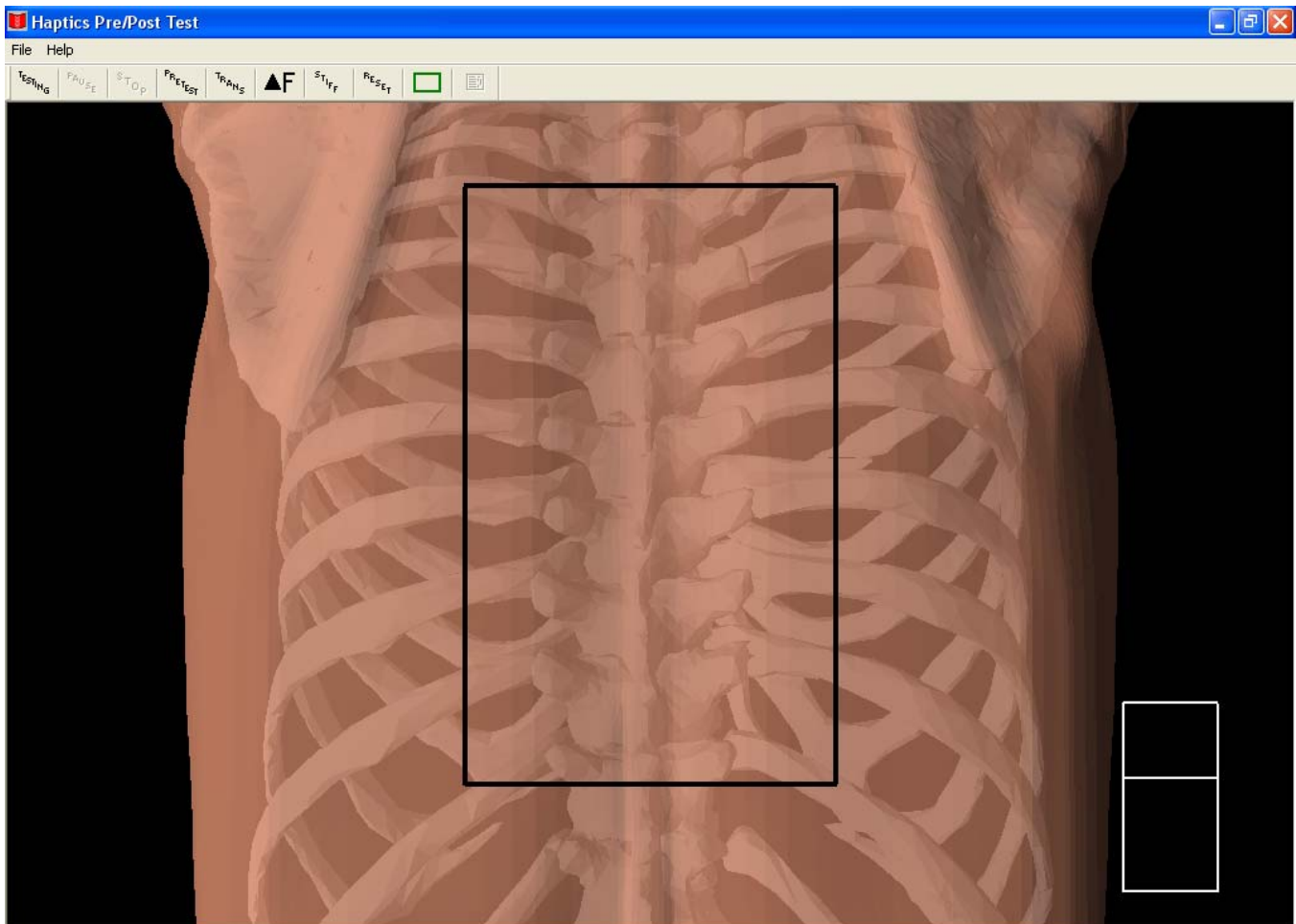
**Figure 12b. Haptic Bump Module**

For the haptic bump test, the variables recorded are the time to completion for both the left and right fingers, the average force exerted by both left and right fingers, and the resulting difference in height between bumps (zero difference would be the ideal result).

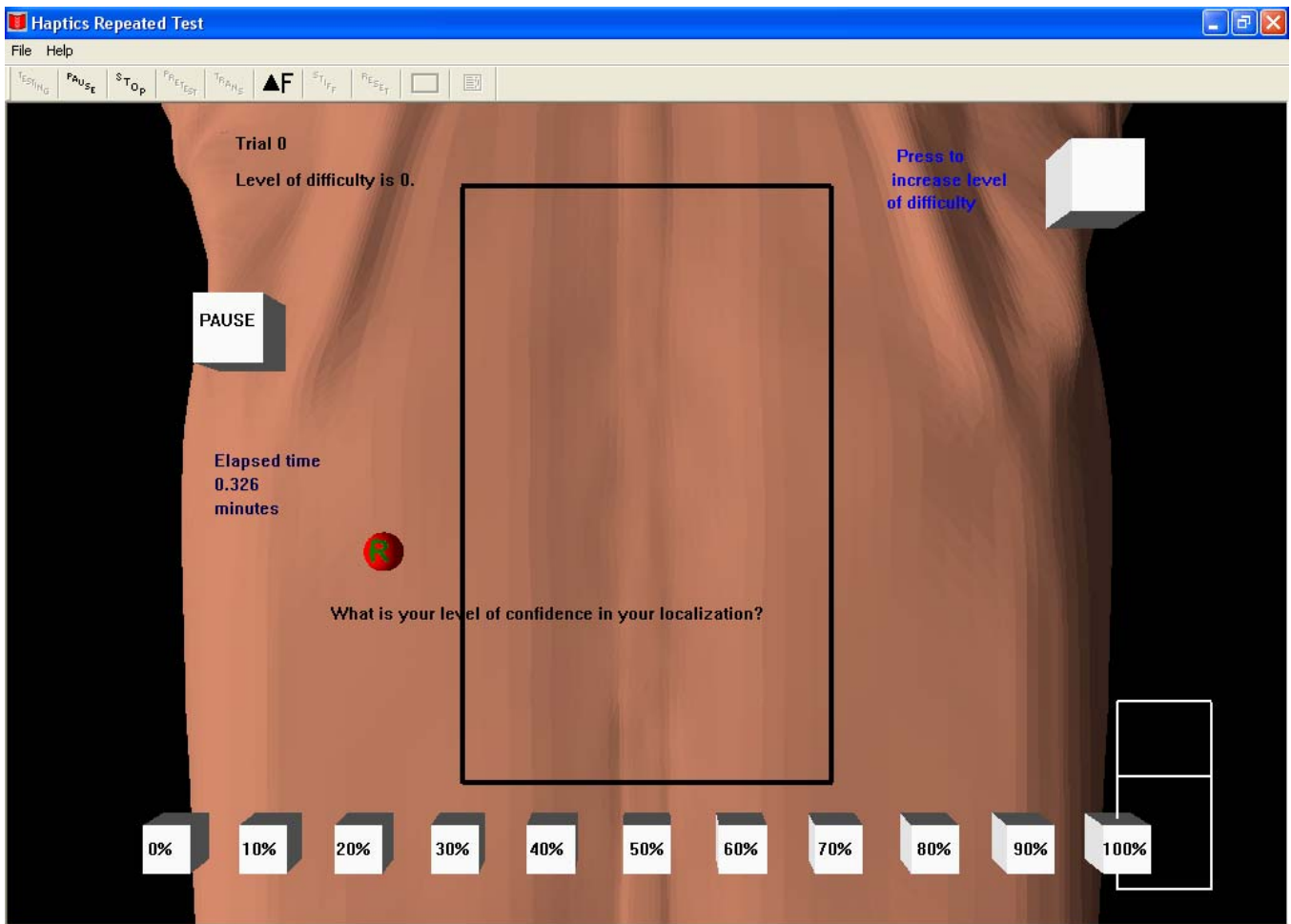


Experiment V Fascial Drag Test Spring '05. Same as in Experiment IV. Subjects were med students and controls in their second year of haptic back testing. The main difference between Experiment IV and Experiment V is that Experiment V is done with the patient prone. The monitor was laid down on a table to simulate a patient lying down. This test differs from the one in Experiment III in a couple different ways. First, the surface used is the 3d surface of a back. The previous fascial drag test was done with respect to a flat surface. The notation was also changed for this test. Instead of N,S,E,W, more anatomical notation was used to describe the direction of the force.

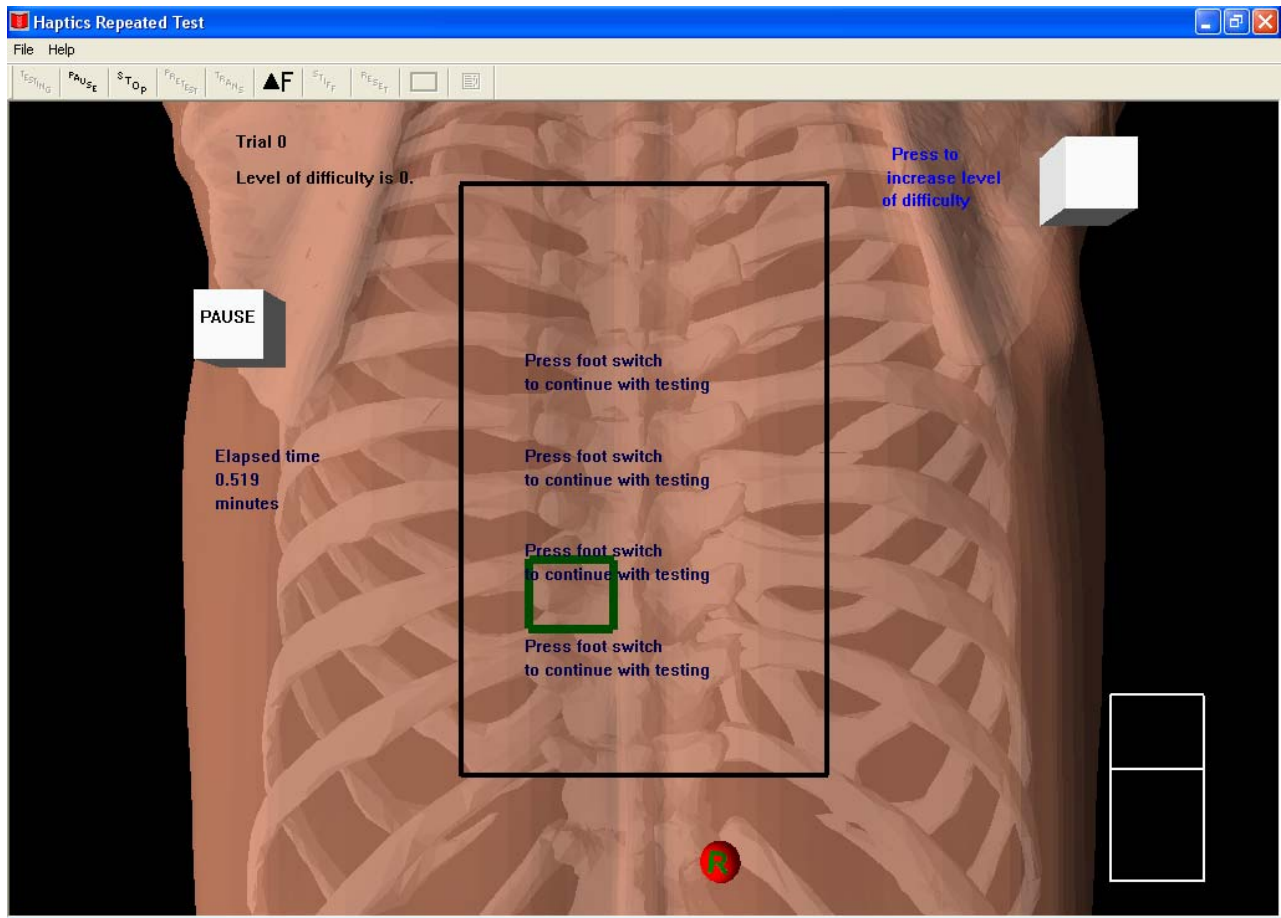
## Virtual Haptic Back, Version 6; Summer 2005



Experiment VI Haptic Back Training Fall '05, Winter '06. 1<sup>st</sup> Year medical students were used as the subjects for this study. The underlying skeleton comes from the Visible Female dataset. The skin was created to fit over top of the underlying skeleton. Testing is done only on the regions T5-T10, the vertebrae completely inside the black box. A dysfunction is randomly located over a transverse process on either side of the back. The white box in the lower right represents how hard the subject is pushing on the back. If the exerted force level exceeds a certain value, a verbal warning is given to the subject not to press so hard. Subjects were first given a pre test, then allowed to train on the back for eight sessions, then took a post training test.

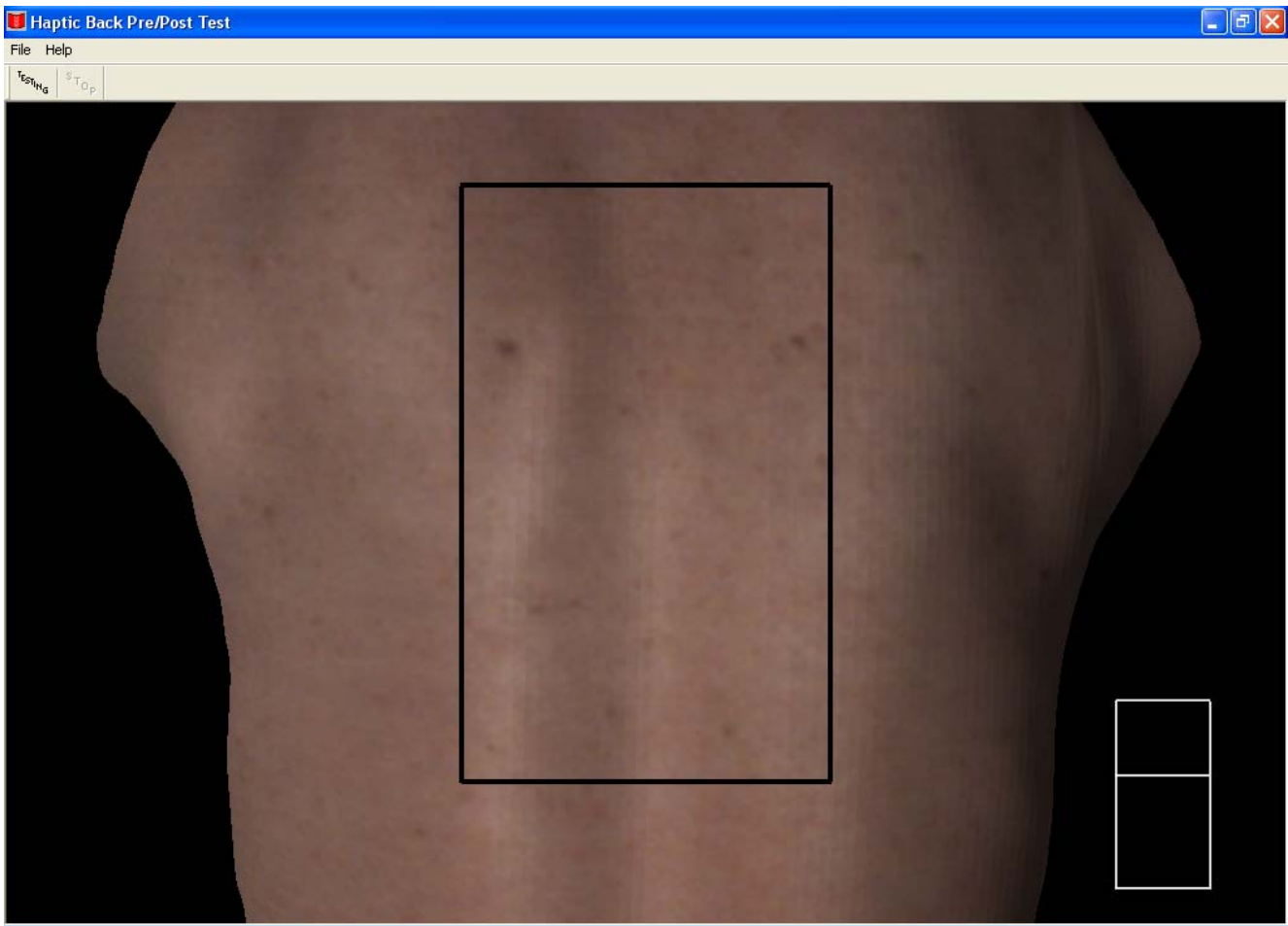


Experiment VI Haptic Back Training Fall '05, Winter '06. Subjects were allowed to practice for 15 minutes on the haptic back. When they found a dysfunction, they pressed a foot switch. Before they were told if the answer was correct, the above dialog appeared asking how confident they were that they had found the problem. Confidence ranged from 0% to 100% in steps of 10%.

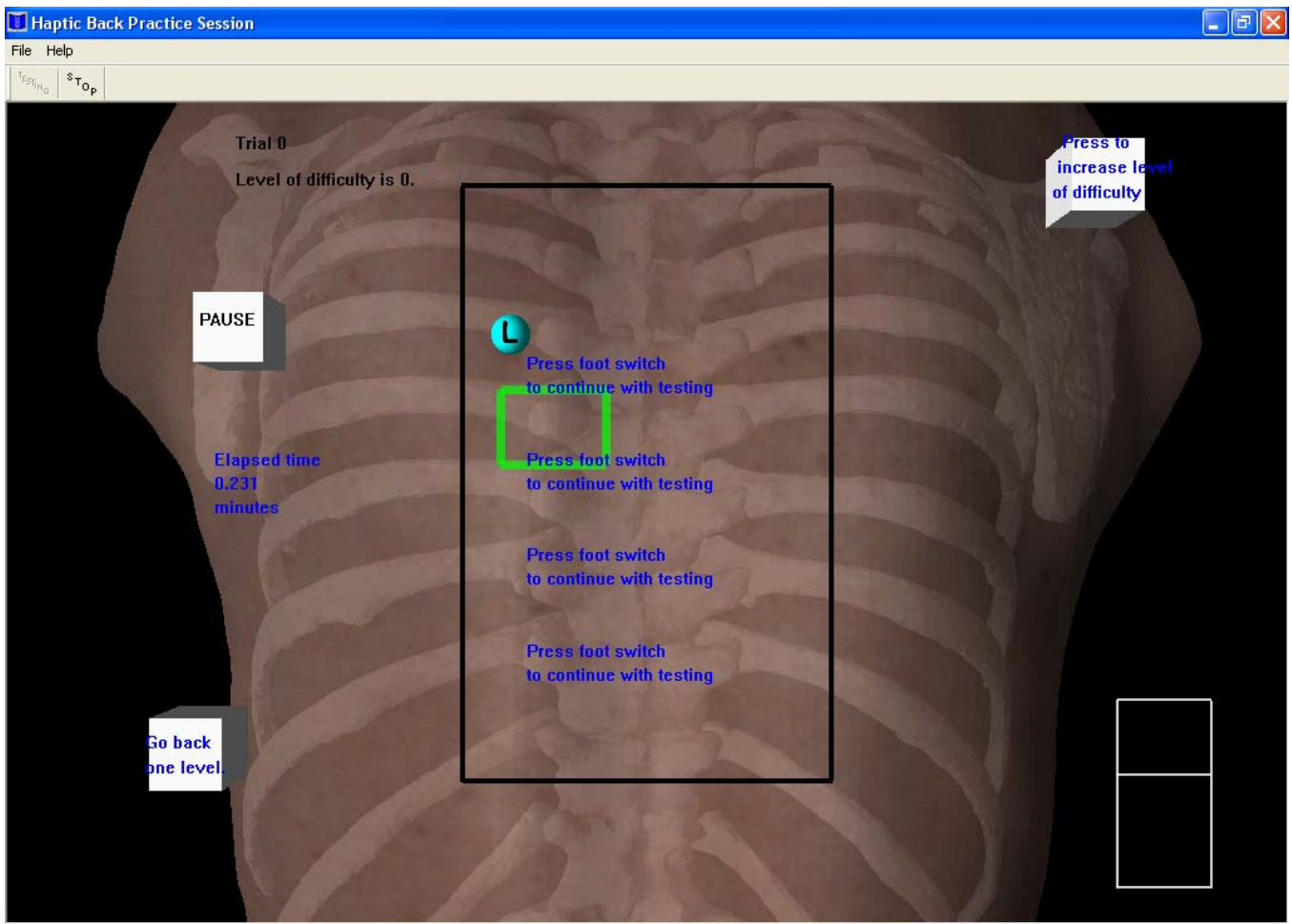


Experiment VI Haptic Back Training. Fall 2005, Winter 2006. If the subject gave a wrong answer, the location of the problem was highlighted and they were allowed to practice feeling the problem area before continuing with the training.

## Virtual Haptic Back, Version 7; Summer 2006



Experiment VIII Haptic Back Training Fall 2006. This version uses data collected from compliance measurements of a real person's back. The image displayed is the actual back. It is generated using our 3D camera. So the contour of the back is realistic and the changes in compliance across the back are also realistic. In the VHB Version 6, the background compliance was the same over the entire back. This version is more realistic and more challenging (the random dysfunctions still have the same compliance change ranges, but with respect to the measured realistically-changing background compliance). Confidence testing has been excluded from this version. Protocol is similar to the previous two experiments. Practice sessions have been dropped to six instead of eight. Dysfunctions are still localized over transverse processes and testing is still from T5 to T10. Subjects are all the 1<sup>st</sup> year medical students at Ohio University.



Experiment VIII Haptic Back Training Fall '06. Display during practice session when subject gets a wrong answer. They are allowed to practice feeling the correct answer before continuing with the testing. The skeleton is from the visible female dataset and has been scaled to fit the back generated with our 3D camera.