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What You Feel Must Be What You See: Adding Tactile Feedback to the Trackpoint

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ABSTRACT The present study makes two contributions to the literature on tactile feedback. First, it investigates the effect of tactile feedback in isometric rate control devices. The use of tactile feedback in this type of device has not been systematically investigated. An isometric joystick, such as the IBM Trackpoint™ in-keyboard pointing device does not perceptibly move and is operated by force. Can tactile information delivered to the user's fingertip through such a device provide a feeling of texture? Second, it investigates the interplay of tactile and visual information. We hypothesized that tactile displays are often ineffective because they are not synchronized with visual information. We developed a simple isometric tactile device, Tractile, based on the Trackpoint™ pointing device, which can vibrate its tip under program control. We conducted an experimental study using this device. Under various visual and tactile feedback conditions, experimental participants performed a tunnel steering task that resembles menu navigation and other real tasks. We found that tactile feedback did in fact give users a feeling of texture, and can speed up steering performance when the texture presented visually matches the texture presented tactilely.

KEYWORDS Tactile feedback, isometric joystick, touch, feel, multi-modal interface, computer input device.

1. INTRODUCTION

In the real world, people are adapted to make optimal use of multiple sources of information (Massaro, 1998). However, most human-computer interfaces provide users but a single channel of information, namely visual. Recently, together with auditory interfaces (Gaver, 1997), tactile and force feedback interfaces for mainstream computing applications have begun to emerge, making it at last practical to construct multi-modal human computer interfaces.

"Computing with feeling" has a long research history. Atkinson, Bond, Tribble, and Wilson (1977) described one early effort in this field. Force-coupled master-slave robots for teleoperation, which feed back the force at a remote robot arm (slave) to the master controller arm in a control room, has an even longer history in hazardous material handling. Brooks, Ouh-Yong, Batter and Kilpatric (1990) applied such an approach to "visual reality," in which the remote site was a data field in a 3D computer visual display rather than a hazardous environment in the physical world. Recently, force feedback or tactile devices have begun to become commercially available, such as the Phantom (SensAble Technologies Inc.) and the MouseCAT (Haptic Technologies), in addition to the more ubiquitous force feedback joysticks for computer games. More recently, Immersion Corp announced the FEELit mouse.

Two factors motivated our current study. One is that despite various engineering efforts, empirical evidence on the usefulness of tactile information for computer applications is scarce and unconvincing (see Shimoga, 1993, for a review). Balakrishnan, Ware, and Smith, (1994) showed users' performance improve in a virtual carving task that mimics physical actions in real work but this rarely occurs in ordinary human-computer interaction. Engel, Goossens and Haakma (1994) showed that contextually appropriate force feedback delivered through a trackball can speed cursor pointing tasks. Akamatsu (1994) showed that shape-tracing speed decreases when appropriate feedback is provided to the fingertip, and that eye movements (fixations) decrease when such haptic feedback is provided. Payette et al. (1996) showed that operators subject to extreme conditions in zero gravity could achieve better performance with force feedback devices than with free moving devices (both in speed and error rate).

We believe that one of the key reasons for the lack of empirical evidence on the utility of tactile feedback is because the interaction between tactile and visual modes is often overlooked. To make the most of multiple information sources, it is reasonable to assume that the tactile feedback should provide information that is consistent with the visual information displayed. Conflicting or unrelated information should hinder performance whereas consonant information should facilitate performance.

The striking effect of combining information from different modalities is a familiar experience. For instance, flight simulators that add three-dimensional motion of the cockpit to what is presented visually give users a far more realistic experience. An amusement park theater that shakes the viewer's seat when the visually presented images shake give a different experience than either visual or physical shaking alone.

The second factor that motivated the current study is that it was unknown if tactile information can be presented through an isometric device, such as the IBM Trackpoint™ in-keyboard pointing device used in many notebook computers. Such a device is most compact and well suited for mobile computing but it does not perceptibly move. Can tactile information be presented effectively at all in such a case?

In summary, our goal is to understand whether tactile information can be presented through an isometric device, whether it enhances user's performance when interacting with computers, and how such an effect relates to visual information. To investigate this, we first developed a simple, compact tactile device based on the Trackpoint isometric joystick.

2. TRACTILE DEVICE

We recently developed the Tractile device, which is a tactilely enhanced Trackpoint (Rutledge & Selker, 1990). The design goal was to provide tactile vibration with a very compact size and power consumption suitable for laptop computers. An actuator on this modified Trackpoint includes a cylindrical coil that – when carrying a current – produces a magnetic field to drive a ferromagnetic slug upward toward the actuator tip, providing tactile feedback to the user (see Figure 1). As shown in the figure, a plastic cap is attached to the post of the pointing device. This cap is rounded to fit inside a cylinder relatively the same size as the ferromagnetic slug, which is housed inside the cylinder. The coil wrapped around the bottom of the sensor has a resistance of 70 ohms. The ferromagnetic slug is inserted into the cylinder with the correct polarity. A rubber cap is attached to the top of the cylinder to retain the ferromagnetic slug. The coil is excited by external electronics to apply a 10ms pulse at

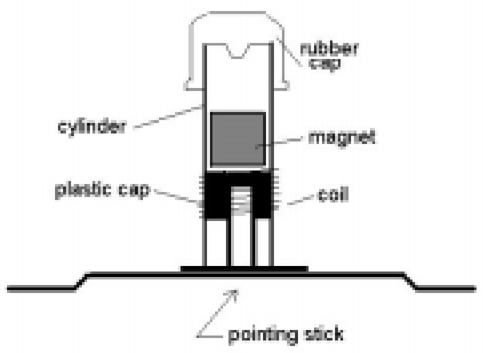

Figure 1: Schematic of the Tractile device.

5volts/100ma. Thus, a magnetic field repels the slug from the coil in an upward motion, striking the underside of the top rubber cap, which is what the user feels as tactile feedback. The maximum pulse rate without significant loss of amplitude is 30Hz, which might be lower than the ideal frequency for a fine texture display, but is acceptable for the task in this experiment.

While the cursor control on the screen is communicated through the PS/2 port as usual, the pulsing of the Tractile is controlled through the computer's serial port. Using the serial connection, a program can control the tactile feedback presented to the user, both when to pulse and how often. The entire Tractile device can be fit into the IBM Thinkpad notebook computers, presenting the same appearance as an unmodified Trackpoint.

3. METHOD

We selected a task that is common in today's computer applications: steering a cursor through a tunnel. This is an elemental task that is similar to highlighting a line of text or selecting an item from nested menus, such as traversing the path Start – Program – Accessories – Notepad in Windows or similar GUI operating systems. Recent studies by Accot and Zhai (1997, 1999) showed that such tasks can be reliably modeled by the steering law, similar to the way pointing tasks can be modeled by Fitts' law. In the present experiment, we asked participants to steer a cursor though tunnels that were filled with small bumps (Figure 2 – 5). The experiment was aimed at determining whether tactile information can facilitate users' steering performance under various visual conditions. That is, if what appears to be a bumpy texture on the screen *feels* bumpy to the user when the mouse pointer is moved over it, can the user more quickly or more easily steer the pointer? To make the task sensitive to performance differences, we choose circular shaped tunnels because they are more difficult to navigate (Accot & Zhai 1997, 1999).

3.1 Participants

Sixteen experienced computer users were recruited from the staff of our research lab (5 females, 11 males). Four had little or no experience using the Trackpoint (never or only used a Trackpoint a few times) whereas the remaining twelve had moderate to high experience (used the Trackpoint regularly). None of the participant had prior experience with this type of tactile device. All participants had normal or corrected vision.

3.2 Design

Participants were presented with four within-subject conditions: Visual + Tactile, Visual Only, Botts dots, and Unconcerted Visual + Tactile. In the Visual + Tactile condition, participants both saw and felt a bumpy texture inside the tunnel. In the Visual Only condition, the texture was merely seen and not felt. For the Botts condition, two rows of bumps lined the inside of the tunnel 5 pixels from the upper and lower borders.[1] These bumps could be both seen and felt. Finally, for the Unconcerted Visual + Tactile condition, bumps that could be seen became denser toward the tunnel borders whereas bumps that could be felt became denser toward the center – the tactile bumps and the visual bumps did not occur in concert. In other words, seeing a bump at a certain location did not necessarily mean feeling a bump at that same location.

Two performance measures were collected, reaction time and accuracy. Reaction time was measured as the time (in milliseconds) starting when the pointer entered the tunnel through the left-end until the pointer exited the tunnel thought the right-end. Accuracy was measured as the number of times the pointer was steered out-of-bounds.

There were four blocks of 30 trials. All trials within a block were from the same condition. The blocks were balanced so that each condition occurred in each ordered position equally often. Trials were redone until the participant completed 30 successfully (without going out of bounds). Thus, each participant was exposed to all four conditions 30 times, for a total of 120 trials.

3.3 Stimuli and Materials

The participant's task was to steer the mouse pointer through a circular tunnel as quickly and accurately as possible. The pointer used was the normal Windows arrow pointer. The visual bumps appeared as small

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[1] The Botts condition is named after "Botts dots", small, raised ceramic lane dividers common on California freeways. When an automobile crosses from one lane to the other, a sudden bumpiness is felt as the tires roll over the "dots". This bumpiness is particularly startling if the lane-change maneuver was unintentional.

(4x4 pixel) half-spheres protruding out of the surface of the tunnel. A light reflectance point in the upper left corner of each bump created a three-dimensional effect. Many participants reported that the bumps gave a good illusion of 3-D texture. Tactile bumps felt like a ticking or snapping sensation in the tip of the Trackpoint device. Pulsing the Trackpoint only occurred when the mouse pointer was in motion and only when it passed over a bump point.

For the Visual + Tactile condition, bump points were seen as bumps on the screen. However, for the Unconcerted Visual + Tactile condition, bump points were not seen. A bump point is a 4x4 pixel area (the same size as a visual bump). When the pointer enters this area from any direction a single pulse is sent to the Trackpoint. When the pointer then leaves the bump area another single pulse is sent. Thus, each bump point feels like the pointer hits the raised bump and then falls from the top of the bump back to the surface. The pulse strength was strong enough so that participants could feel single pulses, although feeling single pulses becomes more difficult when the pulse frequency increases (due to moving the pointer more quickly over the bumpy texture). With faster movements, we noticed that the synchronization of seeing the pointer pass over a bump and the time that bump was felt began to deteriorate. To remedy this, the Trackpoint driver's sampling rate was increased from the default 40Hz to 200Hz. This adjustment was highly effective at maintaining the visual-tactile information synchronization even at a fast rate of movement.

The tunnel that participants had to steer the pointer through was a semi-circle covering 270 degrees of arc, starting at 240 degrees and moving clockwise to 330 degrees. In essence, the tunnel appeared as a large upside-down horseshoe. The radius of the tunnel from the center to the outside boundary was 150 pixels and the width from outside to inside boundaries was 35 pixels.

For the visual only conditions, the texture visually appeared as very dense bumps in the center of the tunnel, becoming less dense towards the outer and inner boundaries (see Figure 2). No tactile information was provided in this condition. For the Visual + Tactile condition, the texture was the same as in Figure 2 but the user also felt the texture through the tactile feedback. In other words, what was felt was what was seen. The frequency of the bumps indicated how

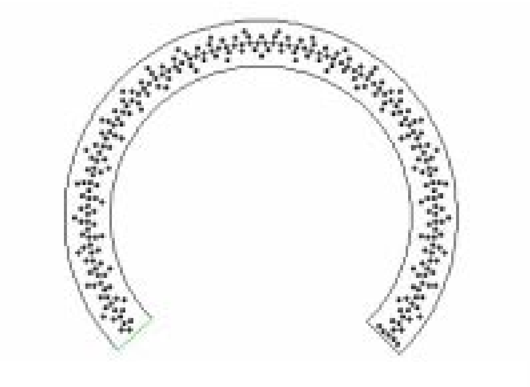

Figure 2: Visual + Tactile and Visual Only Stimuli.

Figure 3: Unconcerted Visual + Tactile Stimulus.

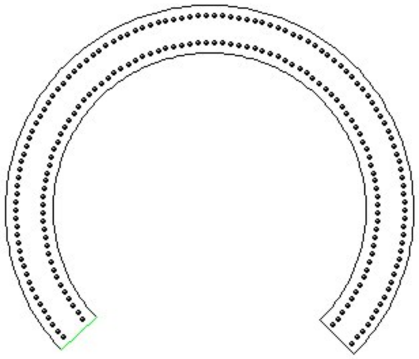

Figure 4: Botts stimulus.

closely the steering was on track: the more frequent the user felt the bumps, the closer to the center the user was steering. In the Unconcerted Visual + Tactile condition, what was felt was different from what was seen: the texture visually appeared very dense at the boundaries of the tunnel and became less dense toward the center (see Figure 3), opposite to how the tactile information was displayed. For the Botts condition, there were no graded levels of texture but a solid line of bumps 5 pixels from the outside boundary and another solid line of bumps 5 pixels from the inside (see Figure 4).

During the experiment, the tunnel was centered horizontally and vertically with indicator bars at the top and bottom of the screen. Before the participant entered the tunnel, the bottom indicator showed the word, “Ready”. After entering the tunnel, the bottom indicator showed the word, “GO!!!” and the top indicator displayed an arrow pointing in the correct direction of movement (clockwise) through the tunnel. If the participant went out-of-bounds, a red light would flash but if the participant went completely through without going out-of-bounds, a green light would flash on the top indicator. The total time steering through the tunnel was displayed on the top indicator after every trial. Finally, the trial number (out of 30 trials for the block) was displayed at the far right on the bottom indicator. Figure 5 shows a sample screen.All participants were run on the same IBM Thinkpad 760E, which has an SVGA display 1024 pixels high by 768 pixels wide. The special Trackpoint was mounted on a plastic surface and placed next to the computer within comfortable reaching distance of the participant. A custom computer program administered the entire experiment, including instructions, practice and experimental trials, and saving the results to disk.

3.4 Procedure

Each participant sat in an isolated room with only the Thinkpad 760E and the tactile Trackpoint prototype placed on the desk. Participants were given both written or oral instructions to steer the pointer through the tunnel from left to right clockwise as quickly and accurately as possible. Additionally, participants were told that on some trials they would receive tactile feedback through the Trackpoint and on other trials they would only see the texture in the tunnel. Finally, the indicator bars were explained, including the reaction time information given in the top display. Participants were encouraged to check their time on every trial and try to improve. After the instructions, two practice trials of each condition were administered and then, if there were no questions the participants began the experiment.

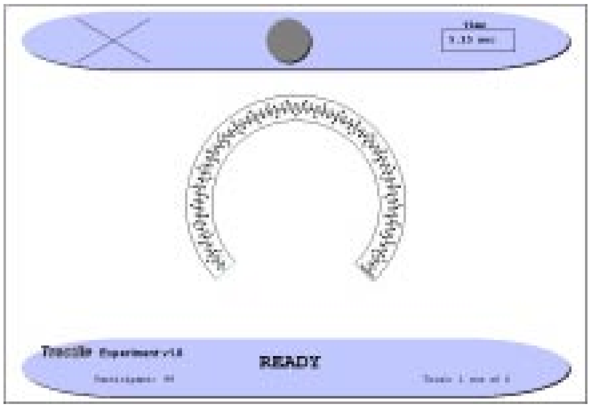

Figure 5: Screen shot of experimental set up.

During the experiment, participants steered the pointer through each tunnel entering on the left and exiting on the right. After successfully steering through the tunnel, a green light and the reaction time were given on the top indicator and the bottom indicator displayed the word, “Done”. The experimental program then reset the trial and the bottom indicator displayed the word “Ready”. During the experiment, there was no indication that a different block was starting other than the reset of the trial number display to 1. Participants were allowed to take a break between any trials for as long as they liked but no formal break was given. Each participant took approximately 25 minutes to complete all 120 trials.

After completing the experiment participants were debriefed and ask about their impressions of the Tractile device and the experiment. Participants were also asked to reflect on the usefulness of tactile feedback for pointer control. Finally, participants were reimbursed for their time with a $5 cafeteria voucher.

4. RESULTS

Task completion time and error rate were calculated for each participant. We discuss these results in turn.

4.1 Task Completion Time

Mean trial completion time was 4.7 seconds (s) for the Visual + Tactile condition, 5.2s for Visual Only, 5.5s for Botts, and 5.2s for Unconcerted Visual + Tactile (see Figure 6). Since the completion time data were skewed, as they usually are, a logarithmic transformation was taken for statistical variance analysis. A repeated measures ANOVA showed that the feedback condition had a significant effect on trial completion time ($F_{3,45} = 5.22$, $p < 0.005$). Pairwise t-tests showed that the mean trial completion time under the Visual + Tactile condition was significantly shorter ($p < 0.01$) than each of the other three conditions, Visual Only, Botts, and Unconcerted Visual + Tactile. The difference among the latter three conditions was not significant.

During the course of the experiment, participants made small but significant ($F_{2,30} = 4.02$, $p < 0.05$) progress in completion time. The mean completion time of the first ten trials (Block 1) was 5.3s. The mean completion time of the last ten trials (Block 3) was 5.1s. However, practice did not affect the difference between feedback conditions, as the interaction term, Condition X Block, was not significant ($F_{6,90} = 0.89$).

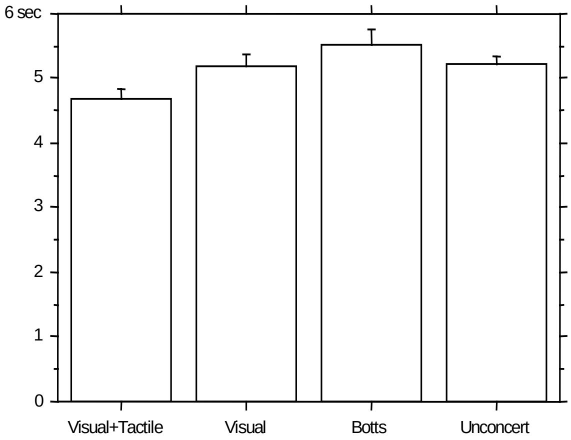

Figure 6: Mean completion time.

4.2 Error Rate

Given the difficulty of the steering task, participants often steered out of the boundaries of the tunnel. In that case, an error was registered but the participant had to re-start the trial until successfully steered out of the end of the tunnel. The mean number of errors was 0.53 for Visual + Tactile, 0.54 for Visual Only, 0.36 for Botts and 0.60 for Unconcerted Visual + Tactile (see Figure 7). A repeated measures ANOVA showed that condition had a significant effect on number of errors ($F_{3,45} = 2.87$, $p < 0.05$). Pairwise t-Tests showed that participants made significantly fewer ($p < 0.05$) errors under the Botts condition than under each of the other three conditions. Differences among Visual + Tactile, Visual Only, and Unconcerted Visual + Tactile were not significant.

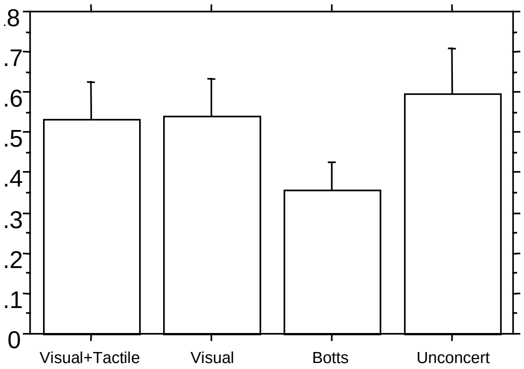

Figure 7: Mean number of errors made.

During the course of the experiment, participants did not make significant progress in terms of errors ($F_{2,30} = 0.16$). The interaction term Condition X Block was not significant either ($F_{6,90} = 0.8$).

5. DISCUSSION

Compared with the Visual Only condition, participants performed significantly faster in the Visual + Tactile condition. This demonstrates that when added tactile feedback was in concert with the visual information, the tactile feedback in the form of texture could indeed help user's steering performance. Note that this time advantage was gained without significant change in the number of errors made.

In contrast, participants made no performance improvement – either in terms of completion time or in terms of error – from the Visual Only to the Unconcerted Visual + Tactile condition. In the latter case, although both visual and tactile information were present, and the participants could conceivably utilize both sources of information, the incompatible mapping between the two modalities apparently prevented participants from taking advantage of the additional tactile information. This confirmed one of the main hypotheses of this study: Tactile information can effectively aid user's performance only if it is presented in concert with visual information. In other words: *What you feel must be what you see.*

In the Botts condition, both visual information and tactile information were presented in concert. As shown, this had an effect on accuracy. The bumps near the boundary served as a warning that the pointer was heading out of the tunnel. Thus, we see significantly fewer errors made in this case. Note that the reduced error rate was at an expense of a small but insignificant increase in completion time (see Figures 6 and 7). The Botts dots might have encouraged some participants try to stay within the boundary of the dots, making the tunnel effectively narrower. Because we did not include a visual only Botts condition, we do not know if or how much tactile information contributed to the results. According Accot and Zhai's (1997) steering law study, human steering time linearly increases as the width of tunnel decreases. We plan to investigate the effect of tactile feedback in relation to the steering difficulty (tunnel width and length) in future work.

To our knowledge, the current study is the first published empirical research on tactile feedback in isometric control devices. The Trackpoint device does not perceptibly move. In daily life, we can only feel texture if we move a finger across a surface (cf. Loomis & Lederman, 1986). In the case of isometric device, there is no physical, kinesthetic motion of the user's hands, only the visual motion of cursor movement on the screen. Nevertheless, our results show that tactile feedback suggesting texture is still effective. Future work will explore if the influence of tactile information can be enhanced with kinesthetic hand motion.

This study has many practical implications. First, it shows that an effective tactile input device can be made in an isometric form, which is well suited for mobile and many other computing applications. Second, it illustrates that we cannot expect user performance improvement by simply adding a tactile device to today's computer systems without modifying the visual GUI interfaces. Because today's GUI is not designed with tactile feedback in mind, it may be difficult to fit tactile feedback to current visual interfaces. Third, the study also suggests that some common human computer interaction tasks can benefit from tactile feedback. For example, hierarchical menu navigation is often slow and error prone, particularly with the long and narrow menu items (See Figure 8). According to the results of this study, the user may accomplish such a task more quickly if the words in the menu item can be felt. Furthermore, the results also suggests the benefit can only be achieved if the words are visually raised (e.g., as in Figure 9) so that the look and feel of the words are consistent. When the goal is to reduce error and "safe guard" the user by facilitating path through a sequence of menu items, our results suggest that placing "Botts dots", both visually and tactilely, inside the boundary of the menu items can be useful. Feeling raised text may facilitate other tasks, such as selecting a block of text in a word-processing application. We studied one example of multi-modal interfaces. By combining multiple sources of information, multi-modal interfaces can (a) increase realism, (b) provide a feeling of immersion, (c) facilitate reliable or robust performance, (d) reduce

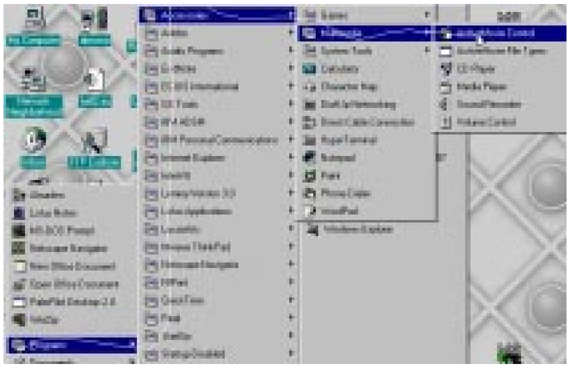

Figure 8. Nested, long menu items.

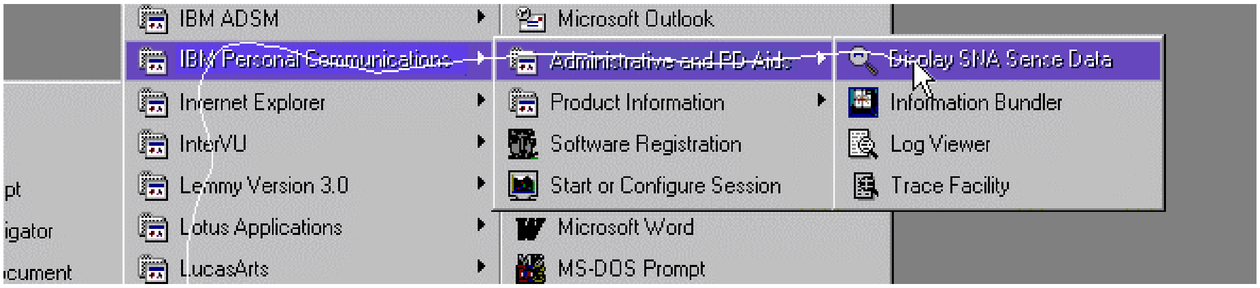

Figure 9. Mockup of menu items with raised, 3D looking text.

fatigue, and (e) add redundant information to provide assistance for users with special needs. One important conclusion of this study is that information presented by multi-modal interfaces ought to work to together to give users a coherent impression of the world.

6. CONCLUSION

Based on the results of our study, we can make the following conclusions. First, tactile feedback *can* improve users' performance, either in reducing error rate or in increasing steering speed. Second, the effect of the tactile feedback depends on how the tactile feedback is presented in relation to the visual feedback. Tactile feedback helps only if it is presented in concert with visual information. If the tactile and visual information are at odds, the information can not be effectively used. Third, tactile feedback in the form of texture can be effectively used in isometric control devices – even without the user having to move a finger across a surface.

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REFERENCES

Accot, J., & Zhai, S. (1997). Beyond Fitts' Law: Models for trajectory-based HCI tasks, in *Proceedings of CHI '97*, pp. 295-302.

Accot, J., & Zhai, S. (1999). Performance Evaluation of Input Devices in Trajectory-based Tasks: An Application of Steering Law, in *Proceedings of CHI '99*.

Akamatsu, M. (1992). The influence of combined visul and tactile information on finger and eye movements during shape tracing. *Ergonomics, 35*, 647-660.

Atkinson, W. D., Bond, K. E., Tribble, G. L., III, & Wilson, K. R. (1977). Computing with Feeling, *Comput. & Graphics*, 2, pp. 97-103

Balakrishnan, R., Ware, C., Smith, T. (1994) Virtual hand tool with force feedback, *Conference Poster, CHI'94: ACM Conference on Human Factors in Computing Systems.*

Brooks, F.P.J., Ouh-Yong, M., Batter, J.J., and Kilpatric, P.J. (1990). Project GROPE – haptic display for scientific visualization. *Computer Graphics*, *24*(4).

Engel, F. L., Goossens, P., & Haakma, R. (1994). Improved efficiency through I- and E-feedback: A trackball with contetual force feedback.. *International Journal of Human-Computer Studies, 41*, 949-974.

Gaver, W. (1997). Auditory Interfaces, in Helander, Landauer and Prabhu (eds), *Handbook of Human-Computer Interaction*, second edition, pp 1003 – 1041, Elsevier Science

Haptic Technologies, The MouseCAT™, http://www.haptech.com/prod/index.htm

Immersion Corp, The FEELit Mouse, http://www.force-feedback.com/feelit/feelit.html

Loomis, J. M. & Lederman, S. J. (1986). Tactual perception, in K. R. Boff, L. Kaufman, & J. P. Thomas (Eds.), *Handbook of perception and performance: Volume II, Cognitive processes and performance*.

Massaro, D. W. (1998). *Perceiving talking faces*. Cambridge, MA: MIT Press.

Minsky, M. Ouh-young, M., Steele, O. Brooks Jr., F. P., & Behensky, M. (1990). Feeling and seeing: Issues in force display, in *Computer Graphics, Proceedings of SIGGRAPH Symposium on 3D Real-Time Interactive Environments*.

Payette, J. Hayward, V., Ramstein, C., Bergeron, D. (1996). Evaluation of a force-feedback (Haptic) computer pointing device in zero gravity. In *Proc. Fifth Annual Symposium on Haptic Interfaces for Virtual Environments and Teleoperated Systems*, ASME Dynamic Systems and Control Division, DSC-Vol. 58. pp. 547-553.

Rutledge, J, Selker, T. (1990) Force to motion functions for pointing, INTERACT'90: Proceedings of Human Computer Interaction, pp 701-705.

SensAble Technologies, Inc., (1996) The Phantom™, http://www.sensable.com/products.htm

Shimoga, K. B. (1993). A Survey of Perceptual Feedback Issues in Dexterous Telemanipulation: Part II. Finger Touch Feedback. In *VRAIS '93*, Vol. , pp. 271-279, Seattle, WA