

Literature Review on the Effects of Multimodal Interactions with Focus on Haptic Interface and Considerable Design Issues

Heekyoung Jung and Sindhia Thirumaran (January, 3, 2008)

Extended Abstract

Multimodal interfaces including auditory and tactile feedbacks have been considered very important in touch screen-based desktops and handhelds to supplement current visual interfaces. The report summarizes the results of studies using multimodal interactions, specifically Haptic in different contexts like desktop, handheld mobile devices etc. This report also summarizes the quantitative and qualitative evaluation of multimodal interactions. However, the contexts of these studies are limited to certain tasks such as targeting or pointing graphic elements and the evaluation criteria are mostly focused on quantitative (performance) parameters. The intention of this review is to explore whether haptic interfaces positively contribute to the interaction experience based on the insights from previous study results and whether it is more than just a curiously interesting interaction factor.

The preliminary attempts in using haptic interactions were not very positive. Eventhough the results from several studies showed reduction in task time, effort and improved error rates in most cases, the mode of evaluation had not taken into account the experience factors, tasks and context sensitive factors. The studies exploring the effects of multimodal interactions in desktop interfaces have concluded different results based on the task type. The combination of modalities in certain cases showed improved task time and slightly decreased error rate whereas in other cases showed no improvement in task time or error rate. The results were quantitatively analyzed mainly based on performance criteria. Specifically, inclusion of haptic stimuli along with visual feedback has proven beneficial and effective when multiple tasks are being performed and when the workload conditions are high. Also, haptic is proven to produce better results for tasks that involve target acquisitions (searching) and alerting.

The studies exploring the effects of haptic interactions in hand held devices (small display area) and In-Vehicle touch screens showed clear improvements in performance and experience. Especially in the case of touch screen keyboards with haptic feedback, they found that users made less errors, faster, better experience etc. It was also found that workload factors like annoyance, frustration, mental and physical demand etc were significantly reduced when using tactile feedback. Evaluations were more qualitative in this category and it was proved that haptic interactions created a better experience with various tasks and contexts (when users are mobile and using handheld screens or in-vehicle touch screens). All this clearly shows the quantitative and qualitative advantage of using haptic interactions in this particular context of use.

From these studies it is evident that haptic feedbacks contribute to better interactions at different levels based on the context of the application and tasks. Eventhough most studies were not qualitatively evaluated, some conducted subjective analysis using

standardized workload keywords such as mental demand, physical demand, frustration, annoyance etc rather than experience keywords. Our study hopes to explore the overall experience evoked by the usage of haptic interactions including efficiency of performance, users' workload preference and experience.

This report will first introduce the concept of haptic/tactile feedback and several case studies of multimodal interactions with focus on haptic feedback. Based on the review of case studies, the effects of different modalities and their combination will be compared among different contexts of applications. Lastly, considerable design issues to maximize the potential of each modality will be discussed.

I. Introduction and Background: Need for Haptic Interactions

Desktop interface has become increasingly complex and so much information is presented graphically that it becomes difficult to attend to all relevant parts (Brewster, 1997). At the same time as computing devices are getting smaller and mobile, compact design with fewer interface elements or touch screen has become a more critical issue. Attempts have been made to overcome information overload using multimodal interactions such as audio and tactile feedbacks as they reduce cognitive burden compared to visual-only interfaces and save space for physical interfaces. While there have been systematic approaches for applying non-speech sound to appropriate tasks such as button clicking and scrolling (Beaudouin-Lafon et al., 1996; Brewster, 1998), there have been rare convincing empirical attempts to reduce overload by using haptic (or force feedback) technology. As Tan (1997) says "In the general area of human-computer interfaces... the tactile sense is still underutilized compared with vision and audition", potentials of touch sense need to be explored for efficient and affective purposes.

II. Preliminary Attempts to Use Haptic Interactions

The human haptic system has been defined to consist of the entire sensory, motor and cognitive components of the body-brain system, so to speak anything relating to the sense of touch (Oakley, 2000). Specifically, the overall haptic system can be distinguished into *proprioceptive* (relating to sensory information about the state of the body), *vestibular* (pertaining to the perception of head position, acceleration, and deceleration), *kinesthetic* (meaning the feeling of motion, relating to sensations originating in muscles, tendons and joints), *cutaneous* (pertaining to the skin itself or the skin as a sense organ, including sensations of pressure, temperature, and pain), *tactile* (pertaining to the cutaneous sense but more specifically the sensation of pressure rather than temperature or pain), and *force feedback* (relating to the mechanical production of information sensed by the human kinesthetic system).

A haptic mouse developed by Akamatsu and Sate (1994), had the ability to produce 'tactile feedback', providing vibration and force feedback with controllable friction effect. Using this device they showed significantly decreased completion times in a targeting task offset by slightly increased error rates. Engel et al. (1994) found improved speed and

error rates in a generalized targeting task using a modified trackball with directional two degrees of freedom force feedback. Akamatsu et al. (1995) have successfully shown that tactile feedback can improve pointing interactions when using a mouse because tactile cues can aid users in hitting targets such as buttons faster and more accurately. However, as technology has advanced there has been no corresponding progress in its evaluation. This disparity has led to a situation where there are no formal guidelines regarding what feedback is appropriate in different situations. This, along with evidence that shows arbitrary combinations of information presented to different senses is ineffective (Ramstein et al., 1994; 1996), leads to the conclusion that empirical evaluation of modern haptic augmentations of the desktop is urgently required.

III. Effects of Multimodal Interactions (for Desktop Interface)

Most tasks utilizing information displays are predicated on the processing of visual information, and a great deal of research has been conducted exploring the benefit of adding auditory or tactile cues in display systems, e.g., (Van Erp, 2004; Wickens et al, 2003). However, the wide disparity in tasks, settings, and measures has muddied the waters, making it difficult to draw clear conclusions as to which modalities can be successfully offloaded for which tasks, and just how much the addition of another modality increases performance.

Oakley et al. (2000) investigates the use of touch as a way of reducing visual overload in the conventional desktop. Two experiments were conducted to test the use of haptics to augment targeting in the standard GUI using PHANToM. The first experiment compared the effects of four different haptic augmentations (texture, friction, recess, gravity well) on usability in a simple targeting task (16 university students). The second experiment involved a more ecologically oriented searching and scrolling task (20 university students). In order to get a full range of quantitative and qualitative results, *time, error rates, and subjective workload measures* were used in both of the experiments. For subjective workload measurement, NASA TLS workload sheets (Hart and Wickens, 1990) were administered with six factors (*mental demand, physical demand, time pressure, effort expended, performance level achieved, and frustration experienced*) and additional seventh (*fatigue*) as a potential problem.

Results indicated that the haptic effects did not improve users performance in terms of task completion time. However, the number of errors made was significantly reduced. Particularly, subjective workload measures showed that participants perceived many aspects of workload as significantly less. The timing results from the two experiments indicate that the haptic effects added to the buttons and scroll bar did not reduce the time taken for either task. It was assumed that one potential reason for the lack of time reduction is that, in all of the effects used, participants had to exert more force to overcome the haptic effects. (However, other previous work claimed contradicting results with a significant reduction in performance times. (Miller and Zeleznik, 1998; Rosenberg, 1997). For example, Rosenberg (1997) reported that FEELit mouse was found to be 60-70% better efficient for targeting and selecting tasks and that it might

reduce the muscle strain associated with standard mice, a contributing factor to Repetitive Stress Injuries.)

More specifically, in Experiment1, gravity well and recess came out best, indicating that they were effective at reducing error rates and decreasing workload. This suggests that they are very robust and can be successfully used in haptic interfaces for targeting tasks, which are important for using many standard GUI widgets, for example hitting a button, selecting a menu item or dragging the scrollbar thumb. On the contrary, texture came out the worst in terms of workload, suggesting that it could potentially perturb users' movement, making it hard for them to stay on target. A kinesthetic device can only simulate gross textures, requiring larger forces, which then make it harder for users to move precisely. In Experiment2, the results showed a significant reduction in the number of times a participant moved on/off the scroll bar in the haptic condition, with little effort and frustration. This showed that it was easy to stay on the scroll bar due to the recess effect made the task much less effortful. However, this decreased time, effort and frustration did not lead to reductions in other categories (e.g. mental demand).

Burke et al. (2006) provide a holistic understanding of the effects of multimodal feedback on user performance, comparing visual-auditory and visual-tactile feedback to visual feedback alone through a meta-analysis of 43 studies. Each study was coded on the following 7 dimensions: 1) *article characteristics* (article source, publication type), 2) *sample characteristics* (age, gender, participant population), 3) *research design* (setting, within vs. between comparisons, random assignment, counterbalancing), 4) *modality* (V: visual, VA: visual-auditory, VT: visual-tactile), 5) *tasks* (single vs. multiple, task type*, workload), 6) *outcome variable* (error rate, performance score, reaction time), and 7) *effect size* (specific comparison). Particularly in terms of task type*, it was determined that a majority of the tasks utilized in the modality studies represented five different task activities: 1) *Alert, Warning, or Interruption* (re-direct operator's attention), 2) *Target Acquisition* (searching the environment to identify a specific goal; inherently visual), 3) *Communication* (speaking, listening to, reading, interpreting, or relaying information), 4) *Navigation* (making decisions about a route or destination), and 5) *Driving/Vehicle Operation* (maneuvering and maintaining control of a vehicle).

Results indicate that adding an additional modality to visual feedback improves overall performance and reaction time, but not error rate. Effects are moderated by task type, workload, and number of tasks. VA feedback is most effective when a single task is being performed, and under normal workload conditions. The results imply that sound may capture the user's attention more quickly than visual cues alone, which leads to quicker reaction times and better scores. However, at the same time, this may suggest that using both channels increases workload, thus proving less advantageous in situations where high workload conditions are already present. VT feedback is more effective when multiple tasks are being performed and workload conditions are high. This explains that the body's natural tendency to react more quickly to tactile stimuli than to visual may be the impetus behind the increased efficiency. Cognitive processing of direction and location may also be reduced due to tactile input, which is supported by Multiple Resource Theory (Wickens, 2002), since the positive effects of adding the tactile modality are more pronounced when workload is high. (Wickens' multiple resource

theory (MRT) suggests that the use of multiple display modalities will reduce cognitive load through distribution of tasks and information across various sensory channels.)

The fact that neither auditory nor tactile feedback had any effect on reducing error rates suggests that the visual modality has more influence on this component of performance. It may be that the information needed to make decisions about accuracy and judgment is best presented visually, or that these decisions are more a reflection of the individual's knowledge and skills than of the type of feedback presentation.

Most of the studies involved either target acquisition tasks or alert, warning or interruptions tasks. Both types of multimodal feedback (VA and VT) are effective for target acquisition tasks; but vary in effectiveness for other task types. VT feedback works the most effectively in alert-type tasks. VA in target acquisition tasks but was not effective for the alert, warning or interruption tasks. It may be because already a lot of noise that must be filtered or because types of sound were inappropriate. In summary, adding an extra modality (auditory or tactile) to visual feedback improved reaction time and performance, but not error rate. The most important difference that emerged between the two multimodalities is the contrasting effects with number of tasks and workload: adding tactile feedback appeared to decrease workload and provide advantages under high workload conditions whereas adding auditory feedback appeared to increase workload and decrease effectiveness under high workload conditions.

The effects of haptic feedback for high workload or multitasking conditions also can be explained by other studies. For example, Brewster and King (2005) designed a tactile progress bar that indicated the progress of a download via the time difference between two tactile pulses; as the pulses got closer together the download got closer to completion. They found that users performed better with tactile progress bars than standard visual ones when involved in a visual typing task mainly because users were able to attend to the tactile feedback and type at the same time.

IV. Applying Multimodal Interactions for Handheld Devices

Effects of multimodal interactions are more critical when users are using handheld devices in dynamic situations. It is usually assumed that audio feedback would be difficult in a noisy environment and that visual feedback would be difficult as there is already much to look at in the small screen. Also, it is hard to generalize the benefits or advantages of the same interaction modality in different context of use. However, the results from various studies would provide meaningful understanding about multimodal interactions for mobile applications.

Chang et al. (2005) investigated users' feeling and quality of sound comparing audio-based haptic user interface (UI) feedback with audio-only feedback. (42 participants, no structured task but overall exploration; use of e398 phone with audio-haptic sounds from MFT: Multi-Functional Transducer was compared to a v400 phone with audio-only sounds.) The results show that users were receptive to audio-haptic UI feedback, suggesting that audio-haptic seems to enhance the perception of audio quality. 35 out of

42 people reported that the haptic phone felt better. At the same time, 20 participants thought the haptic phone had better audio, while 20 felt the audio between the two were the same. This means that the presence of haptic increases the perception of sound in the phone. “The little haptic feedback on the button press is good. The big wiggles feel strange though.” Some others pointed out further possibilities for vibration as a medium and need for exploring more variety of sensations. In general, users were very positive about the possibility of expanding the user interface to include more variations in vibration.

Brewster et al. (2007) investigated the use of vibrotactile feedback for touch-screen keyboards on PDAs. They conducted a laboratory study comparing standard buttons to ones with tactile feedback added (6 participants). Using simple tactile icons (Brewster and Brown, 2004; Brown et al., 2005), they represented two stimuli: one to indicate a successful button press and one to indicate an error. Each tactile feedback was played either when a button was correctly pressed and then released, or when a slip or double tap error occurred. Results showed that with tactile feedback users entered significantly more text, made fewer errors and corrected more of the errors they did make. They ran the study again with users seated on an underground train to see if the positive effects transferred to realistic use (12 participants). There were fewer beneficial effects, with only the number of errors corrected significantly improved by the tactile feedback. This result implies that tactile feedback was less beneficial when users were mobile.

For the second study, they administered NASA TLX workload sheets with an extra category of *Annoyance* to see how people felt about the extra feedback (Hart and Wickens, 1990). Overall workload was significantly reduced, including reductions in workload in the tactile condition for *mental demand*, *physical demand*, *effort expended* and *frustration*. There was a significant increase in perceived *performance level* for the tactile condition. Annoyance was also found to be significantly reduced in the tactile condition. Formal statistical analysis is limited due to the small number of participants, but the study results suggest that tactile feedback has a key role to play in improving interactions with touch screens based on strong subjective user response.

Similarly, Brewster (2002) showed that sonic enhancement of buttons could improve performance. For example, he also found more data was entered when extra feedback was given. Another similarity was a large reduction in workload with the extra feedback when users were mobile. The downside of his solution was that sounds could be intrusive or not heard in noisy environments. Tactile feedback is an effective alternative and does not suffer the same drawbacks. Also, touch-screen buttons are hard to use in mobile settings and users benefit when they are given extra assistance. A future study will directly compare audio, tactile and a combination of the two feedback types to see which is most beneficial.

V. Applying Multimodal Interactions for In-Vehicle Touch Screens

The ongoing proliferation of vehicle cockpit content and functionality continues to drive increasing complexity into the driver experience. It was assumed that audio feedback

would be difficult in such a noisy environment and that visual feedback would be difficult as there is already much to look at in the small screen and drivers should not be distracted with the visual information displayed on the screen.

Serafin et al. (2007) conducted two studies to investigate the addition of haptic feedback as well as auditory feedback on user perceptions of the touch screen experience. The first study was conducted in a desktop setting (34 participants) and the second study was conducted with the touch screen integrated in a vehicle (33 Americans and 31 Germans). In both studies, participants assessed four different types of feedback conditions: visual feedback only (V), auditory and visual feedback (AV), haptic and visual feedback (HV), and auditory, haptic, and visual feedback combined (AHV). The results of these studies support the claim that individuals strongly prefer touch screen implementations that incorporate haptic elements in terms of *ease of use, impression, preference, and operation while driving*. However, reliable reasons for those responses have not been deeply investigated and it was implied that the results may be change over time and use. Likewise, results from regional differences have not been investigated.

Liu (2001) conducted a simulator study to compare 16 younger (mean age 22 years) and 16 older (mean age 68 years) drivers' ratings of workload (*time, visual, psychological stress*) and performance of navigation and button-pushing (identification of vehicle or road hazards) tasks under both high- and low-load driving conditions when simple or complex advanced traveler information (ATI) was presented visually only, aurally only or by multimodality (visual and auditory) display. For all participants, both the auditory and multimodality displays produced better performance in terms of *response times, total number of correct turns and subjective workload ratings* than those of using the visual-only display. Participants using the multimodality display also made the fewest errors related to push-button and navigation tasks, and controlled their vehicles properly. The visual display led to less safe driving, apparently because it imposed higher demands on the drivers' attention. An age effect was found in the present study, with younger drivers performing better and reporting less stress than older drivers. Notably, however, use of the multimodality display significantly improved the older drivers' performance in the button-pushing task.

VI. Conclusion

As a number of study results show, evaluation of multimodal interactions is hard to be generalized because it is difficult to distinguish the effect of each sensory feedback and also because the contexts and characteristics of tasks differently influence users' responses for the same feedback interface. However, by reviewing previous studies, we could still get some insight on the benefits of using haptic and methods of evaluation, particularly in terms of the workload criteria. Some emerging patterns of user's preference on feedback according to task types and contexts of use are summarized in the following table.

Study	Main Application	Task Type	Independent Variables	Dependent Variables	Results
Akamatsu et al. (1994)	Haptic mouse with tactile feedback	Targeting task offset	GUI, Force feedback with controlled friction	Time, Error rate	Decreased completion times, Slightly increased error rates
Engel et al. (1994)	Trackball with directional 2 DOF force feedback	Targeting task	GUI, Force feedback	Time, Error rate	Improved speed and error rates
Akamatsu et al. (1995)	Mouse with tactile feedback	Pointing interaction	GUI, Tactile feedback	Time, Error rate (accuracy)	Improved speed and accuracy (tactile cues guide users)
Oakley et al. (2000)	PHANToM	Targeting task	GUI, Haptic augmentations (texture, friction, recess, gravity well)	Time, Error rates, Subjective workload (mental demand, physical demand, time pressure, effort expended, performance level achieved, frustration experienced and fatigue)	No Improved completion time (due to exertion of force), Reduced error rates, Overall less effort in terms of workload
		Searching and scrolling task			Reduction in the number of times, Little effort and frustration with texture effects
Brewster and King (2005)	Mouse with force feedback	Multitasking (checking the download status and typing texts)	GUI progress bar, Tactile feedback indicating the progress of downloading	Performance	Haptic enabled multitasking (visual typing) while checking the status of download
Burke et al. (2006)	Meta-analysis of various 43 studies	Alert, Warning, Interruption, Target acquisition, Communication, Navigation, Driving and vehicle operation	Modality (V: visual only, VA: visual-auditory, VT: visual-tactile) Sample characters (age, gender)	Error rate, Performance score, Reaction time	VT works well for cases in which multiple tasks are performed and the workload is high. (the body stimuli to tactile feedback.) Auditory and tactile feedback did not show any reduction in error rate. Tactile feedbacks are effective for target acquisition and alert tasks.

Chang et al. (2005)	Mobile phone	Usual exploration	Audio-based haptic feedback, Audio-only feedback	Users' feeling and quality of sound	Better perception of sound quality with haptic feedback but possibility of annoyance (no specific beneficial effects)
Brewster et al. (2007)	Touch-screen keyboards on PDAs. (lab setting)	Text entry (typing).	Typing on GUI keyboard with stylus	Number of text entered, Errors made and corrected	With tactile feedback users entered significantly more text, less errors and were also able to correct their mistakes.
	Touch-screen keyboards on PDAs. (travelling in an underground train)		Vibrotactile feedback indicating success and error	NASA TLX Workload (Mental demand, physical demand, effort expended, frustration, annoyance)	Tactile feedback was not very beneficial when users were mobile. Although users perceived that their performance level was high and also annoyance and other workload factors were significantly reduced.
Brewster et al. (2002)	PDAs	Text entry (typing).	GUI buttons with different sizes Sonic enhancement of buttons	Workload factors as above	Large reduction in workload and improved usability But audio feedback can add on to the noise levels while tactile does not.
Serafin et al (2007)	Desktop based touch screen	Adjusting climate and audio settings	Visual only (V), Auditory (VA), Haptic (VH), Auditory and Haptic (AHV)	Ease of use, Impression, Preference, Operation while driving	Strong preference for haptic elements in terms of ease of use, impression, preference, and operation while driving.
	In-Vehicle haptic screen	Playing and controlling CDs			
Liu (2001)	Advanced traveler information (ATI) provided for driving	Tasks under high and low driving conditions: navigation, operation and interaction	Modality (visual only, aurally only, visual and auditory combined) Age (young and old participants)	Workload (time, visual and psychological stress) Performance of navigation and button pushing	Multimodal was considered safer and beneficial than just visual. Multimodal provided for fewer errors and they controlled and navigated their vehicles properly.

VII. Discussion about Design Issues

As described above, haptic feedback is becoming an important design element for human-computer interfaces. However, its effects have been considered only in terms of efficiency and accurate performance issues. Variations of haptic feedbacks have been applied in a level of technical implementation with little or no understanding of the experience and quality of touch sense. Also, most studies did not explore design patterns according to types of tasks and use of contexts. In order to maximize the benefits and potentials of haptic feedbacks for various multimodal interaction applications, the unique attributes of the touch sense in physiological and psychological terms, and the nature of information and control that touching provides should be fundamentally considered.

MacLean (2000) suggests special qualities of touch to be considered when designing with haptic feedback, such as bidirectionality, social loading, gesture and expression, multi-parameters include force, pressure, moisture, temperature, and spatial and temporal textures, etc., resolution and associability (sensitive and subtle but hard to memorize, grade or distinguish). Based on understanding of its special qualities, he suggests the following reasons as needs for using haptics in designing interactive applications:

Reasons for Touching

- Anticipation: directing and accommodating a potential users' preconception of what the interaction will do, and what the experience will be like.
- Motivation: do a task, probe an object, communicate a message, poke something, verify, enjoy aesthetics pleasure, fidget to relieve tension, connect physically or emotionally with other subject.
- Inhibition: uncomfortable, unpleasant and unnatural feeling, annoyance, message of alert or alert

Information available from touching

- Assessments of object's dynamic and material property
- Verification of engagement and completion (snap or gear)
- Continuous monitoring of ongoing activity and gradual doneness
- Building mental model of invisible parts
- Judgment of other people

As mediums of tangibility, *practical haptic language* (with a lexicon of distinguishable haptic symbols (Hoggan, 2007)), *synthesized haptic feedback* (permitting real-time representation of a changing computing environment rather than specific constant handle), and *mediation of haptic interfaces* between users or between person and a machine through appropriate physical analog should be systematically studied. Attempts to those studies of haptic interactions will lead to exploration of affects and aesthetics of computing as well as dealing with complex interface problems of current applications.

References

- Akamatsu, M., MacKenzie, I. S., & Hasbrouq, T. (1995). A comparison of tactile, auditory, and visual feedback in a pointing task using a mouse-type device. *Ergonomics*, 38, 816-827
- Akamatsu, M. & Sate, S. (1994). A multi-modal mouse with tactile and force feedback. *International Journal of Human-Computer Studies* (40), 443-453.
- Chang, A. & O'Sullivan, C. (2005). Audio-haptic feedback in mobile phones. CHI '05 extended abstracts on Human factors in computing systems, April 02-07, 2005, Portland, OR, USA
- Beaudouin-Lafon, M. & Conversy, S. (1996). Auditory illusions for audio feedback. In *ACM CHI'96 Conference Companion (Vancouver, Canada)* ACM Press, Addison-Wesley, 299-300.
- Brewster, S.A. (1997). Using Non-Speech Sound to Overcome Information Overload. *Displays*, 17,179-189.
- Brewster, S.A. (1998). The design of sonically enhanced widgets, interacting with Computers, 11(2), 211-235.
- Brewster, S.A. Overcoming the Lack of Screen. (2002). Space on Mobile Computers. *Personal Ubiquitous. Comput.* 6, 3 (Jan. 2002), 188-205.
- Brewster, S., & Brown, L. M. (2004). Tactons: structured tactile messages for non-visual information display, *Proceedings of the fifth conference on Australasian user interface*, p.15-23, January 01, 2004, Dunedin, New Zealand
- Brewster, S., Chohan, F. and Brown, L: Tactile feedback for mobile interactions, CHI '07 extended abstracts on Human factors in computing systems, April 28-May 03, 2007, San Jose, CA, USA
- Brewster, S.A. & King, A.J. (2005). An Investigation into the Use of Tactons to Present Progress Information. In *Proc. of Interact 2005*, Springer, 6-17.
- Brown, L.M., Brewster, S.A. & Purchase, H.C. (2005). A First Investigation into the Effectiveness of Tactons. In *Proc. of Worldhaptics 2005*, IEEE Press, 167-176.
- Burke, J.L., Prewett, M., Gray, A., Yang, L., Stilson, R., Redden, E., Elliott, L., & Coovert, M. (2006). Comparing the effects of visual-auditory and visual-tactile feedback on user performance: A meta-analysis. *Proceedings of the ACM 8th International*

Conference on Multimodal Interfaces, Banff, Canada, November 2006.

Engel, F.L., Goossens, P. & Haakma, R. (1994). Improved Efficiency through I- and E-Feedback: A Trackball with Contextual Force Feedback. *International Journal of Human-Computer Studies*, 41(6), 949-974.

Hart, S.G. & Wickens, C. (1990). Workload assessment and prediction. *MANPRINT*, an approach to systems integration, 257-296, Van Nostrand Reinhold.

Hoggan, E.E. (2007). New parameters for Tacton Design, CHI '07 extended abstracts on Human factors in computing systems, April 28-May 03, 2007, San Jose, CA, USA

Hoggan, E. E., Brewster, S. A. (2006). Crossmodal icons for information display, CHI '06 extended abstracts on Human factors in computing systems, April 22-27, 2006, Montréal, Québec, Canada

Liu, Y. C. (2001). Comparative study of the effects of auditory, visual and multimodality displays on drivers' performance in advanced traveler information systems. *Ergonomics*, 44(4), 425--442.

MacLean, K.E. (2000). Designing with haptic feedback. *Proceedings of IEEE Robotics and Automation*. San Francisco.

Michelitsch, G, Williamms, J., Osen, M., Jimenez, B., Rapp, S. (2004). Haptic chameleon: a new concept of shape-changing user interface controls with force feedback. CHI '04 extended abstracts on Human factors in computing systems, 2004, Vienna, Austria

Miller, T. & Zeleznik, R. (1998). An Insidious Haptic Invasion: Adding Force Feedback to the X Desktop. In *ACM UIST'98*, (San Francisco, CA) ACM Press, 59-64.

Oakley, I., McGee, M. R., Brewster, S., Gray, P. (2000). Putting the Feel in 'Look and Feel', *Proceedings of the SIGCHI conference on Human factors in computing systems*, p.415-422, April 01-06, 2000, The Hague, The Netherlands

Ramstein, C. & Hayward, V. (1994). The Pantograph: A Large Workspace Haptic Device for Multi-Modal Human-Computer Interaction. In *Summary Proceedings of ACM CHI'94*, (Boston, MA) ACM Press, Addison-Wesley, 57-58

Ramstein, C., Martial, O., Dufresne, A., Carignan, M., Chassb, P. & Mabileau, P. (1996). Touching and hearing GUIs: Design issues for the PC-access system. In *Proc. of ACM Assets'96*, (Vancouver, Canada), ACM Press, 2-10.

