

The Virtual Haptic Back (VHB): a Virtual Reality Simulation of the Human Back for Palpatory Diagnostic Training

John N. Howell

Interdisciplinary Institute for Neuromusculoskeletal Research, Ohio University, and the Department of Biomedical Sciences

Robert L. Williams II¹, Robert R. Conatser², Janet M. Burns³, and David C. Eland³

Interdisciplinary Institute for Neuromuscular Research, Ohio University, and the Departments of Mechanical Engineering¹, Biomedical Sciences², and Family Medicine³

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ABSTRACT

The Virtual Haptic Back (VHB) is designed as an aid to teaching medical palpatory diagnosis. It uses two PHANToM 3.0 haptic interfaces (SensAble Technologies, Inc.), permitting palpation by force feedback with two fingers of a life-sized virtual human back. A graphics image of the back is displayed on a monitor a few inches behind the palpable back. Movement of back components, e.g., skin or underlying vertebrae, by exertion of palpatory force by the user is reflected graphically. Mechanical properties of the back, e.g., spring constants of the surface, are chosen based on feedback from physicians experienced in palpatory diagnosis. Although subjective evaluation of the VHB by 81 users over 2 years is positive, results have not yet shown students being trained in palpatory diagnosis to perform better than controls subjects. Results guide modifications of the haptic model itself and of the user tasks employed during testing.

INTRODUCTION

Haptics, particularly in the form of force-feedback, is finding applications in medical training in which the feel of a procedure, such as insertion of a biopsy needle or laparoscopic surgery, provides crucial information to the practitioner under conditions of limited available visibility (Okamura et al., 2004; Okamura, 2004; Montgomery, 2003; Rattner and Park, 2003). A second area of potential significance for haptics, which has received less emphasis, is palpatory diagnosis itself. Direct palpation is used in the detection of edema, masses,

organomegaly, fremitus, crepitation, pulse, muscle tension, herniations, as well as joint and connective tissue abnormalities. In 1997 Langrana reported development of a tumor palpation simulation (Langrana, 1997), and in 1999 Burdea et al., described a prototype for palpation of the prostate (Burdea et al., 1999). We have developed the Virtual Haptic Back (VHB), a simulation of the human back for training osteopathic students in the palpatory diagnosis of somatic dysfunction (Williams et al., 2004).

Somatic dysfunction, diagnosed by palpation as alteration of the musculoskeletal tissues of the back, and generally associated with pain and restriction of motion, is often treated by manipulative intervention. During their first two years of training osteopathic medical students learn palpatory diagnosis and manipulative treatment, largely in student labs, where prominent examples of somatic dysfunction may not be commonly encountered. The palpatory changes students are expected to sense in their partners are often subtle, and may not remain constant with repetitive palpation in the laboratory setting. The possibility of practicing palpation of a variety of typical cases of somatic dysfunction with a haptic simulator offers an attractive adjunct to current training methods. If the fidelity of the simulation can be made sufficient, such a simulation also offers the possibility of an objective measure of palpatory skill.

In order to establish the validity of the VHB for training, it would be ideal to demonstrate that practice on the VHB improves clinical palpatory performance by students. However, there is currently no way to objectively measure of clinical palpatory performance. Our approach is to establish transference of skill

between the VHB and clinical palpation by comparing the performance of skilled palpators, and medical students being trained in palpatory diagnosis, with control subjects who have no such experience. We hypothesized that experienced palpators would do better than controls on the VHB.

The project began with a PHANToM 1.0 haptics interface being used as the platform for haptic simulation of the back. Experiment I, described below, used the PHANToM 1.0 to compare med student and control performance on the VHB over a two year period. During this period the med students were in continual training in palpatory diagnosis. Experiment II, also described below, utilized two PHANToM 3.0 interfaces. These allowed two-finger palpation, a better approximation to clinically performed palpation.

Despite the impression by medical student users that the VHB would be helpful to them in learning palpation, the objective results to date have failed to show performance differences between med students and controls. They have, however, led to modifications both of the haptic model of the back and of the tasks used in the testing procedure. The modifications are designed to make the model and the testing more reflective of the circumstances in which osteopathic medical students train. They are currently being tested.

This paper describes the VHB used in Experiments 1 and II and summarizes results obtained with users.

METHODS

The VHB hardware and software

The original model of the back used in Experiment I was based on surface measurements from one subject obtained with a Metrecom (Faro Technologies). Underlying vertebral spines and transverse processes were added to the model and represented by spheres and cylinders available in the software package (General Haptic Open Software Toolkit (GHOST® SDK) provided with the PHANToM interface by SensAble Technologies (Woburn, MA.) For Experiment II the model was transferred to a system using two PHANToM 3.0 interfaces, allowing two-fingered palpation of a life-sized model. The graphics were made more realistic by the addition of images of underlying vertebrae obtained by digitizing individual vertebrae from a human model.

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 NVIDIA Quadro4 900XGL, 128 MB graphics card. The GHOST® SDK 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 haptic loop performs the following haptic functions in real time:

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

The haptics are modeled by a spring-damper system. The motors of the PHANToM limit how solid these objects feel. Spring stiffness for skin and bone in the model were not taken from measurements. Instead they were set according to subjective feel by the development team, which included three physicians experienced in palpatory diagnosis. An image of the back, with or without the underlying vertebral column visible, is displayed on a monitor a few inches behind the virtual haptic back that is felt by the user. The graphics frame rate is 30Hz.

The two tasks for users of the VHB

The tasks were the same in the two experiments, the only difference being that in Experiment II two PHANToM 3.0 units were available so that users palpated with two fingers instead of one, and the palpation was done on larger, life-sized simulated back.

Following a routine of familiarization with the VHB, users began each session with the task of determining which individual vertebra is abnormally stiff to rotation, the stiffness task. This was done with the transparency function turned on so that the user could see where to push on the transverse processes to test for stiffness (Fig 1). The task required the user to push sequentially on the transverse process of each vertebra to determine

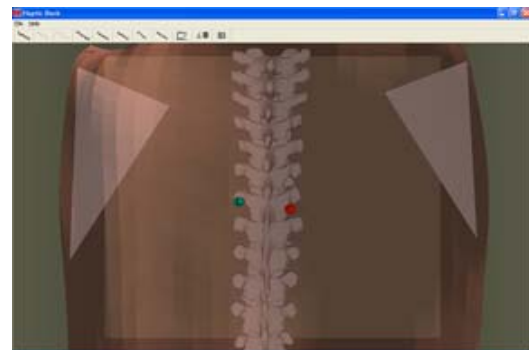


Fig. 1. Graphic image of the VHB (Experiment II). Scapulae are stylized. The two dots represent the positions of the palpator's fingers, shown here over the transverse processes of thoracic vertebra #7. Of the 12 vertebrae shown only T1-T10 were candidates for being abnormal.

which one was stiffer to rotation than the others. As the user pushed on a transverse process it could be seen graphically to move. The user recorded his/her choice by pressing a footswitch while holding a finger on the abnormal transverse process. A recorded voice responded, indicating to the user if the choice had been the correct one. When the correct choice was made the program carried the user to the next step. The test was done three times, with the level of difficulty increasing each time, i.e., the degree of stiffness difference became less abnormal. For each repeat a different vertebra was chosen by means of a randomization process. The

computer recorded the time to correct identification and the number of erroneous identifications the user had made before making the correct choice.

The second task, the position task, was to identify a vertebra abnormally rotated with respect to the others. For this test the transparency function was turned off so that the user could not make the identification visually. Again, three degrees of (increasing) difficulty were sequentially tested, and the computer recorded time to completion and the number of errors.

Both speed (time to completion) and accuracy (number of errors) are important in clinical palpation. Accuracy of diagnosis is of obvious importance. The need to complete physical examination of patients efficiently, in terms of time, is of increasing importance in light of pressures to control health care costs. Physicians are under considerable pressure to see as many patients as possible per unit time.

Experimental subjects

In Experiment 1 there were 19 medical students (8 males and 11 females; mean age 24.4) and 17 controls (8 males and 9 females; mean age 24.8). In Experiment II there were 20 medical students (4 males and 16 females; mean age 25.1) and 19 controls (8 males and 11 females; mean age 23.4). The two groups, medical students and controls, allowed us to test the hypothesis that training in palpatory diagnosis would result in better performance on the haptic back by medical students than controls, illustrating a transference of skill from the palpatory training of medical students on people to the VHB.

The sequence of testing

In Experiment I subjects, both medical students and controls, were tested 5 times, once a quarter over two academic years. In Experiment II subjects were tested 3 times, once a quarter over one academic year.

Subjective analysis

Subjects filled out evaluation forms after sessions 1, 2 and 5 in Experiment I and after sessions 1 and 2 in Experiment II. They rated the simulation as to realism and ease of use on a 1 to 10 visual analog scale. The medical students were also asked the following: "Do you think practice with the haptic back might be helpful to you in the development of your palpatory skills in the OMM lab?"

Statistical analysis

Results were analyzed by repeated measures analysis of variance (RMANOVA). $P < 0.05$ was taken as significant.

RESULTS

Experiment I

Figure 2 shows the time to completion of the stiffness task of medium difficulty, i.e., the time to identification of the correct vertebra. Users got faster over time, the

initial mean being about 3 minutes and the final mean being about half that. No differences can be seen between the two groups. The number of errors, not shown, was small, averaging about 1. It was not different between the groups and did not vary significantly over time. Figure 3 shows the results of the position task of medium difficulty, which showed no convincing improvement in time to completion over the trials, and showed no difference between groups. The mean number of errors was somewhat higher than in the stiffness task, but was highly variable.

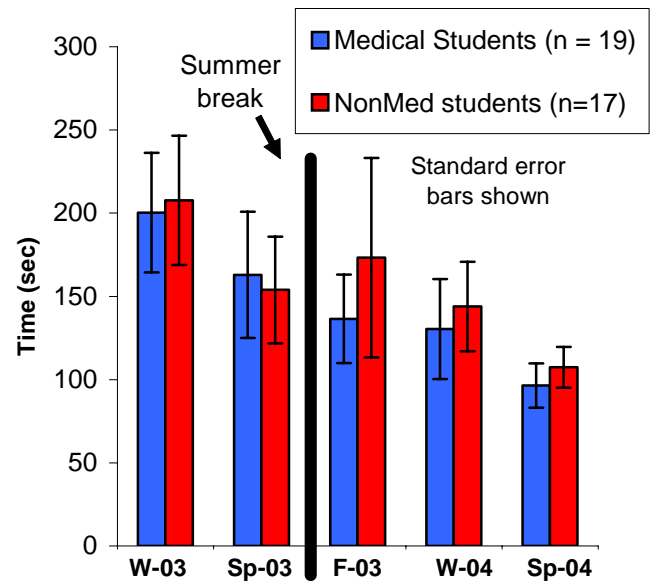


Figure 2. Experiment I. Time to completion of the stiffness task of medium difficulty. The five trials began in winter quarter 03 and ended in spring quarter 04.

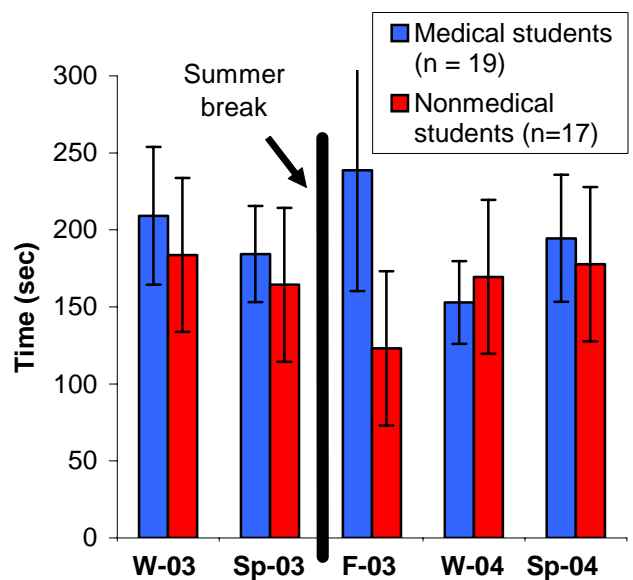


Figure 3. Experiment I. Time to completion of position task of medium difficulty.

Experiment II

In experiment II palpation became more realistic in that it was two-fingered instead of one, and was life-sized. Figure 4 shows the time required for identification of an abnormally stiff vertebra in the stiffness tasks of all three levels of difficulty. Neither group was perceptibly faster with the easiest task (high stiffness) than with the hardest (low stiffness). Only in the medium stiffness task was there any suggestion of the learning across trials that was visible in Experiment I. The number of errors (not shown) was highly variable, but appeared to increase over those in Experiment I.

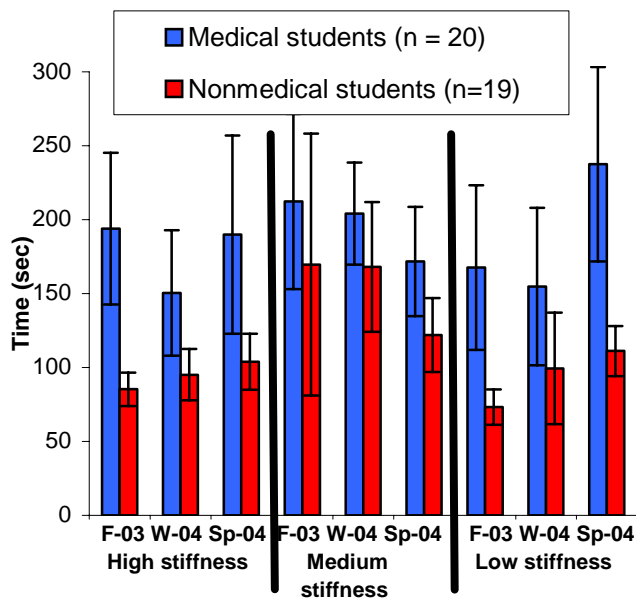


Figure 4. Experiment II. Time to completion of 3 difficulty levels of the **stiffness** task, repeated over 3 academic quarters, beginning in the fall of 03.

In the position task of Experiment II (Fig. 5) the time required for completion by the subjects was comparable to that in Experiment I, and, as in Experiment I, showed no improvement over the trials. The average number of errors was highly variable, but on average higher than in Experiment I (data not shown). Thus the introduction of two-fingered palpation on a life-sized model did not make the tasks easier, or reveal skill differences between the groups.

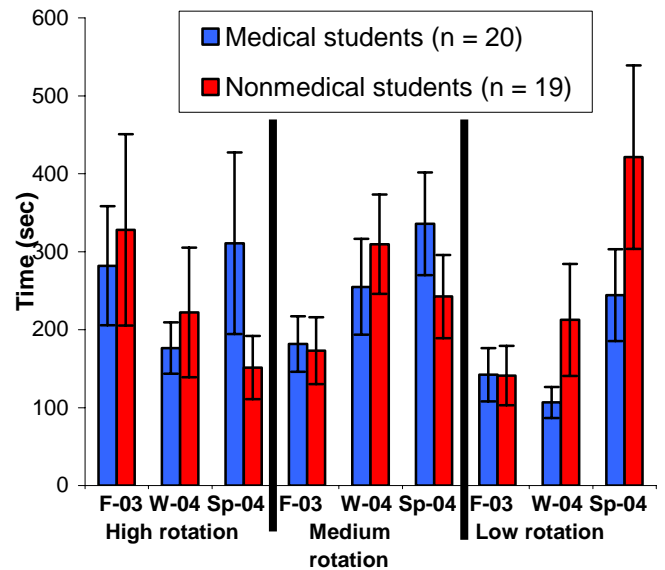


Fig. 5. Experiment II. Time to completion of each of 3 levels of difficulty of the **position** task.

User evaluation of the VHB

Both the medical students and controls evaluated the VHB after use in terms of apparent realism (Fig. 6) and ease of use (Fig. 7). While medical students found the VHB somewhat less realistic than controls, it was perceived as being more realistic by both groups in Experiment II than in Experiment I. Both groups found the VHB version of Experiment II somewhat easier to use than that of Experiment I (Fig. 7). Medical student evaluation as to the potential usefulness of the VHB in learning palpatory diagnosis was very positive (Fig. 8).

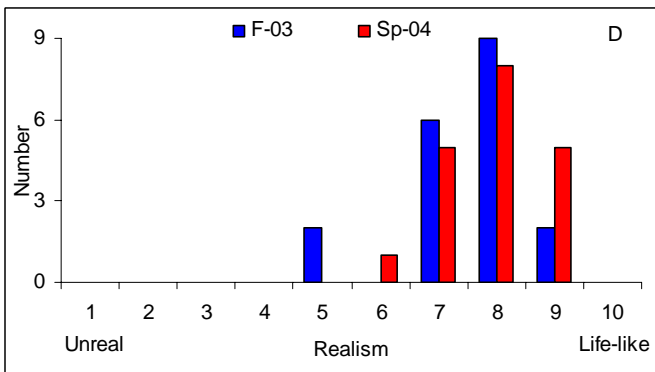
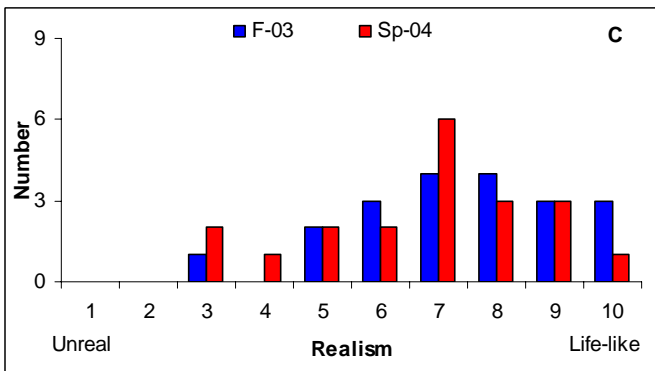
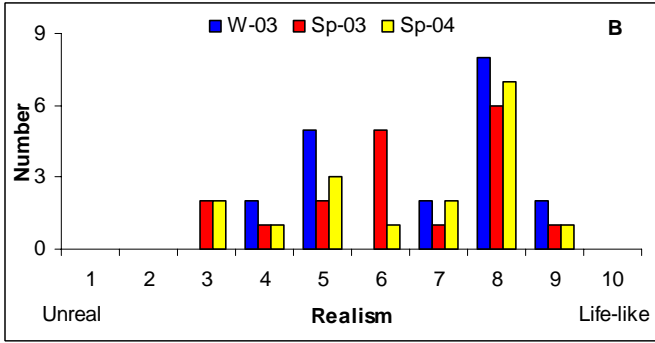
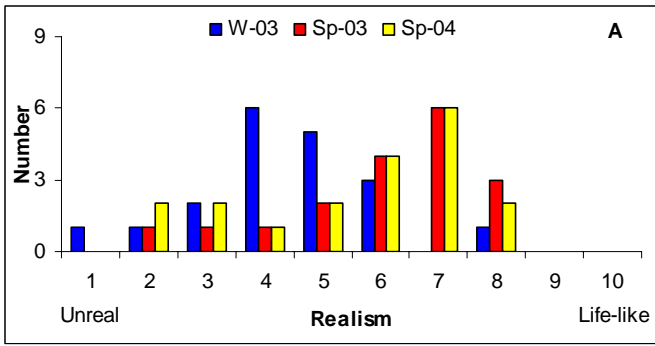


Figure 6. User evaluation of the sense of realism of the VHB simulation by med students and controls. In Experiment II realism was rated more highly than in Experiment I by both groups. Med students, experienced with actual palpation, rated it lower in realism than did controls. A – Experiment 1: Medical students, B – Experiment 1: Nonmedical students, C – Experiment 2: Medical students, D – Experiment 2: Nonmedical students

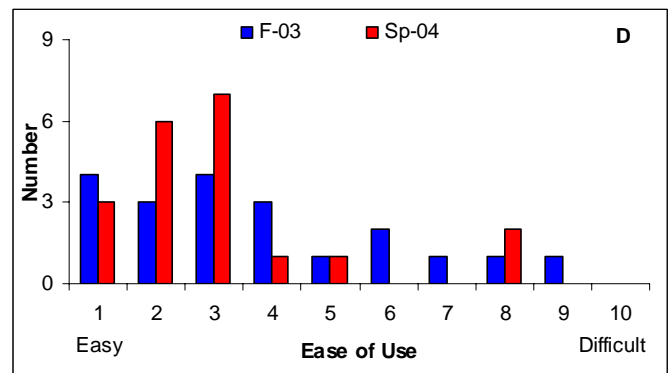
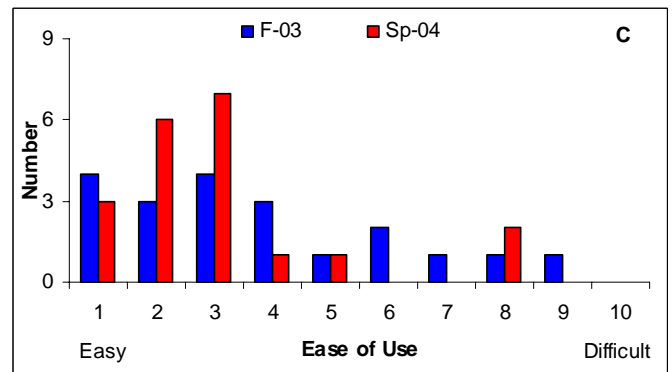
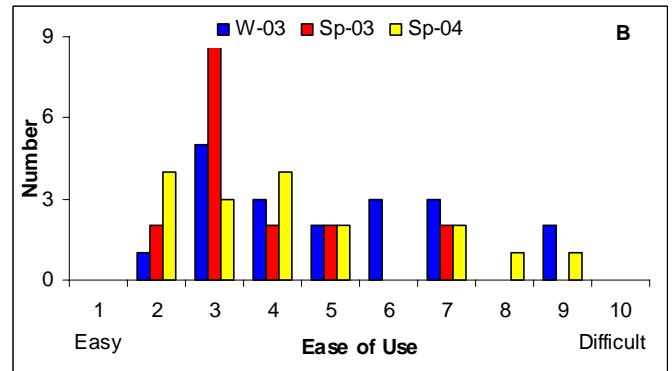
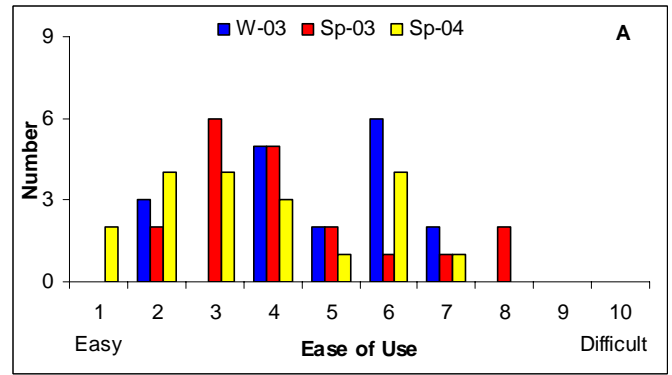


Fig. 7. User evaluation of the sense of ease of use of the VHB simulation by med students and controls. Shift to the left from Experiment I to II indicates increasing ease of use. A – Experiment 1: Medical students, B – Experiment 1: Nonmedical students, C – Experiment 2: Medical students, D – Experiment 2: Nonmedical students

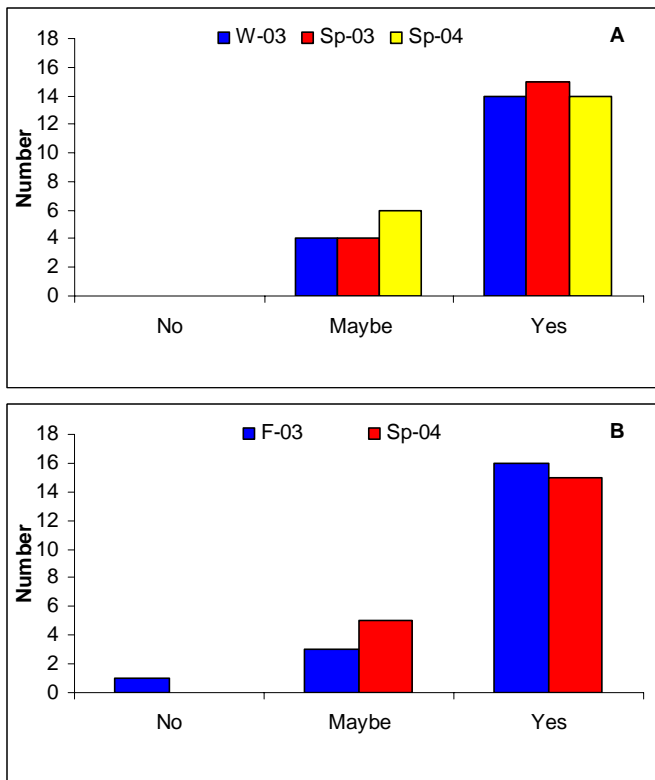


Fig. 8. Medical student responses to the question, “Do you think practice with the haptic back might be helpful to you in the development of your palpatory skills in OMM lab?” A – Experiment I, B – Experiment II.

DISCUSSION

Simulation and haptics in medical education

Visual images from various imaging techniques play a central role in medical diagnosis. Visual simulation, in the form of the Visible Human (Reinig et al., 1997), permits medical students to perform what might be called a simulated dissection of a human body. Dynamic palpatory “images” in the form of haptic simulation, are beginning to find a place in medical training. Real-time haptic simulations of laparoscopic surgery (Montgomery et al., 2002; Okamura, 2004; Rattner and Park, 2003, Reinig et al., 1996) and needle insertions (Okamura et al., 2004) are being used. Efforts at simulation of palpatory diagnosis of tumors (Burdea et al., 1999; Langrana, 1997) have been reported.

Our efforts have been directed toward haptic simulation of the human back, to use as model for training students in palpatory diagnosis of somatic dysfunction (Holland et al, 2004; Williams et al., 2004a; Williams et al, 2004b). Such a model will allow osteopathic medical students and others to practice palpating various musculoskeletal abnormalities as they learn the difficult art of palpatory diagnosis. Despite the development of sophisticated imaging and other diagnostic techniques, palpation will undoubtedly remain an important part of medical diagnosis. It is direct, quick and inexpensive, but it is a skill that is not easy to acquire. First year medical students learning palpatory diagnosis frequently express frustration at being unable

to feel what their instructors say they should feel. As our subjective data show, they think that the availability of a palpatory simulation, like the VHB, would be very helpful to their learning. However, in order to justify the investment in such simulations, it is necessary to demonstrate transference of skill from the virtual to the real world.

Status of the evolution of the VHB

The first iteration of the VHB, done with the PHANToM 1.0, was well received by osteopathic physicians, despite its small size and its single finger palpation. This led to funding of the project by the Osteopathic Heritage Foundation. With its support we have developed a testing protocol designed to assess the transference of skill between the VHB and real palpation. The ideal would be to demonstrate that practice on the VHB results in better palpatory performance in the real world. That is difficult to measure adequately, because there is currently no objective test of real-world palpatory skill. Our approach has been the inverse, namely to determine if osteopathic medical students receiving laboratory training in palpatory diagnosis perform better than control subjects receiving no such training. The hypothesis is that the medical student performance on the VHB should be better than controls. So far we have not yet been able to demonstrate such a difference.

One potentially confounding variable is the experience level subjects had with computer use, especially video games that involve virtual reality. We attempted to minimize this factor with a pre-experiment questionnaire asking subjects about their hobbies and their computer experience. Although the groups were not exactly matched age- and gender-wise, it is difficult to see how the small differences there were could have obscured a real difference between the group performances with the VHB. Since we were testing first and second year students, it is possible that they had not yet achieved a palpatory skill level that distinguishes them from controls. We have preliminary data with 6 experienced osteopathic physicians, but their performance with the VHB also does not look significantly different from that of the student users or controls. It seems likely that either the simulation is still not sufficiently realistic to permit a significant transference of skill, or the tasks used for testing are too easy, or in some other way inappropriate.

This does not necessarily mean, however, that the simulation will not be helpful to students learning palpatory diagnosis. The practice of feeling something that is entirely reproducible, unlike the situation with real patients, allows many repetitions, and may indeed help a student become more aware of the force feedback detectable by his own neuromuscular system during palpation. Subjective data (Fig. 8) obtained from our medical student users suggests that this may be the case for the VHB. A potential criticism of these data is that students might have responded positively in order to please their instructors. This was minimized in that their contact was entirely with a technician while they were doing the VHB tests and filling out the forms.

Furthermore, none of the VHB developers are instructors of record in the courses medical students are taking.

The failure to show differences in performance between med students and controls has led us to make modifications in both the model itself, to make it feel more realistic, and the tasks used in testing users. Modification of the tasks is designed to make them correspond better the skills needed in palpatory diagnosis and treatment. These modifications are currently being testing with a new group of users. Preliminary results are suggestive at least of trends in the expected direction.

We have also developed a playback system, whereby the path taken and the forces generated by the fingers of an expert doing the VHB diagnosis can be recorded (Williams et al., 2003). Users will be able to let the VHB take their fingers along the path recorded by the expert user, and/or by following the expert's path visually the user can experience the forces that were exerted by the expert. This system is also currently being tested to see if it contributes to the transference of skill.

CONCLUSION

Subjective reports from users of the VHB indicate that it has potential for use in training medical students in palpatory diagnosis. A protocol for testing transference of skill between the virtual reality simulation and the real world of palpatory diagnosis has been developed, but such transference has not yet been demonstrated.

ACKNOWLEDGMENTS

The investigators gratefully acknowledge the support of the 1804 Fund of Ohio University in the initial stages of the project, and generous current support from the Osteopathic Heritage Foundation of Columbus, OH.

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