Palpatory training on the Virtual Haptic Back improves detection of compliance difference

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ABSTRACT

The Virtual Haptic Back is under development at Ohio University for augmenting teaching and learning of the difficult art of palpatory diagnosis (detection of medical problems via touch). We are currently focusing on the human back and spine for osteopathic medical education. This paper presents our first data in repeated practice with the Virtual Haptic Back by medical student subjects. Data from the pre- and post-tests indicate statistically significant skill improvement and the data from the practice sessions reveal a pattern of tactile improvement. We also present just-noticeable-difference results in compliance detection and our associated Weber fractions fall in a range reported by others in the literature.

Keywords: haptics, training, palpatory diagnosis, PHANToM, Virtual Haptic Back, Weber fraction.

1 1INTRODUCTION

The Virtual Haptic Back is being developed as an aid in the teaching of medical palpatory diagnosis [1]. Palpation of the human back is used diagnostically by osteopathic physicians and others to detect musculoskeletal abnormalities collectively referred to as somatic dysfunction. These abnormalities include altered tissue texture, which reflects altered tension in underlying muscles and other tissues. A major component of tissue texture is tissue compliance, displacement per unit of applied force (the reciprocal of stiffness). The VHB simulates the contour and compliance properties of human backs, which are palpated with two haptic interfaces (SensAble Technologies, PHANToM 3.0), permitting simultaneous palpation with two fingers. Students can practice detecting and localizing compliance patterns that reflect clinically observed abnormalities. In this study we used the VHB to determine if training on the VHB would increase the ability of users to detect small differences in compliance between adjacent areas on the back.

The ability to detect small differences can be characterized by the smallest difference that can be detected, the just-noticeable-difference (JND). When the JND is expressed as a fractional change it is known as the Weber fraction [2]. Dhruv and Tendick [3], using a PHANToM 1.5 haptic interface, found Weber fractions in the range of 0.14 – 0.25 for a finger pressing against a resistance behaving as a linear spring. Weber fraction values obtained depended on the range of compliances examined, being 0.14 with a mean compliance level of 8 mm/N and 0.25 with a mean compliance level of 2 mm/N. DeGersem [4], also using the PHANToM 1.5 with compliance values in the range of 0.83 to 3.33 mm/N, reported Weber fractions between 0.08 and 0.12 in six subjects studied.

2 METHODS

The VHB model consists of the contour of a back plus the compliances of the surface. The contour was modified from the Visible Female data set. The compliance values were initially chosen to match the subjective feel of a back, as determined by osteopathic specialists in neuromusculoskeletal medicine. They were spot checked against compliance measurements made on actual human backs, using the PHANToM 3.0, equipped with a modified probe 2 cm in diameter, which assessed displacement as a function of force applied in graded steps up to 6 N.

VHB users feel the virtual back with two fingers or a finger and a thumb, from the same or different hands, placed into the thimble-like receptacles at the ends of the mechanical arms of the PHANToMs. Approximately 15 cm behind the virtual haptic back is a full-sized visual image of the back displayed on a 23 inch flat screen monitor (Figure 1).

Two dots (L and R) on the screen indicate visually where the user's fingers are with respect to the haptic back. In this way the user is able to bring his/her fingers directly to the center of the back in order to begin palpation.

Figure 1: Graphic image of VHB during the pre- and post-tests. Dots marked L and R indicate the position of the two palpating fingers. The rectangle indicates the region where abnormal compliance can be found. Trial number and difficulty level appear at upper left. Total time elapsed in the test appears at left; time remaining in the present trial appears at right. The box in the lower right is a force indicator which rises to the level of the horizontal line before a voice warns against using too much force.

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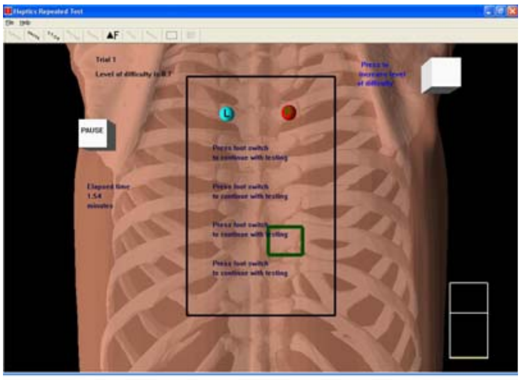

Figure 2: Appearance of the screen following a wrong answer in the practice sessions. The small green box indicates the actual location of the abnormal area. By touching the upper left box with a L or R finger dot, the user can pause the program; by touching the upper right box the user can alter the difficulty level of the next trial. These boxes can be accessed at any time during the practice sessions. (Skeletal elements were taken from the Visible Female data set.)

In the model used for testing, the back was programmed in C++ in the General Haptic Open Software Toolkit, GHOST®SDK, with OpenGL for graphics to have a uniform compliance except for one 2.5 by 3.0 cm region (Figure 2).

The entire region of testing was a rectangle superimposed on the graphics image of the back 13.5 cm wide and 22 cm high; it encompassed thoracic segments T5 – T10.

The compliance of the abnormal region, which ranged from 2.45 to 0.972 mm/N, was made to blend smoothly into the compliance of the surrounding areas (2.52 mm/N) with a hyperbolic tangent function:

$$F(x) = \frac{1}{2}\left[\tanh(a(x-b)+c) - \tanh(a(x-b)-c)\right]$$

where a is the distance over which compliance transitions, b is the distance between the center of the abnormal area and a reference point, such as the body midline, and c is the width of the abnormal area. Subjects typically moved their fingers along the back searching for regional differences in feel, and then went back to explore the region or regions they suspected might be abnormal. When they had decided which area was abnormal, they pressed a foot switch. A recorded voice provided immediate feedback as to whether their choice was correct or not.

In discriminating between two different linear compliances, applying greater force causes increasingly greater differences in displacement. This led users to press harder if they were having difficulty detecting the abnormal region. This was undesirable for two reasons. Sustained application of force levels over 6 N caused the electric motors of the PHANToM to overheat. Second, application of high forces is inappropriate clinically, both because of potential patient discomfort and because palpatory information from superficial soft tissues can be lost by applying too much force. We did the following in order to discourage users from pushing too hard. 1. When they applied unacceptably high forces, automated voice feedback warned them not to press so hard. 2. A visual gauge in the lower right of the screen monitored their force levels, enabling users to see when they were approaching the forbidden zone. 3. More importantly, the programmed compliance difference between the abnormal area and the surrounding areas was multiplied by a hyperbolic tangent function that made the difference gradually disappear with increasing displacements between 8 and 16 mm. Thus the differences were maximum in a desirable range of force application, about 3 N in the normal regions (Figure 3). Based on preliminary measurements, this force level falls within the range of forces typically exerted by fingers of experts in clinical palpatory diagnosis during palpation of superficial soft tissues.

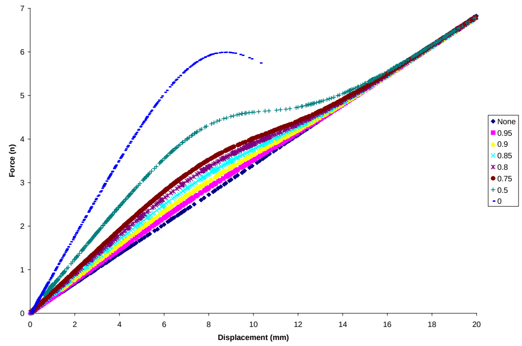

Figure 3: Relation between force and displacement at different difficulty levels. The straight line indicates background stiffness (= 1/compliance). Increasing deviations from background make the task progressively easier. The deviations disappear at high displacements produced by application of high forces.

Volunteer subjects (N = 21) were first year osteopathic medical students within the first 5 months of their palpatory training. During their first session in the lab they were given an opportunity to familiarize themselves with the haptic interfaces, practicing 10-15 minutes identifying regions of abnormal compliance until they were comfortable with the task. During these initial familiarization sessions a transparency function was activated, permitting the user to see the skeletal elements beneath the skin. This feature was turned off during the pre- and post-training sessions and during the training sessions in between the tests.

Following the practice phase subjects took a test in which they had to locate the regions of abnormal compliance presented in successive trials. The locations varied randomly between sessions. The abnormalities could be on the left or on the right and at any one of 6 vertebral levels (T5 – T10). Five different levels of difficulties, i.e., magnitude of compliance differences, were presented, starting with the easiest and progressing step-wise to the most difficult (1.51, 1.98, 2.25, 2.35 and 2.45 mm/N, compared to a baseline value of 2.52 mm/N). At each difficulty level there were two trials. Each trial was completed in 1 minute; time remaining in each was presented on the screen. Midway through the test, the program paused, giving the user an opportunity to take his/her fingers out of the apparatus and rest his/her arms, before finishing the test. This test was administered again at the end of the two-week practice sequence as a post-test in order to determine the improvement in performance resulting from the practice.

Following the pre-test, subjects carried out the first of eight practice sessions, which were completed over a 2-week period. Subjects were permitted to do the practice sessions at their own convenience, but no more than one session per day. The total time of each practice session was limited to 15 minutes. More levels of difficulty, 10, were available in the practice sequence than in the pre- and post-tests. They ranged from 0.972 mm/N to 2.50 mm/N; baseline value = 2.52. Although the default setting of the program started at the easiest level (greatest compliance difference), subjects could at any time pick any level of difficulty on which to work. Most tended to start with the easier levels and progress to the harder levels. In the practice sessions, when subjects made an incorrect diagnosis, i.e., incorrect localization, the recorded voice told them of their error and the program displayed a box around the correct area on the screen with the transparency function turned on. Subjects could then go back and feel the abnormality before going on to the next trial. Subjects could also choose to pause the program at any time in order to rest their arms.

Results from the pre- and post-tests were analyzed with a repeated measures ANOVA.

3 RESULTS

Improvement in accuracy of localizing the dysfunctional areas increased significantly between the pre-test, taken prior to the eight practice sessions, and the post-test, taken after the sessions (Fig. 4). Improvements at all difficulty levels were statistically significant, but the greatest differences were at intermediate levels, especially at levels of 0.7 and 0.8. At the hardest difficulty level, 0.95, performance was near chance levels (See Discussion.). At the easiest levels users performed well above chance levels even on the pre-test. While accuracy was improving, speed also improved (Figure 5).

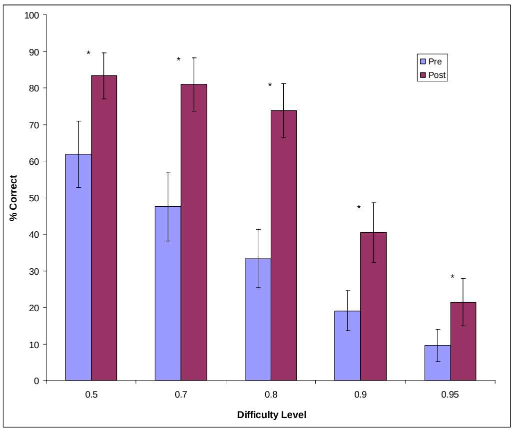

Figure 4: Accuracy on the pre- and post tests at five different levels of difficulty increasing from left to right. As difficulty levels increase accuracy falls, but was significantly higher throughout in the post-test than the pre-test.

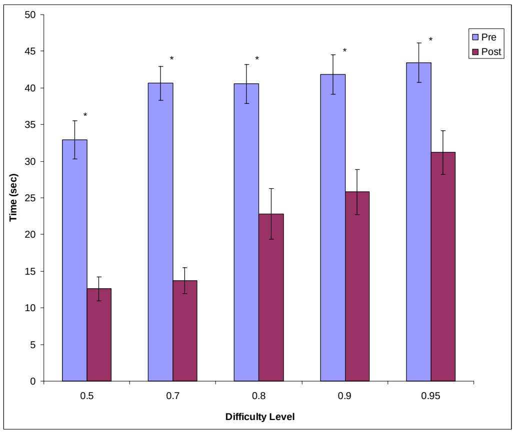

Figure 5: Speed on the pre- and post-tests at five different levels of difficulty, increasing from left to right. Users take longer at the harder difficulty levels, especially in the post-test.

Data from the practice sessions are shown in Figure 6. At the easiest levels, to the left, users did very well even in the first practice session. At the hardest level, at the far right, accuracy improved with successive practice sessions, but remained near chance level throughout. The most dramatic improvement is seen at intermediate levels of difficulty where users performed poorly during the first practice sessions, but progressively better in successive sessions.

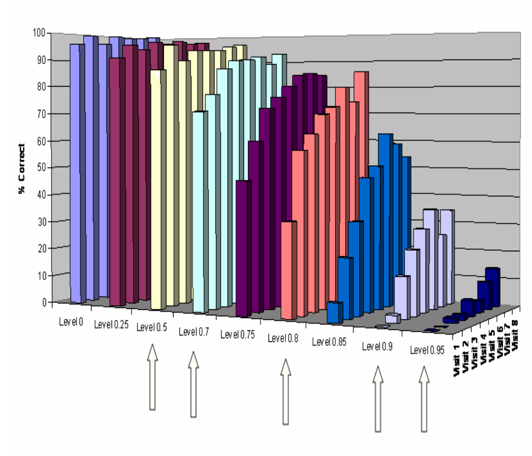

Figure 6: Accuracy at 9 different difficulty levels during the 8 practice sessions (front to back – labeled “visits”). The arrows indicate difficulty levels used in the pre- and post-tests.

Upon finishing the training and the post-test, subjects were asked three questions. The first question was “Do you think this practice with the haptic back will be of help to you in the development of your palpatory skills in OMM lab?” Of the 21 subjects, 17 marked “yes;” 4 marked “maybe;” and no one marked “no.” The second question was, “Do you think further practice with the haptic back would be of help to you in the development of your palpatory skills?” Twelve subjects answered “yes;” 8 marked “maybe;” and 1 subject marked “no.” They were also asked to rate the realism of the simulation on 0 to 10 scale, with 0 being unrealistic and 10 being very realistic. The mean value reported was 6.5.

4 DISCUSSION

Both the objective results obtained in this study and the subjective responses of users indicate the potential value of the VHB as an aid in learning the difficult art of palpatory diagnosis. Data from the pre- and post-tests indicate statistically significant skill improvement and the data from the practice sessions reveal the pattern of improvement. The subjects in the study were first year medical students taking a course in Osteopathic Manipulative Medicine (OMM). OMM training at Ohio University is spread over 2 years, consisting of two hours of practical training weekly in a lab supplemented with occasional lectures. The VHB study was carried out during the fall and winter quarters, at an early stage in their training, but at a time when they were being trained to palpate abnormalities simulated by the VHB.

Some of the skill improvement between the pre-test and post-test was undoubtedly simply familiarization with the unusual environment of the haptic simulation. The jump in performance levels between the pre-test and the first practice session may reflect that familiarization process. The near 100% performance at the easiest levels even in the first practice sessions, suggests, however, that the novelty of the situation did not prevent them from detecting obvious compliance differences.

The gradual improvement seen over the successive practice sessions at levels 0.7 through (at least) 0.85 suggests that real skill improvement was taking place with practice. Feedback from student users lent credence to that conclusion.

Osteopathic medical students often lament the lack of supervised practice time in palpatory diagnosis and manipulative medicine, time in which they could get feedback about the correctness of palpatory impressions and manipulative techniques. The immediate feedback provided by the VHB allows students to develop confidence in their palpatory abilities. It also allows them to explore different modes of palpation, e.g., use of different fingers, to find out which works best for them.

In order to determine thresholds of detection by any sensory system, the just-noticeable-difference (JND), a large number of trials is typically carried out, simply asking subjects to determine which of two inputs is larger than the other. When the inputs are the same, subjects are correct 50% of the time. When the differences are large they are correct 100% of the time. Generally the JND is taken as the level that is correctly identified 75% of the time, i.e., halfway between chance and certainty. In our experiment chance performance is far less than 50%. The JND is often expressed in a normalized way by dividing the JND by the reference value against which the comparison is made. This is called the Weber fraction. Experiments of this type have been done on the ability to detect differences in compliance (softness) of objects [5] and of virtual objects [3, 4]. Compliance detection of virtual objects, or surfaces, has been done with the PHANToM haptic interface, and has yielded Weber fraction estimates as low as 0.08-0.12 with time-invariant surfaces [4]. These estimates come from the standard pyschophysical paradigm of probing two surfaces and indicating which is more compliant.

In our case the smallest compliance difference detectable is judged by correct localization of the abnormal area of the back. Here the chance value is far less than 50%. The actual area that is abnormal, 7.5 cm^2 constitutes only 2.5% of the area in which the palpation is done. But chance level is higher than that because the users quickly realize that the distribution of the abnormal areas is limited to a smaller region on either side of the vertebral column. There are only twelve different sites where the abnormality can occur. Assuming the users knew the location of those twelve sites, and if they were using only one finger for identification of the abnormal area, the chance level would be 1 in 12, 8.3%. Theoretically, at least, chance level could be higher than that because, with the two-finger palpation, the user could be touching two different areas at once when s/he hits the foot switch. If either finger is on the correct area the user is credited with a correct answer. That could, in principle, raise the chance level to 1 in 6, or 17%, if, at each identification, the users were touching two different places on the back. Thus, chance level may have varied among users depending on their approach. We have chosen 20% as a conservative estimate of chance level, although it must certainly be lower than that.

Using 20% as chance level, we can take the performance level of 60%, which is half-way between 20% and certainty (100%), as the JND. The JND difference improves with successive practice sessions, beginning at difficulty level 0.7 and rising to .85. This corresponds to Weber fractions of 0.21 and 0.092. The latter figure, 0.092, falls in the range obtained by DeGersem [4] with a standard psychophysical design having subjects palpate two smooth surfaces and judge which surface has the higher compliance. The task in our experiment was more complex in that 1) the areas of abnormal compliance first had to searched for and found, and 2) the abnormal compliance was superimposed not on flat surface but on a surface with the complex contour of the human back. Further studies are needed to determine if a training effect, as we observed, would also be observed in the simpler experimental paradigm.

It is interesting that the data seem to reveal performance improvement with successive practice sessions, even at the 0.9 and 0.95 difficulty levels. At these levels the 60% mastery criterion was not reached, but the improvement seen raises the question as to whether further practice would have permitted users to reach that criterion level.

5 CONCLUSION

In summary, the training effect represented by the performance improvements in speed and accuracy on the VHB, coupled with the positive endorsements by student users, suggest that haptics can be used as an effective teaching aid for medical palpatory diagnosis.

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