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Effects of Multimodal Error Feedback on Human Performance in Steering Tasks

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Abstract

This paper investigates the relationship between "error feedback" (when tracking or trajectory errors are made) and user performance in steering tasks. The experiment examines feedback presented in visual, auditory and tactile modalities, both individually and in combinations. The results indicate that feedback significantly affects the accuracy of steering tasks but not the movement time. The results also show that users perform most accurately with tactile feedback. This paper contributes to the basic understanding of "error feedback" and how it impacts on steering tasks, and it offers insights and implications for the future design of multimodal feedback mechanisms for steering tasks.

Key words: Multimodal feedback, steering task, human performance

1 Introduction

Graphical user interfaces (GUI) have long been used to communicate between humans and computers through the visual channel, i.e., "what you see is what you get". As interaction tasks become more complex and intense, visual feedback as the sole channel is showing its limitations. It is necessary to study user performance under different modalities both individually and in combinations. Several classes of fundamental task exist, such as pointing, crossing [3], and steering. Jennifer et al. [7] mentioned that the effect of sensory channel feedback was likely to vary across different tasks. Many researchers [4, 5, 11, 12] have compared the effects of different modalities of feedback on user performance in pointing tasks and crossing tasks. However, little work has been done on steering tasks. The term "steering task" stands for a set of human actions in HCI, for example, navigation in hierarchical menus, drawing, writing etc. With pen-based interaction becoming increasingly popular, the steering task has also become a common task in daily human-computer interaction, and is thus worthy of further investigation.

Another reason we chose the steering task is we are interested in feedback that continuously alerts users to errors and prompts them to make corrections on the fly; discrete tasks such as pointing and crossing are not as suitable. Trajectory-based tasks (also known as steering tasks) [1], such as navigating through a tunnel or tracing a picture, require continuous adjustment along the trajectory and are thereby appropriate for our purpose. In standard steering tasks such as those performed with a stylus, the user traces a path through a visual tunnel, and is required to keep the stylus within the tunnel at all times. Therefore, we conducted a controlled experiment to study the effects of multimodal feedback on human performance in steering tasks.

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Although two papers [8, 9] present studies on steering tasks, they used feedback as "affirmative" feedback for guidance and affirmation. Affirmative feedback has been shown to be beneficial especially for the older and/or visually impaired population as it confirms that they are on the right track. For example, when a traffic light turns green, a sound starts and changes in timely fashion. The blind can be guided to cross the road with the help of voice prompts. They can also understand how long it will be before the light changes color, according to the rhythm or tempo of the sound. However, continuous affirmative multimodal kinds of feedback may have considerable drawbacks for people with normal sensory capabilities. Firstly, most people do not like to be disturbed when they are performing normally. Imagine you are driving on a flat road: nonstop vibrations or constant extra sounds, above normal road noise, informing you that you are in the right lane, would be disturbing and even annoying. Secondly, when presented over a long period, continuous tactile or auditory feedback may result in fatigue or even low responsiveness from the user. As a result, the user may not be able to promptly detect feedback that indicates that an abnormal situation requires attention. Thirdly, for motor tasks, the presence of tactile feedback may interfere with the normal motion of the hand and pen and compromise performance. For example, continuous vibrations may affect the stability of a stylus causing lower trajectory accuracy.

Here, we propose error feedback that is triggered only when the user's performance moves in the wrong direction or area. Highways are designed so that, if a car moves too close to the edge of the road, changes in the texture of the road give continuous feedback in the form of sound and/or vibrations. This is used to good effect to warn drivers who unintentionally drift between lanes. We observed that, in contrast to the affirmative feedback studies mentioned above, there has been relatively little research on the effects of other types of error feedback.

In this paper, we review related work and then an experiment is reported which investigates the effects of multimodal feedback on human performance in steering tasks. Several parameters are measured to evaluate accuracy and speed. We conclude with a discussion of our results, implications for feedback design and directions for future work.

2 Related Work

A high demand for visual attention is imposed on computer users. This not only causes fatigue, it also prohibits the performance of secondary activities. The increasing requirement to present a large amount of information to the user also challenges the capacity and effectiveness of the visual modality. It becomes necessary to expand the interaction bandwidth by introducing alternative or additional sensory modalities, and many devices [15, 16, 18-21, 23] have been developed to enable this. For example, Luk et al. [15] created a handheld display platform to provide tactile feedback for users. EarPod [23] enables eyes-free menu selection with the help of reactive auditory feedback, and its performance is comparable to traditional visual techniques in terms of both speed and accuracy. Poupyrev et al. [20, 21] applied tactile feedback not only to desktop computing but also to mobile devices. Liao et al. [15] developed a pen with multimodal pen-top feedback, which effectively helped users detect errors early and provided support for interface discovery.

Akamatsu et al. [4] used a multi-modal mouse to confirm that the cursor was on a target during pointing tasks. Although the overall response times didn't change, final positioning time with tactile feedback improved significantly. In another paper, Akamatsu et al. [5] concluded that tactile feedback could reduce selection times. Tactile and force feedback improved performance when the interface contained small targets. Jacko et al. [11, 12] conducted a series of experiments to examine the effects of multimodal feedback on the performance of senior adults whose visual health varies a lot. Multimodal feedback was triggered when a file icon was correctly positioned. In drag-and-drop tasks, non-visual and multimodal feedback demonstrated significant performance gains over sole visual feedback for both Age-Related Macular Degeneration (AMD) and normally sighted senior users.

Five different task activities were analyzed in a meta-analysis. Burke et al. [7] compared the effects of uni-modal and bi-modal feedback on user performance. The effects of workload, and the number of tasks were considered. Error rate, performance score, and reaction time were analyzed. The results showed that bi-modal feedback improved performance and reduced reaction times, however it had little effect on error rates.

To investigate the effect of force feedback in steering tasks, Dennerlein et al. [9] used a mouse that employed a force to pull the cursor to the center of the tunnel. Results showed that force feedback improved movement times by 52%. A combined steering and targeting task, navigating through a tunnel and then clicking on a target, also showed that force feedback can reduce times to complete such a task. In order to investigate the interaction between the tactile and visual modalities, Campbell and Zhai [8] used an IBM Trackpoint mounted with an actuator and put virtual bumps in the tunnel. When the cursor entered or left a bump, a tactile pulse was triggered to guide the user through the tunnel. They concluded that user performance was enhanced by tactile feedback and that it is important to ensure that the visual feedback corresponds to the tactile feedback.

In summary, our literature review indicates that little work has been done on the study of the relationship between the modalities of error feedback and user performance in steering tasks. This study offers an important basic understanding in this field of HCI literature.

3 Pilot Study

We conducted a pilot study with eight participants and expected to determine suitable feedback parameters for the experiment. A pen with an attached motor was used in the experiment. We wanted to determine the input voltage that would provide maximum comfort and effectiveness for users. Different input voltages (2.0~3.6V) supplied to the motor, which mapped to different amplitudes of vibration, were chosen as input parameters. During the pilot study no participants complained that the vibration was significantly disturbing. After summarizing the experiment results and subjective evaluations, most of the participants preferred tactile feedback supplied at 3V. Audio feedback is also discussed. Firstly, we chose the Windows XP Error sound found in the Windows XP Operating System. However, some participants complained that the sound was too loud. We changed it to the sound of Windows XP Notify. Visual feedback was in the form of color change. The results gave us the required data to choose appropriate parameter values for our experiment.

4 Experiment

4.1 Apparatus

The experiment was conducted on an IBM ThinkPad X41 Tablet PC, running Windows XP and using a stylus as the input device. The screen size was 12.1-inches with a resolution of 1024×768 pixels. The experimental software was developed with Java. In order to supply tactile feedback, a vibration motor (2.0 volts to 3.6 volts, SE-4F-A3A1-X0, manufactured by Shicoh Engineering Co., Ltd. Japan) was mounted on the stylus. The size of the motor was 4 × 10.9 mm. The rated speed was 8400rpm. We used adhesive tape to attach the motor to the tail of the stylus, 2 cm from the end. The stylus was about 13 cm long in total. This product was a brushless and geared motor supplied with 3.0Vdc as determined in the pilot study. The electrical signal was supplied by an AD/DA converter card (CSI-360116, manufactured by Interface Co., Ltd. in Japan) and was controlled by the Tablet PC. The motorized pen [14] is shown in Figure 1.

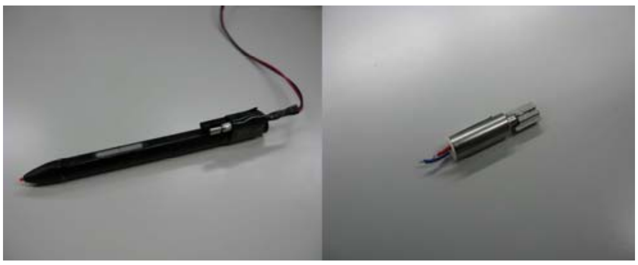

Figure 1. stylus with an attached motor and the motor

4.2 Participants

Twelve right-handed university students (10 males, 2 females, aged from 21 to 32 years) participated in the experiment. All participants had normal or corrected to normal vision and reported that they each had normal hearing. Eleven of the participants had previous experience using a stylus. All of them had medium-to expert level computer experience.

4.3 Task & Procedure

There are two kinds of traditional steering task. In general, straight steering represents linear movement and circular steering represents non-linear movement. Our experiment uses a steering task through a circular tunnel (Figure 2). The circular steering task is more complex than the linear movement task. For a circular tunnel, the movement amplitude *A* is equal to the circle's circumference $2\pi R$, where *R* is the radius. According to the steering law [1] developed by Accot and Zhai, the index of difficulty for steering through a circular tunnel is $ID = 2\pi R/W$. The task completion time *MT* can then be expressed in the formula: $MT = a + b\ ID$, where *a* and *b* are empirically determined constants.

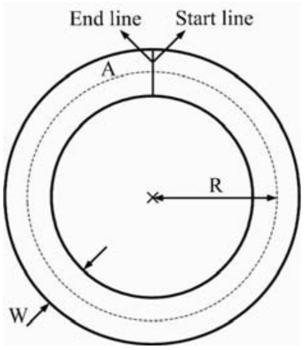

Figure 2. Experimental task

If the stylus moved out of the boundaries of the tunnel during the task, feedback is presented to the user to indicate an error. We used three modalities for error feedback: visual, auditory, and tactile. Visual feedback turned the steered trajectory (trail) to red when an error occurred. Auditory feedback was a notifying sound that played repeatedly. Tactile feedback was supplied by the vibration of the motor. In all three cases, the error feedback continued until the stylus returned to the tunnel. We also included a baseline condition where there is no feedback.

The direction of the circular steering task was always clockwise. At the beginning of each trial, the tunnel was displayed in the center of the screen. Once the stylus crossed the start line, the color of the drawn trajectory turned from green to blue as a signal that the task had begun. The user then steered the stylus through the circular tunnel. The trial ended once the cursor crossed the end line. Then the next trial was presented.

Before the experiment, the task was explained to the participants and they were asked to perform some warm-up trials in each operational bias until they were familiar with both the steering task and the different kinds of feedback and felt that they could begin the experiments. Participants could adjust the volume of auditory feedback themselves. Seated participants were instructed to perform the tasks as fast and as accurately as possible. Participants were allowed to have a rest between trials.

We measured the movement time *MT* (time taken to move from the start line to the end line). To measure the accuracy of the trajectory produced, we calculated its lateral standard deviation *SD* (standard deviation of the distances between trajectory points and the center of the circular tunnel) and out of path movement *OPM* (percentage of trajectory points outside the tunnel boundary). For both *SD* and *OPM*, higher values indicate lower accuracies. In this paper, we use the OPM to measure the out of path movement. OPM is the percentage of trajectory points outside the tunnel boundary. This metric was previously used by Kulikov et al. [13] and it was defined as "OPM (Out of Path Movement, percentage of sample points outside the Constraint lines). For example, if 100 points were sampled and 14 of those points were outside the Constraint lines, then OPM would be 14".

4.4 Design

We used a fully crossed within-subject factorial design. The independent variables were: *tunnel width W* (12, 20, 30, 40, 50, 60 pixels), *tunnel amplitude* (300, 600, and 800 pixels), and *feedback type* (no feedback (NONE), auditory (A), tactile (T), visual (V), auditory + visual (AV), visual + tactile (VT), auditory + tactile (AT), auditory + visual + tactile (AVT)). Each participant performed the experiment using all 8 feedback types in sequence. The presentation orders of the feedback types were counterbalanced across participants.

All participants conducted the experiment in sitting postures. Within each *feedback type*, the participant performed all combinations of *tunnel widths* and *tunnel amplitudes* presented in random order, each for 3 trials.

In summary, the experiment consisted of:

12 participants ×
8 feedback types ×
6 tunnel widths ×
3 trials ×
3 tunnel amplitudes ×
= 5184 times in total.

The experiment took approximately 30 minutes per participant. After the experiment, participants completed a questionnaire to rate their subjective preferences for the feedback types.

4.5 Hypotheses

H1. Feedback type will affect movement time, especially when the task is difficult.

H2. Feedback type will affect accuracy.

H3. Tactile feedback outperforms other individual feedback modalities.

5 Results

Repeated measures of analyses of variance were used to assess the effects of multimodal error feedback (eight kinds) on movement time, standard deviation and out of path movement.

5.1 Movement Time (MT)

Repeated measures ANOVA showed that there was no significant effect ($F_{7, 77} = 0.575$, $p = 0.774$) from *feedback type* on the movement time *MT*. The index of difficulty ($ID = 2\pi R/W$) for the tasks had a significant main effect ($F_{14, 154} = 91.666$, $p < 0.001$), with higher *ID* corresponding to longer *MT*. There was no significant interaction effect from *feedback type* × *ID* ($F_{98, 1078} = 1.118$, $p = 0.212$). The overall means for *MT* were 1567, 1657, 1600, 1601, 1588, 1582, 1595, and 1619ms for the NONE, A, T, V, AV, VT, AT, and AVT feedback (Figure 2). The movement time with NONE feedback was the shortest among these feedback types.

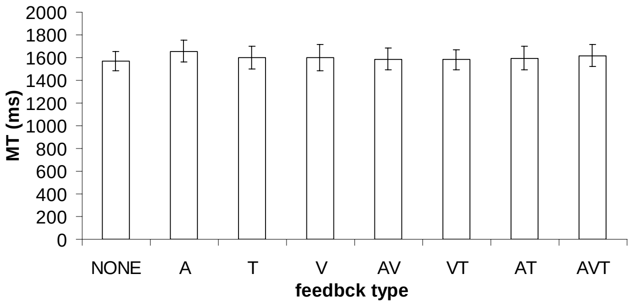

Figure 3. Mean *MT* by different feedback types (with standard error bars)

The regression analyzes on *MT* and *ID* indicated that they followed a linear relationship with each *feedback type*, as predicted by the steering law ($R^2 > 0.97$ in all cases).

5.2 Standard Deviation (SD)

The overall mean of *SD* is 4.62 pixels. The main effect of *feedback type* was statistically significant ($F_{7,\ 77} = 2.148$, $p = 0.048$) on *SD*. There was also a significant effect ($F_{14,\ 154} = 110.050$, $p < 0.001$) of *ID* on *SD*. There was no significant interaction effect from *feedback type* × *ID* ($F_{98,\ 1078} = 0.876$, $p = 0.796$). Pair-wise comparison tests showed that there was no significant difference in *SD* between A and T, or between AV and V. A and T produced the lowest *SD*, and AV and V produced the highest *SD*. The baseline performance with NONE feedback was between these two extremes, however this difference was not statistically significant.

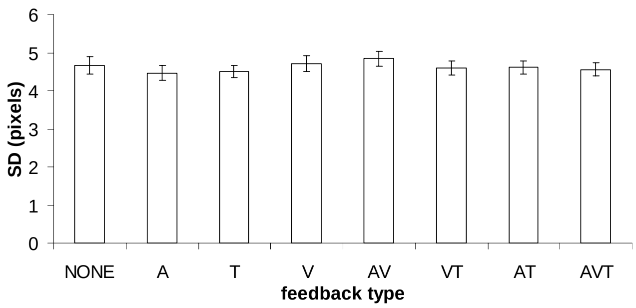

Figure 4. Mean *SD* with different feedback types

5.3 Out of Path Movement (OPM)

The overall mean of *OPM* was 2.35%. The main effect of *feedback type* was statistically significant ($F_{7,\ 77} = 3.458$, $p = 0.003$) on *OPM*. There was also a significant effect ($F_{14,\ 154} = 13.942$, $p < 0.001$) of *ID* on *OPM*. There was no significant interaction from *feedback type* × *ID* ($F_{98,\ 1078} = 1.034$, $p = 0.395$). Pair-wise comparison tests showed that there was no significant difference in *OPM* between AVT and T, or between NONE, V, AV and VT. AVT and T produced the lowest *OPM*, and NONE, V, AV and VT produced the highest *OPM*.

Summarizing the experimental data, we showed that different modalities of feedback significantly affected human performance in steering tasks in terms of accuracy but not in terms of completion time. From the results of *OPM* and *SD*, we concluded that users performed the task most accurately with tactile (T) feedback, and least accurately with AV (auditory + visual) and V (visual) feedback.

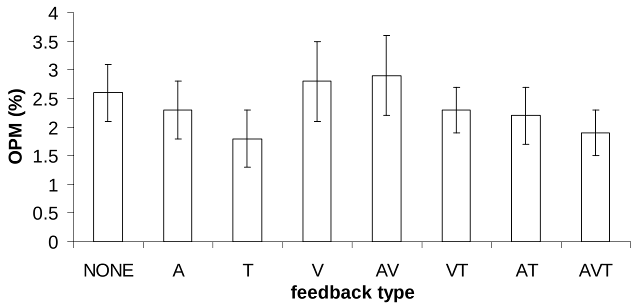

Figure 5. Mean *OPM* with different feedback types

5.4 Subjective Evaluation

According to the results of the questionnaire, the majority of participants (8/12) preferred AV feedback to indicate an error condition. The reason is that “hearing the sound feels comfortable and gives a clear warning. Compared to sole auditory feedback, the additional visual modality makes cursor movement more accurate”. Some participants (7/12) disliked tactile feedback because “vibration from the motor disturbed the movement of the pen-tip”, but, one participant highly praised the direct and active response delivered by tactile feedback. Some participants (7/12) disliked AT and AVT feedback, because they felt “the combination of auditory feedback and tactile feedback confused them”.

5.5 Steering Law analysis

Each of the feedback modalities fit the steering model with correlations greater than 0.97. As mentioned before, there was no significant effect from *feedback type* on the movement time *MT*. The indexes of performance ($IP = 1/b$) for different feedback types are similar.

Table 1. Steering law models with different feedback

Feedback	Steering law model	r^2
NONE	MT = 64.7 ID + 87.5	0.98
A	MT = 64.7 ID + 177	0.99
T	MT = 67.9 ID + 47.7	0.98
V	MT = 67.3 ID + 61.8	0.98
AV	MT = 68.3 ID + 26.2	0.97
VT	MT = 67.8 ID + 32.1	0.98
AT	MT = 64 ID + 130.3	0.99
AVT	MT = 68.8 ID + 45.6	0.98

6 Discussion

In the experiment, the analysis of *SD* and *OPM* shows that feedback type affects accuracy significantly. Tactile error feedback outperforms the other error feedback types in steering tasks. In contrast to H1, no significant effect of *feedback type* on *MT* was found. However, Forlines and Balakrishnan [10] found that *feedback type* did have a significant effect on completion time in their study on pointing and crossing tasks. Although Akamatsu et al. [5] concluded the effect is more pronounced for small targets for the tactile condition, we cannot draw the same conclusion from the results of our experiment. These observations could be explained by their different usage of feedback. They used feedback as an affirmation, e.g., notifying the user when the tip of the cursor was on a target. Therefore the feedback was always in effect in every trial. By contrast, in our study we used feedback as an alarm to indicate errors. There are two possibilities in extreme cases. Firstly, if the tunnel is wide enough, no error occurs during the trial and no feedback was presented. Secondly, if the tunnel is too narrow, error activated feedback is very similar to “affirming” feedback. In summary, feedback type was irrelevant to the overall temporal performance in most cases.

On the other hand, feedback directly contributed to the reduction of errors in the task, therefore, feedback type has a significant effect on performance accuracy, and thus H2 is confirmed. Comprehensive analysis of OPM and SD confirms that tactile feedback outperforms all other feedback types, both single and combined, with almost the same accuracy, thus confirming hypothesis H3. This phenomenon may also be explained from the following point. We used a direct input device in this study. Visual feedback is more or less unavailable when the target is covered by the hand or stylus (this particularly relates to the sitting posture and writing posture). Compared with audio feedback, tactile feedback is a real-time interactive modality. It transforms information through skin displacement both in space and time, while audio feedback is transmitted though the air and has some delay.

An interesting observation is the apparent disparity between the actual performance of the users and the subjective preferences of the users. The majority of participants felt that tactile feedback disturbed the movement of the pen-tip. In order to avoid triggering unwanted vibrations that might distract their attention, they performed the task more carefully. As a result, they achieved the highest level of accuracy. Visual feedback does not impact the user forcefully and is the easiest to ignore. This may be the reason the lowest levels of accuracy are produced by the AV and V feedback. This tradeoff between performance and comfort may guide us to choose the most suitable form of feedback in different scenarios. In addition, the different human response times for different sensory channels (with tactile being the fastest [22], while visual and auditory having more considerable delay) may have also contributed to the performance difference.

Considering these points, we suggest that error feedback mechanisms, as investigated in this paper, might be the most suitable applications for tactile feedback, where the feedback is presented intermittently to indicate abnormal situations rather than continuously to indicate normal situations. The results of our experiment confirmed the suitability of the tactile modality for this purpose, especially in the context of a steering task. Accot and Zhai [1, 2] gave some examples of steering tasks. For example, drawing, writing, and steering in 3D space. Error feedback can be widely used to improve the performance of these tasks, or used as a training tool such as to teach handwriting.

In calligraphy practice scenarios, children are often taught how to write beautiful characters. Tracing paper with standard sharp letters is used; this is a kind of visual feedback. Traditionally after tracing the characters, children will be given comments by teachers, indicating where they should be careful next time writing the character. This post hoc feedback can prove inefficient sometimes. In order to get a better effect, we can apply real-time tactile feedback on the pen, when the pen tip is out of the printed trajectory. In addition, we may create a “pre-warning” buffer area in which to remind users before a mistake is made. Given this potential, it is important to have a detailed understanding of different error feedback modalities to inform future designers. Applications may include not only regular computer interaction tasks, but also real world activities such as driving safety systems, rectification systems for handwriting, and 3D applications. Conversely, the less intense and less disruptive visual modality might be reserved for continuous affirmative feedback, to complement tactile and auditory channels.

7 Conclusion and Future Work

Different tasks, workloads and feedback types in different forms may affect user performance. In this work, we conducted an experiment to investigate the effects of different modalities on error feedback in steering tasks. The results show that users perform most accurately with tactile error feedback. Our work provides insights and implications for the future design of multimodal error feedback mechanisms. In the future, we want to study the effects of the forms and strengths of auditory and tactile feedback, as well as expanding our investigation to other fundamental interaction tasks. Perception response times (PRT) increase significantly with age. We also want to investigate the age effect which is an important factor affecting performance with multimodal feedback.

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References

1. Accot, J., and Zhai, S. Beyond Fitts’ Law: Models for Trajectory-Based HCI Tasks. *Proceedings of the SIGCHI conference on Human factors in computing systems*, ACM Press (1997), pp. 295-302.
2. Accot, J., and Zhai, S. Performance evaluation of input devices in trajectory-based tasks: an application of the steering law, *Proceedings of the SIGCHI conference on*

Human factors in computing systems, ACM Press (1999), pp. 466-472, Pittsburgh, Pennsylvania, USA.

3. Accot, J. and Zhai, S. More than dotting the i's -foundations for crossing-based interfaces. *Proceedings of the SIGCHI conference on Human factors in computing systems*, ACM Press (2002), pp. 73-80.
4. Akamatsu, M., MacKenzie, S., and Hasbrouc, T. A comparison of tactile, auditory, and visual feedback in a pointing task using a mouse-type device. *Ergonomics*, 38(4), (1995), pp. 815-827.
5. Akamatsu, M., and MacKenzie, S. Movement characteristics using a mouse with tactile and force feedback. *International Journal Human-Computer Studie*s, 45(4), (1996), pp. 483-493.
6. Apelle, S., Haptic perception of form: activity and stimulus attributes, *The psychology of touch*, M. Heller and W. Schiff, Editors. Lawrence Erlbaum: Hillsdale, NJ. (1991), pp. 169-188.
7. Burke, J.L., Prewett, M.S., Gray, A.A., Yang, L., Stilson, F.R.B., and Coovert, M.D. Comparing the Effects of Visual-Auditory and Visual-Tactile Feedback on User Performance: A Meta-analysis. *The 8th International Conference on Multimodal Interfaces*, (2006), pp. 108-117, Banff, Alberta, Canada.
8. Campbell, C.S., Zhai, S., May, K.W., and Maglio, P.P. What You Feel Must Be What You See: Adding Tactile Feedback to the Trackpoint. *Proceedings of INTERACT 99*, (1999), 383-390.
9. Dennerlein, J. T., Martin, D. B., and Hasser, C. 2000. Force-feedback improves performance for steering and combined steering-targeting tasks. *In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM Press (2000), pp. 423-429, New York, USA.
10. Forlines, C., and Balakrishnan, R. Evaluating tactile feedback and direct vs. indirect stylus input in pointing and crossing selection tasks. *In ACM Conference on Human Factors in Computing Systems*, ACM Press (2008), pp. 1563-1572, New York, USA.
11. Jacko, J.A., Barnard, L., Kongnakorn, T., Moloney, K.P., Edwards, P.J., Emery, V.K., and Sainfort, F. Isolating the effects of visual impairment: exploring the effect of AMD on the utility of multimodal feedback, *Proceedings of the SIGCHI conference on Human factors in computing systems*, (2004), 311-318, Vienna, Austria.
12. Jacko, J.A., Scott, I.U., Sainfort, F., Barnard, L., Edwards, P.J., Emery, V.K., Kongnakorn, T., Moloney, K.P. and Zorich, B.S., Older adults and visual impairment: What do exposure times and accuracy tell us about performance gains associated with multimodal feedback? *In ACM Conference on Human Factors in Computing Systems*, ACM Press (2003), pp. 33-40.
13. Kulikov, S., MacKenzie, I.S., and Stuerzlinger, W. Measuring the effective parameters of steering motions, *CHI '05 extended abstracts on Human factors in computing systems*, (2005), pp. 1569-1572, Portland, OR, USA.
14. Lee, C.J., H.P. Dietz, D. Leigh, S.W. Yerazunis, and E.S. Hudson. Haptic pen: a tactile feedback stylus for touch screens. *ACM UIST Symposium on User Interface Software and Technology*, (2004), pp. 291-294.
15. Liao, C., Guimbretiere, F., and Loeckenhoff, C. Pentop feedback for paper-based interfaces. *ACM UIST Symposium on User Interface Software and Technology*, (2006), pp. 201-210.
16. Luk, J., Pasquero, J., Little, J., MacLean, K., Levesque, V., and Hayward, V. A role for haptics in mobile interaction: initial design using a handheld tactile display prototype. *ACM CHI Conference on Human Factors in Computing Systems*, (2006), 171-180.
17. Mackenzie, I. S. Movement time prediction in human-computer interfaces, *Proceedings of Graphics Interface '92*, (1992), pp. 140-150, Toronto: Canadian Information Processing Society.
18. MacLean, K.E., and Enriquez, M. Perceptual Design of Haptic Icons. In Proc. *EuroHaptics 2003*, (2003), pp. 351-363.
19. Morris, D., and Joshi, N. Alternative ‘Vision’: A Haptic and Auditory Assistive Device. *Proceedings of the SIGCHI conference on Human factors in computing systems*, ACM Press (2003), pp. 966-967.
20. Poupyrev, I., M. Okabe, and S. Maruyama. Haptic Feedback for Pen Computing: Directions and Strategies. *Proceedings of the SIGCHI conference on Human factors in computing systems*, ACM Press (2004), pp. 1309-1310.
21. Poupyrev, I., and S. Maruyama. Tactile interfaces for small touch screens. *ACM UIST Symposium on User Interface Software and Technology*, (2003), pp. 217-220.
22. Sklar, A. E., and Sarter, N. B. Good Vibrations: Tactile feedback in support of attention allocation and human-automation coordination in event-driven domains. *Human Factor*, 41(4), (1999), pp. 543-552.
23. Zhao, S.D., Dragicevic, P., Chignell, M.,Balakrishnan, R., and Baudisch, P. Earpod: eyes-free menu selection using touch input and reactive audio feedback. *Proceedings of the SIGCHI conference on Human factors in computing systems*, (2007), pp. 1395-1404.