Haptic Modules for Training in Palpatory Diagnosis

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ABSTRACT

We have developed and evaluated a novel tool based on haptics and virtual reality technology for augmenting the teaching of palpatory diagnosis. This novel tool illuminates palpatory diagnosis concepts by touch on a laptop PC using affordable haptic interfaces. There are six training modules each targeting a specific aspect of palpation. The difficulty level for all modules is adjusted automatically by measuring user's performance in real-time. The haptic interface used in this study was the PHANTOM Omni® (SensAble Tech., Inc.) and it was modified to enable manipulation with only one finger. 22 osteopathic medical students (16 first- and 6 second-year) participated in the evaluation of the system. The majority of the participating students (>90.9%) thought that future practice with the system may help them develop their palpatory skills. The majority (>77.3%) of the students also thought that the instructions on the module screens were clear. When the students were asked about the user interface, most of the students (>86.4%) responded that it was clear and easy to interpret. Evaluation results also showed that when the students were asked whether they would like to use the modules in the future for training at least 90.9% of them answered "Yes" or "Maybe". The achievement of purpose ratings for individual modules changed between 6.27 and 8.82 on a 10-point scale. This system can be used for unlimited student practice for improving skills from Osteopathic Manipulative Medicine laboratory and also as a repeatable and objective measure of palpatory skill to track student progress.

KEYWORDS: Haptic modules, haptic medical simulation, medical training, osteopathic medicine, palpatory diagnosis.

1. INTRODUCTION

Palpation, an economical and effective first line of medical diagnosis used in many fields of healthcare, plays an important role in medicine. It is fast and inexpensive, but lack of real-life patients with a variety of problems and a lack of expert teachers make training of professionals difficult. The training of osteopathic medical students on palpation methods is usually performed in laboratories where they work on each other. These settings do not provide the typical population that these students will diagnose and/or treat. Therefore, we developed the Virtual Haptic Back (VHB) as a training tool for medical students [1, 2]. The VHB is a simulation of contours and tissue textures of a human back that is presented graphically and haptically. Students use haptic devices to feel the VHB and identify dysfunctional regions. A dysfunctional region is simulated as increased stiffness compared to the background stiffness of the palpable portion of the back.

The VHB is the only human back simulation that is being used in palpation training of osteopathic medical students. A virtual reality-based simulator prototype for the diagnosis of prostate cancer has been developed using the PHANToM haptic interface [3]. An earlier tumor palpation VR simulation was developed by [4]. E-Pelvis is an electronic mannequin that enables users to see on a computer screen where in the pelvis they touch during training and the pressure they apply to those touch points [5]. The Bovine Palpation Simulator is used to teach veterinary students to identify fertility problems and diagnose pregnancy [6]. The Core Skills Trainer aims to improve palpatory skills of students in five different areas: stiffness, size, texture, movement detection and shape identification [7]. Another palpation simulator for veterinary students was developed for feline abdominal palpation training [8]. A survey of palpation simulators, as classified into three types (physical model based, virtual reality based, and hybrid simulators), can be found in [9].

We are developing the haptic modules described in the current paper to reinforce palpatory diagnosis principles learned in Osteopathic Manipulative Medicine (OMM) and palpatory laboratories, in a more portable and affordable manner than the existing VHB. The modules were developed and programmed in one umbrella program to be used on a laptop PC. They were designed in such a way that each module targets improving a certain aspect of palpation and introducing some of the hardest clinical concepts to comprehend and master towards becoming skilled manipulators. A performance level algorithm was developed and programmed for all modules, where the computer automatically adjusts the difficulty level based on trainee performance and automatically assesses their performance level in each evaluation session. A database automatically stores training and evaluation data from any number of subjects, including both objective performance data and subjective questionnaire responses. The training on the modules is based on comparison of physical properties such as stiffness, motion, and force magnitude. As part of the learning process, the clinical relevance and goal of each module is presented to the user prior to module training. Upon an incorrect answer, users are given the opportunity to feel the correct response until they are comfortable to proceed.

In this paper, we present the development efforts and discuss the evaluation results for the six haptic modules: bump height, stiffness discrimination, fascial drag, ropey, pitting edema, and bump location. This project has the potential to be extended from osteopathic medicine to allopathic medicine, veterinary medicine, physical therapy, massage therapy, and chiropractic schools.

2. SYSTEM DESCRIPTION

2.1 Haptic Interface

We need users to interact with the virtual environment using their fingers rather than the whole hand or forearm. The Omni® haptic interface from SensAble Technologies, Inc. was used in this project. It was modified in order to provide finger interaction (Figure 1) rather than using the provided pen-like stylus. The Omni® was chosen because of its commercial availability, relatively low cost, and our experience using the OpenHaptics SDK. It can exert 0.88 N continuous and 3.3 N maximum force. When the forces during a typical screen-scan procedure in which

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the examiner simply locates any region of altered tissue texture were measured, it was found that the average force applied by faculty members of Osteopathic Manipulative Medicine Section of the Department of Family Medicine and advanced OMM fellows at Ohio University is 0.9 N [10], which is within the exertable force range of the Omni®.

This gimbaled modification of the Omni® haptic interface enables users to interact with the virtual environment with the finger or thumb of choice as they would in a clinical situation. User inserts the finger of choice into the finger holder that is attached to the gimbal with a plate that stays under the user's fingerpad. The location of the haptic interface point (end point of the second link) is at the intersection of the axis passing through the rivets on both sides of the gimbal and the axis of the innermost hollow cylinder. This location is the same with the original stylus. In order to calibrate the Omni®, a calibration piece that includes the part from the original stylus which docks into the inkwell is also manufactured. This calibration piece replaces the removable innermost rotating part that houses the finger holder and is inserted into the inkwell during calibration. The current design does not detect the orientation of the finger. The design also includes a finger strap that can be adjusted to accommodate different finger sizes.

Figure 1. Omni® Haptic Interface (SensAble Technologies, Inc.) Modified for the Haptic Modules with a Finger Gimbal

2.2 Virtual Environment

The virtual environment for the modules was designed using the same functional elements in order to ease the transition from one module to the other. The users are required to navigate and interact in a 3D space by means of the haptic interface. The main menu for the haptic modules is a dialog box and serves as the entrance to the system. Using the main menu, users can: 1) Create a user name and a password before they start their training, 2) Retrieve their user name/password in case they forget, 3) Select a module to train with, and 4) View their progress report. Users are required to sign in to be able to access the available modules. This unique user name is necessary to store individual user data in the database to keep track of users' progress with practice.

The screen layout (Figure 2) is the same for all modules and consists of several elements. A user feedback status box presents information on the current level, number of correct responses, and whether the last given response was correct or incorrect. Another box includes the set of instructions for each module. The indicator in the middle of the screen shows which button the users will press on the keyboard (highlighted) to respond to the current testing task at hand. Its shape and function varies between the modules depending on the skill tested. The palpable surface changes according to the specific goal of each module. The haptic device status is also displayed to the users to warn them in case they apply a force that exceeds the manufacturer's recommended maximum. The position of the users' fingers inside the virtual environment is displayed using a haptic cursor. The haptic cursor can be chosen by users to be a virtual right/left hand or a small sphere indicating the fingertip. The orientation of the virtual hand can be adjusted any time during a training session by using the arrow keys. The remaining time for that session and the number of trials are also displayed.

2.3 Performance Level Algorithm

The purpose of the performance level algorithm is to automatically identify the best level attained by each subject in a testing session. The best level is the most difficult level of palpatory skill the subject achieves. For all modules, 11 skill levels are implemented, with 1 being the easiest and 11 being the most difficult. The performance level algorithm for all of the haptics-augmented palpatory diagnosis modules is designed as follows: 1) Each subject is started at the easiest level for all modules; 2) The level is increased automatically by the program when the user either gets 3 correct answers in a row or 6 correct answers out of the last 10; 3) The level is decreased automatically by the program when the user either gives 4 incorrect answers in a row or cannot get 6 correct answers out of the last 10.

The current session for any module is terminated after 3 level reversals (a method of termination used in psychophysics experiments, e.g. [11]) or after reaching the overall 10-minute time limit, whichever comes first. A reversal is a change in level in the opposite direction, namely when a previous increase (or decrease) of level is followed by a decrease (or increase) of level. The last successful level within these constraints is defined to be the subject's achievement for that particular test and is termed the subject's "Performance Level". Once the current session is completed, users can start another session of the same module or any other module using the main menu.

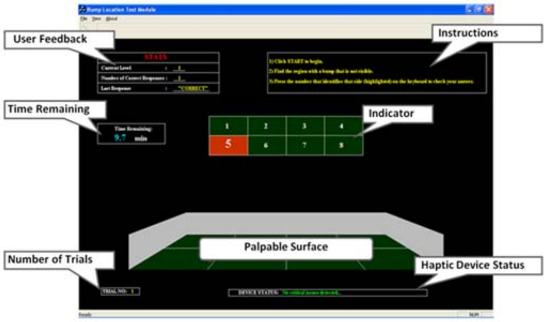


Figure 2. Sample screen layout for the haptic modules

2.4 User Performance Reports

In addition to the instant feedback users receive during training on the haptic modules as to correct and incorrect answers, users can also view their performance reports. The purpose of these automated reports is to keep track of the users' performance over time and allow them to see their standing with repeated training. Users are automatically provided with an MS Excel file with four graphs for visual interpretation of their performance. The graphs show: 1) The performance level by session; 2) The percentage of correct answers by session; 3) The total time per level by session; and 4) The average trial time per level by session.

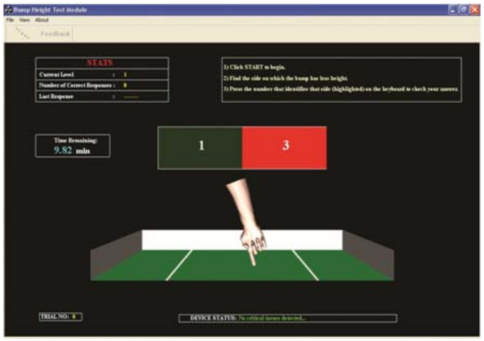
3. HAPTIC MODULES

We have developed six haptic modules for palpatory diagnosis activities for osteopathic training: bump height, stiffness discrimination, fascial drag, ropey, pitting edema, and bump location modules. These modules were designed to improve user skill and confidence in palpation by using a haptic interface that allows for immediate feedback and tracking of skill level. The following sections present the underlying model of each module in detail. The haptic modules development was accomplished iteratively in close consultation with expert palpators (OMM faculty and fellows).

3.1 Bump Height Haptic Module

The purpose of this module is to train the palpatory diagnosis skill of distinguishing different patient tissue bump heights. Users quantitatively compare the height of two bumps, shown in Figure 3, and identify the shorter one. As the difficulty level increases, the height difference between the bumps decreases. The height difference decreases down to a level (0.06 mm) which is slightly higher than the position resolution of the haptic interface (0.055 mm). Users can only feel the bumps during a trial unless they give an incorrect answer. In the case of an incorrect answer, users are allowed to see and feel the correct answer until they are ready to continue with the next trial.

As shown in Figure 4, the contours of the bumps are drawn as ellipses that extend into the screen. The bumps are invisible during a trial, that is, the users must respond based solely on haptic feedback. An incorrect answer, however, reveals the bumps, enabling the user to compare the heights of the bumps by feeling and seeing the correct answer. Then the user can proceed to the next trial by pressing the spacebar on the keyboard whenever he/she is ready. During this period, the timer is stopped in order not to rush the user to proceed to the next trial.



1) Click START to begin.
2) Find the side on which the bump has less height.
3) Press the number that identifies that side (highlighted) on the keyboard to check your answer.

Figure 3. Bump Height Haptic Module screen shot

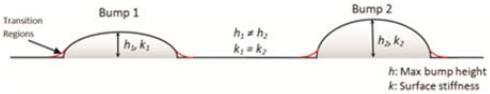
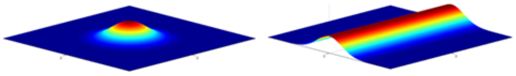


Figure 4. Bump Height Module Diagram

A smoothing region from the flat surface to the elliptic surfaces where the bumps are drawn is necessary. Otherwise, the slope of the surface that users feel would suddenly increase from zero (flat surface) to the slope of the elliptic surfaces which is relatively higher. These transition regions are defined by using a 2D Gaussian function:

$$f(x,y) = Ce^{-\left(\frac{(x-x_0)^2}{2\sigma_x^2}+\frac{(y-y_0)^2}{2\sigma_y^2}\right)} \qquad (1)$$

Where C is the amplitude of the Gaussian function, σ_x and σ_y define the spread of the curve, and (x_0, y_0) is the center of the curve on the xy plane when $\sigma_x = \sigma_y$ (Figure 5a). The Gaussian function with different σ_x, σ_y values is used to create the transition regions (gradual increase of slope) on both sides of the elliptic surfaces (Figure 5b) for the Bump Height Module.



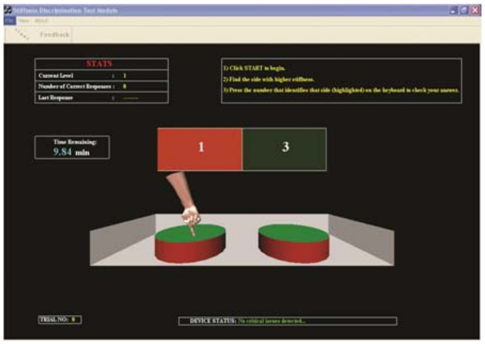
a. $\sigma_x = \sigma_y$ b. $\sigma_x \neq \sigma_y$

Figure 5. Gaussian curves centered at (0, 0)

3.2 Stiffness Discrimination Haptic Module

The purpose of this module is to train the palpatory diagnosis skill of identifying stiffer tissue. As shown in Figure 6, users identify the stiffer of two surfaces (top faces of the cylinders) by touch. Stiffness is the reciprocal of compliance.

As shown in Figure 7 (front view), the palpable surfaces for stiffness discrimination are the top faces of two cylinders. One of the surfaces represents the standard stiffness which remains the same throughout a session. This standard stiffness value can be adjusted to reach up to 0.5 N/mm which is in the stiffness range of some portions of the human back [12]. A 0.25 N/mm standard stiffness value was used for the evaluations. The stiffness of the remaining surface is less than the standard stiffness at all times. The stiffness difference between the surfaces decreases with increasing difficulty level. There is no height difference between the surfaces. The location of the cylinders is switched randomly.



1) Click START to begin.
2) Find the side with higher stiffness.
3) Press the number that identifies that side (highlighted) on the keyboard to check your answer.

Figure 6. Stiffness Discrimination Haptic Module screen shot

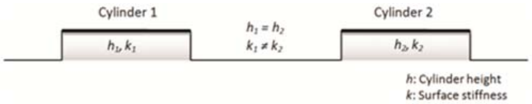


Figure 7. Stiffness Discrimination Diagram

3.3 Fascial Drag Haptic Module

The purpose of this module is to train the palpatory diagnosis skill of identifying the direction of maximum tension due to underlying fascia. As shown in Figure 8, users must find the direction of maximum tension by touch.

1) Click START to begin.
2) Find the direction (shown by the arrow) that is hardest to push towards.
3) Press the number that identifies that side (highlighted) on the keyboard to check your answer.

Figure 8. Fascial Drag Haptic Module screen shot

In the fascial drag module, the user touches the palpable surface and moves horizontally in different directions, displayed on the indicator. The task is to find the direction that is hardest to push against.

As shown in Figure 9, when the user touches the palpable surface, an anchor point (O) is fixed at that point of touch and as the user moves to another point (O'), without removing contact, the user's finger is pulled toward the anchor point with a force that is calculated by:

$$\mathrm{F} = -k\mathrm{r} \qquad (2)$$

Where r is the position vector from O to O', k is the stiffness constant of the spring in the direction of movement. This variable stiffness constant is a function of the orientation of r and is calculated as:

$$k = (1 - N)k_{initial} + Nk_{final} \qquad (3)$$

Where N $(0 \leq N \leq 1)$ is the weighting function that ensures a continuous transition between minimum and maximum value ($k_{initial}$ and k_{final}) of the spring constant and is calculated as:

$$N = \begin{cases} \frac{1}{\pi}(2\pi - |\alpha_i - \theta|) & if\ |\alpha_i - \theta| > \pi \quad i = 1,2,\ldots,8 \\ \frac{1}{\pi}|\alpha_i - \theta| & if\ |\alpha_i - \theta| \leq \pi \quad i = 1,2,\ldots,8 \end{cases} \qquad (4)$$

Where α_i and θ are the angles that the pre-specified direction vector for that trial and r make with the horizontal, respectively. This pre-specified direction is chosen to be the direction that is hardest to push towards out of the possible eight directions. It should be noted that calculating the spring constant in this way creates an axis of symmetry, AA' in Figure 9. As the level of difficulty increases, the difference between $k_{initial}$ and k_{final} decreases, therefore making it more difficult to find the hardest direction to push towards.

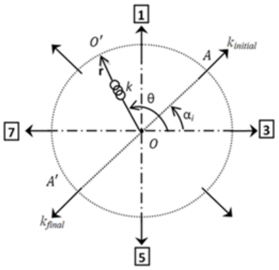
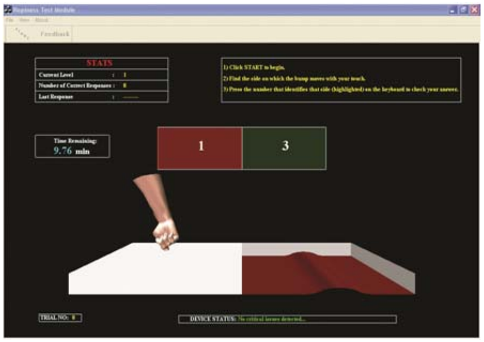


Figure 9. Fascial Drag Haptic Module Diagram

Using fascial drag for diagnosis is an advanced form of palpation. Therefore, based on expert opinions, we designed a beginner version of this module that includes only four directions to choose from instead of eight. The model for the beginner version is the same as described above. The beginner version of this module was used in the evaluations reported later.

3.4 Ropey Haptic Module

The purpose of this module is to train the palpatory diagnosis skill of identifying ropey tissue. Ropey areas in tissue are associated with regions of somatic dysfunction. This module helps the user to identify ropey tissue with progressively finer degrees of motion. Ropey tissue is fibrous with one palpable rope that moves under the palpator's finger. As shown in Figure 10, two identical ropes are presented in this module, but only one moves under the finger. When touched by the user, the corresponding half of the palpable surface is covered by a non-haptic 3D rectangle to prevent visual cues.



1) Click START to begin.

2) Find the side on which the bump moves with your touch.

3) Press the number that identifies that side (highlighted) on the keyboard to check your answer.

Figure 10. Ropey Haptic Module screen shot

In the ropey module the users identify the bump that moves when they touch and apply force. The bumps used are constructed the same way as described in the Bump Height Haptic Module, with Gaussian-smoothed edges. The movable bump in this module simulates the movement and feeling of a muscle bundle underneath the skin when touched and pressed whereas the stationary one represents a bony structure. The movable bump is simulated as a string-like material that is attached with a spring and has only one degree-of-freedom, translation in the horizontal (Figure 11). F is the force applied by the user and k is the stiffness of the spring. As the difficulty level increases, the stiffness of the spring becomes higher, restricting the amount of movement. Therefore, with increasing levels, it becomes harder to differentiate the movable bump (ropey) from the stationary one (boney).

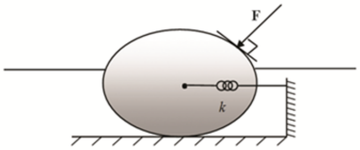


Figure 11. Ropey Haptic Module Diagram

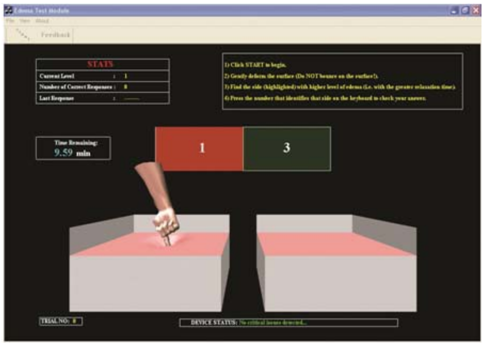
3.5 Pitting Edema Haptic Module

The purpose of this module is to train users in the identification of a spectrum of tissue textures from boggy to pitting edema. As shown in Figure 12, the users train to identify one of two surfaces that deforms depending on the amount and the period of the applied force. Realistic soft tissue deformation is represented by viscoelastic engineering principles [13]. Different levels of pitting edema are simulated by adjusting the relaxation time of the surface after the force is removed.

One of the surfaces starts as a representation of boggy tissue whereas other surface represents a high level of edema. Tissue with bogginess rebounds more quickly than tissue with pitting edema and is modeled via spring constants with no damping. Bogginess is acute with inflammatory tissue and fluid buildup and is often associated with tissue fibrosis. Bogginess, along with ropiness, is also a tissue property that is used and taught in clinical practice to differentiate tissue textures.

The deformation and force feedback to the user is calculated by using a Kelvin Body (Figure 13) which closely simulates stress relaxation and creep properties of a real human viscoelastic soft tissue [13]:

$$\mathbf{F} + \boldsymbol{\tau}_{\boldsymbol{\varepsilon}}\dot{\mathbf{F}} = \mathbf{E}_{\mathbf{R}}(\mathbf{u} + \boldsymbol{\tau}_{\boldsymbol{\sigma}}\dot{\mathbf{u}}) \qquad (5)$$



1) Click START to begin.
2) Gently deform the surface (Do NOT bounce on the surface!).
3) Find the side (highlighted) with higher level of edema (i.e. with the greater relaxation time).
4) Press the number that identifies that side on the keyboard to check your answer.

Figure 12. Pitting Edema Haptic Module screen shot

In (5), τ_ε is the relaxation time for constant strain, τ_σ is the relaxation time for constant stress and E_R is the relaxed elastic modulus. They are calculated as:

$$\tau_\varepsilon = \frac{\eta_1}{\mu_1} \qquad \tau_\sigma = \frac{\eta_1}{\mu_0}\left(1 + \frac{\mu_0}{\mu_1}\right) \qquad E_R = \mu_0 \tag{6}$$

Where η_1 is the damping coefficient of the damper, and μ_0 and μ_1 are the spring constants in Figure 13. The initial condition for (5) is:

$$\tau_\varepsilon F(0) = E_R \tau_\sigma u(0) \tag{7}$$

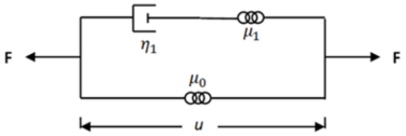


Figure 13. Kelvin body diagram [18]

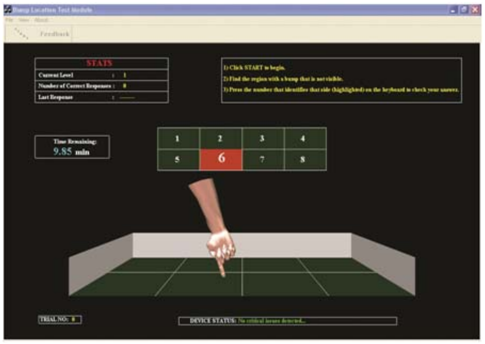
The only difference between the two surfaces in Figure 12 is that they are represented as Kelvin bodies with different damping coefficients, therefore different relaxation times. As the level of difficulty increases, however, the difference between the damping coefficients decreases, making it difficult to differentiate which side has the higher level of edema.

This module has a unique characteristic in that the users receive haptic and visual feedback at the same time since the method of identifying a pitting edema is performed both by touch and visually. The rest of the modules require users to solely rely on their haptic sense and visual feedback is only given in the case of an incorrect answer.

3.6 Bump Location Haptic Module

The purpose of this module is to train the palpatory diagnosis skill of locating patient tissue with differing stiffness than surrounding tissue without graphical cues. Stiffer regions or areas with increased tissue tension may imply an area of somatic dysfunction. As shown in Figure 14, users find the location of a stiffness bump (as opposed to a contour bump).

In this module the bump is defined by modifying (1), in such a way that the amplitude of the Gaussian function corresponds to the maximum stiffness value of the bump (instead of the maximum height of the contour in the Bump Height haptic module). Figure 15 shows the visualization of a stiffness bump, derived from Figure 5a. A constant stiffness value is added to this function in order to have a background with a non-zero stiffness value. This enables the comparison of the bump stiffness to the background while the user palpates the surface area to locate the region with the bump. There are eight different regions in which the single stiffness bump could be located. The computer randomly picks the location of the bump after each trial. The user is asked to identify the region where the bump is located by feel only. As the difficulty level increases the maximum stiffness of the bump becomes closer to the background stiffness value, therefore making it more difficult to locate the stiffness bump.



1) Click START to begin.
2) Find the region with a bump that is not visible.
3) Press the number that identifies that side (highlighted) on the keyboard to check your answer.

Figure 14. Bump Location Haptic Module screen shot

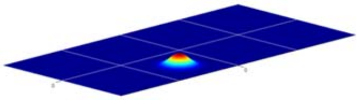


Figure 15. A Stiffness Bump (not visible to user)

4. EVALUATION OF THE HAPTIC MODULES

4.1 Experimental Setup

The haptic modules evaluation experiments were run on a 1.8 GHz dual Pentium PC with 1 GB RAM and an NVIDIA GeForce Go 6600 video adapter. A PHANToM Omni® haptic interface displayed the haptic feedback to the subjects. The software was written using Microsoft Visual C++ and the OpenGL® graphic library. The haptic effects were implemented by using the SensAble OpenHaptics Toolkit. Haptic rendering was performed using the Haptic Library API (HLAPI). The Haptic Device API (HDAPI) was utilized to initialize the haptic device and to get haptic device status such as motor temperature and current force. This information updates the onscreen haptic device status.

4.2 Subjects

Twenty-two adult subjects (16 first-year and 6 second-year osteopathic medical students) from the Ohio University College of Medicine (OUCOM) participated the evaluations. Ohio University IRB approval was obtained for this experiment and all participating subjects signed an informed consent form. Subjects received $15 for their participation time.

4.3 Procedure

The experiment consisted of one single session including six modules. The modules were presented in random order for each participant. Participants were introduced to the modules before they started their session. They had 10 minutes to complete each module and were allowed to take breaks if desired by pausing the system. The participants also chose the palpation finger.

Each participant completed a computer-based questionnaire upon completion of each module. The questionnaire included six questions which asked for user feedback on their experience with the modules. The participants were instructed to carefully read the goal and the clinical relevance of each module that were presented as a pop-up message box before they started a particular module test. This was important in order for them to be able to rate the accomplishment of purpose (Q6 in Table 1) for the modules.

4.4 Results

The responses of the participants (first- and second-year osteopathic medical students) to the questionnaires is shown in Figure 16. The results show that at least 59.1% (lowest response for the Pitting Edema Haptic Module) of the participants thought that the current practice with any module would certainly help improve their palpatory skills. This percentage was highest for the Bump Height Haptic Module (86.4%). None of the second-year students responded “No” to the question regarding the helpfulness of the current practice on any of the modules.

When students were asked if they thought that future practice with the haptic modules would certainly help them improve their palpatory skills, at least 45.5% (lowest response for the Pitting Edema haptic module) responded “Yes”. This percentage was highest for the Bump Location haptic module (95.5%). None of the second year students responded “No” to the question regarding the helpfulness of future practice on any of the modules.

The majority (at least 77.3%) of the students thought that the instructions on the module screens were clear. When the students were asked about the user interface, the majority (at least 86.4%) responded that it was clear and easy to interpret.

Results also showed that when the students were asked whether they would like to use the modules in the future for training at least 90.9% of them answered “Yes” or “Maybe” (lowest response for the Pitting Edema haptic module). This percentage reached to 100.0% for the Bump Location haptic module.

An independent-samples t-test revealed no significant difference between the first- and second-year medical students when the achievement of purpose rating was compared. The pooled data showed that the achievement of purpose rating for the Pitting Edema haptic module was the lowest (6.27/10). For the remaining modules the lowest rating was for the Fascial Drag haptic module (7.91/10) and the highest rating was for the Bump Height haptic module (8.82/10).

The average performance levels attained by the students and average trial times are shown in Figures 17 and 18, respectively. The means of the performance levels reached by second-year students were higher as compared to the first-year students except in the Fascial Drag haptic module. However, an independent-samples t-test showed that this difference was not statistically significant. Comparing the average trial times, the first-year students had higher average trial times than the second-year students. This difference was also not significant.

5. Discussion

Experienced palpators can acquire information on tissue tone, motion, and assessment of symmetry by means of a single, almost simultaneous, palpatory procedure. On the other hand, in the case of students and trainees, each element of palpation is studied as if they are independent procedures. Eventually, they combine these elements into one single procedure [14]. Therefore, developing tools, such as the haptic modules described in this paper, for students of medical and related professions that targets training different aspects of accurate palpation is an important step in improving palpation skills. Then, the individuals can blend these trained elements together in order to become proficient palpators. These tools must be objective to eliminate any confusion during the learning process. There are many (out of classroom) objective methods that are still recommended for students to improve their tactile and kinesthetic skills such as feeling a hair under a piece of paper, picking head and tails of a coin by touch, recognizing the change in weight using birdshot, etc. [15]. The modules were designed in such a way that they compose objective exercises that make up some of the elements of palpation as detailed in this paper.

These modules enable students to spend as much time as they need to improve their palpatory skills without any pressure due to time or instructors who may expect them to perform well in front of their peers. Sufficient time and unlimited opportunity to make mistakes during practice sessions can help students in two different ways: 1) They learn how to focus their minds on the sensation resulting from every single touch, and 2) They could build confidence in their ability to palpate accurately. Concentration is very important, especially when it comes to detecting very subtle differences and/or changes. Lack of palpatory confidence may be the main reason why students rely on their visual estimation rather than the information they receive by palpation [15]. The haptic modules add a repeatable component of science to the art of palpatory diagnosis.

The evaluation results were encouraging in the sense that the majority of the students are open to the idea that the modules may be of help to them in the future. The instructions on the screen and user interface had high rates of approval from all students. In simulations like the haptic modules where the users are required to perform simple basic tasks repetitively, as in many psychophysics experiments, it may be hard to attract potential users to train more extensively and keep them interested. As shown in the results section, at least 90.9% of the students said that they would consider using the modules again. We believe that adding game-like elements with difficulty levels, time constraints to complete a task, and display of high scores for all users increases the competitiveness and desire to achieve more. Even the expert palpatory physicians, who tried the modules and gave informal feedback, found themselves competing with the computer and each other. Although we didn’t utilize it during the evaluations, the computer also keeps track of the best users and displays them to all users as the highest scorers. This is a feature that exists in almost all computer games and should drive students to do better on the modules.

In the current study, the objective data collected did not reveal any significant differences between first- and second-year students in terms of average trial time and performance level. The difference in skill levels could possibly be more prominent between, for instance, the first- and fourth-year students (or experts) mainly due to the amount of training the students receive during curricular training in osteopathic manipulation labs and palpation experience. It was shown that stiffness perception is a clinical skill which is developed with training and/or experience [16]. Even though this finding was confirmed for veterinary medicine, one may argue that the same outcome would hold for osteopathic and allopathic medicine as well since stiffness discrimination is an important component of palpation in all of these professions, e.g. detection of problems such as muscles in spasm, lumps in breasts, testes, and abdomens. Therefore, a study between students new to palpation (i.e., first-year medical students) and expert physicians, in terms of the difference in performance levels and average times to reach those performance levels would be illuminating for validation purposes.

A limitation of the system arises from the fact that the users are able to use only proprioceptive feedback during haptic exploration. During active touch, humans use tactile and proprioceptive sensory systems to receive haptic information. It has been shown that covering a finger with a rigid sheath (in our case a thimble-like finger holder), as compared to a bare finger, decreases recognition accuracy of geometry, reduces pressure sensitivity and impairs size detection threshold in identifying lumps in simulated soft tissue [17].

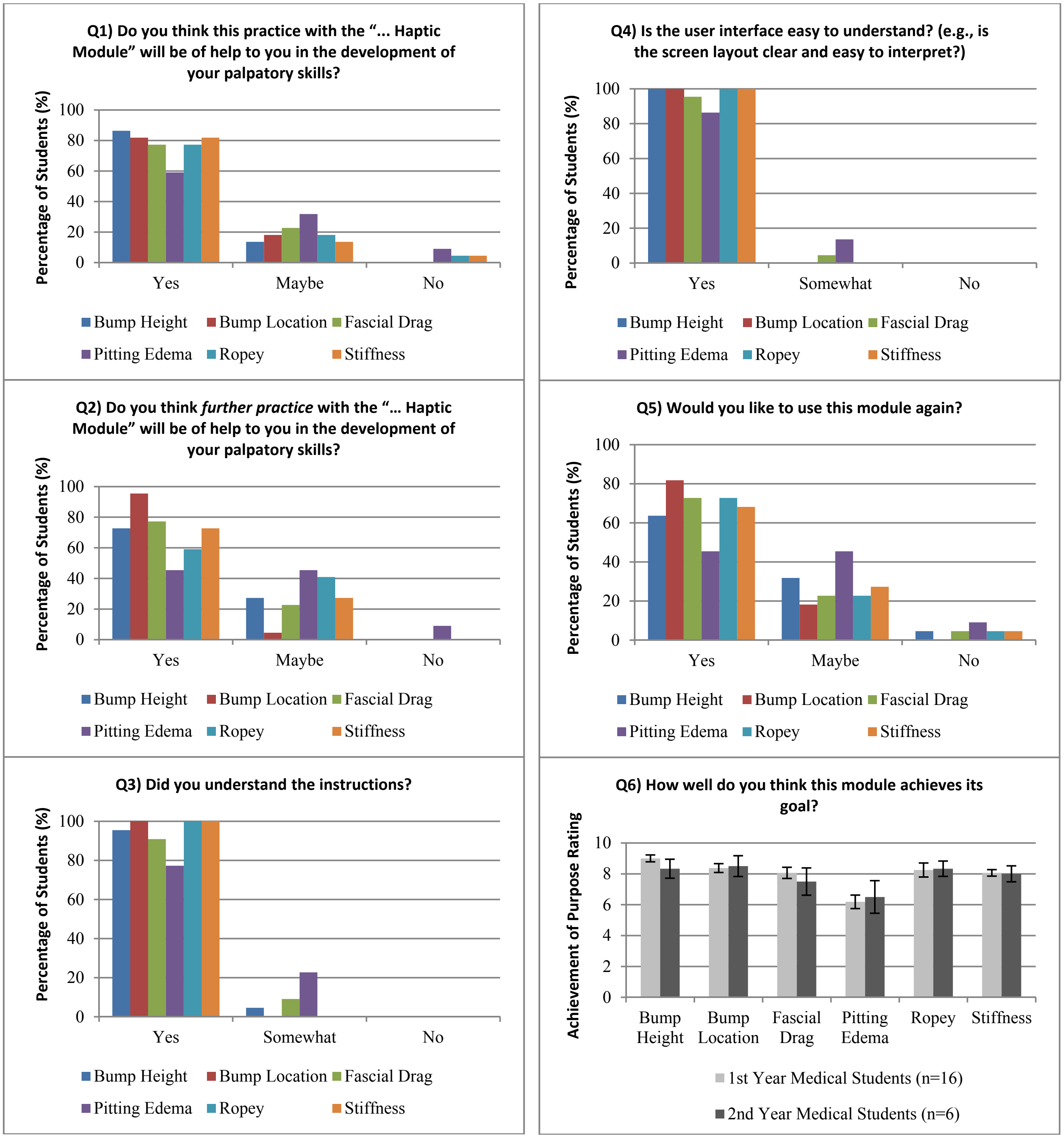


Figure 16. Haptic Modules Evaluation Results (standard error bars shown for Q6)

The evaluations also revealed that the least favorable module appears to be the Pitting Edema haptic module. As discussed previously, this module is the only one that provides haptic and visual feedback at the same time (in the remaining modules, users must depend solely on haptic feedback). This is in accordance with clinical diagnoses of edematous tissue. That is, the edema and its severity are defined by deforming the surface with pressure and then observing the time for the tissue to spring back. Expert physicians who tried the modules found this particular module quite helpful and expressed that they mostly used the haptic feedback to differentiate between two surfaces with different viscous properties. We, however, observed that the most of the students tried using the visual feedback rather than the haptic. This made it hard and frustrating to get the correct answer, especially when they reached higher levels when the visual comparison became hard. Some of the students confirmed this by stating that they relied mostly on visual feedback for the pitting edema module. As discussed previously, this could be related to the confidence levels of students. With continuing training and experience they should be able to gain the confidence they need and learn to trust their palpatory skills. We don't think that visual dominance [18] played an important role here since the students tried to visually compare relative, rather than absolute, speeds of recovery and amount of deformation of two surfaces. This outcome will be taken into account in future versions by removing the visual feedback from this module and, therefore, forcing users to rely on only their haptic perception.

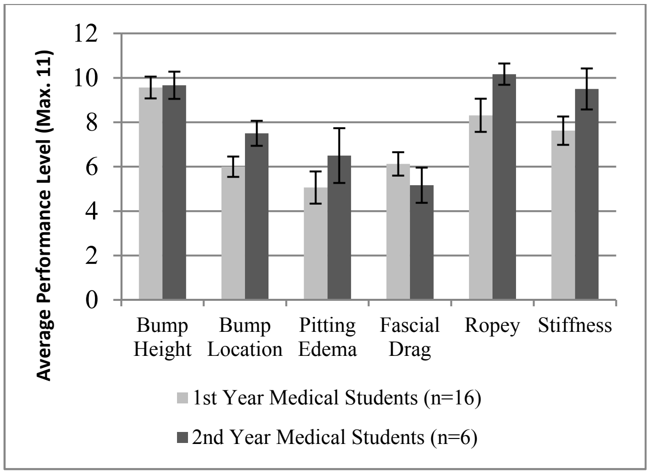


Figure 17. Average performance level (standard error bars shown)

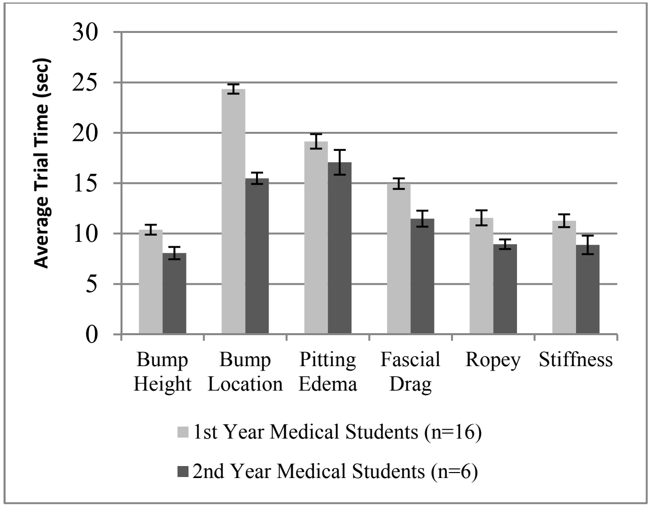


Figure 18. Average trial time (standard error bars shown)

In the current design, users can interact with the modules by one finger of the chosen hand. This keeps the cost of the system down. However, some procedures such as examination of vertebrae for existence of asymmetry and/or increased stiffness about an axis are generally performed using two fingers. In order to accommodate these training needs, a second haptic interface can be incorporated to the system to allow two-fingered palpation when it is necessary. The addition of the second haptic device would definitely increase the overall cost of the system and make simultaneous two-fingered palpation of relatively small areas difficult due to the apparent sizes of the gimbals on the haptic devices.

6. Conclusion

We introduced six different haptic modules for palpatory diagnosis training: bump height, stiffness discrimination, fascial drag, ropey, pitting edema, and bump location. The main purpose of the modules described herein is to develop and improve the palpatory diagnosis skills of osteopathic medical students and practitioners. The modules, as a portable system consisting of a haptic device and a laptop PC, can be used as a stand-alone teaching station in a medical library where medical students can get access anytime to practice on their own. Overall, these modules are low-cost and objective tools designed to train medical students and/or professionals to become better palpators.

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