

# The Value of Haptics

*A summary of recent published findings on the value of haptic feedback in human-computer interaction*



## Introduction

Once found only in offices, computers are now in every conceivable device: mobile phones, cash registers, automatic teller machines, cars, and even household appliances. They provide significant advances in productivity, but because they're now used in so many settings without the benefit of a mouse and keyboard, they can exhibit unprecedented interface design complexity.

A key advantage of computer-driven interfaces is the flexibility provided by a programmable, dynamic display. A single touch panel can replace many mechanical buttons, switches, and knobs, and provide increased communication with the user. But the transition from mechanical knobs, switches, and dials to electronic controls poses a challenge to interface designers: the expected tactile cues aren't there.

As the scientific studies reviewed here indicate, haptic (tactile) feedback provides several benefits, not the least of which is, according to research performed by NCR (NCR 2004), that it provides an essential component in human-computer interaction (HCI) and has a quantifiable effect on efficiency and error rates as well as user satisfaction.



Recently introduced mobile phones, such as the Apple iPhone, Samsung SCH-W559, and the Prada phone by LG, are good examples of a device type previously designed with more than 12 mechanical buttons—but that is now being designed with very few buttons and a touch-sensitive screen capable of displaying a wide variety of button configurations.

## Types of Haptic Feedback

Haptic feedback can be broadly divided into two modalities: vibrotactile and kinesthetic. Vibrotactile feedback stimulates human subcutaneous tissue. It's been employed in mobile phones, video console gamepads, and certain touch panels. Kinesthetic feedback focuses on the gross movement of the human body. It's been employed in medical simulation trainers, programmable haptic knobs, video game steering wheels, and virtual reality systems, such as Immersion's CyberForce® system. "Force feedback" is a term often used to describe vibrotactile and/or kinesthetic feedback.



Haptic stimulation supplies access to an important and often overlooked information channel in human-computer interaction (HCI). Although vision accounts for the majority of sensory input—as much as 90%, according to Mauter and Katzki (Mauter and Katzki 2003)—the sense of touch is also a common information source. Tactile feedback lets us tap someone on the shoulder, find the radio dial in a car without looking, play a musical instrument, and know when fingers are correctly placed on a QWERTY keyboard because of the bumps on the F and J keys.

This paper categorizes the published findings on haptic feedback as it relates to HCI as follows:

**Quantitative Task Performance.** In a laboratory setting, it is possible to directly measure the performance gains associated with haptic feedback. Presented here are several scientific studies that used objective performance measures to directly evaluate tactile feedback interfaces for task execution time, error rate, and overall human-computer communication capacity.

**Absence of Tactile Feedback.** Researchers have investigated how removing tactile feedback—something that commonly occurs when mechanical or electromechanical controls are replaced with electronics—affects user performance.

**Multimodal Feedback.** Several publications document performance gains when haptic feedback is combined with sight and sound.

**User Satisfaction.** A common observation in many objective studies is that users prefer haptic interfaces over non-haptic ones, even when there is no measurable performance increase.

**Non-visual Interaction.** Findings from several studies show that a key advantage of haptic interfaces over non-haptic ones is that users can effectively communicate with a computer without visual feedback. This advantage applies in many scenarios and also provides an

enabling mechanism for users with limited or no vision.

**Other Benefits.** As a unique bi-directional communications channel, tactile feedback provides benefits that also include important user interface paradigms that are either impossible or extremely difficult to produce without it.

## Quantitative Task Performance

Various quantitative measures can be used to evaluate and compare the effectiveness of HCIs. P.M. Fitts (Fitts 1954) proposed an information-based methodology that has become a standard for evaluating peripherals such as mice and keyboards. His research investigated the movement time associated with a peg-in-hole task (put a peg in a hole) when mediated by an interface device. The modern equivalent of peg-in-hole is drag-and-drop, a popular graphical user interface (GUI) metaphor. The Fitts approach to measuring user interface performance is so prevalent that it has been codified as an international standard, ISO 9241-9, which describes three task performance measures:

- **Movement Time:** The mean time in seconds for a specified task, for example, drag-and-drop
- **Error Rate:** A measure of the fraction of incorrect selections
- **Throughput:** A composite measure that captures the volume of information flow associated with the interface

Research that uses the Fitts analysis method to objectively evaluate tactile feedback in HCI includes the following:

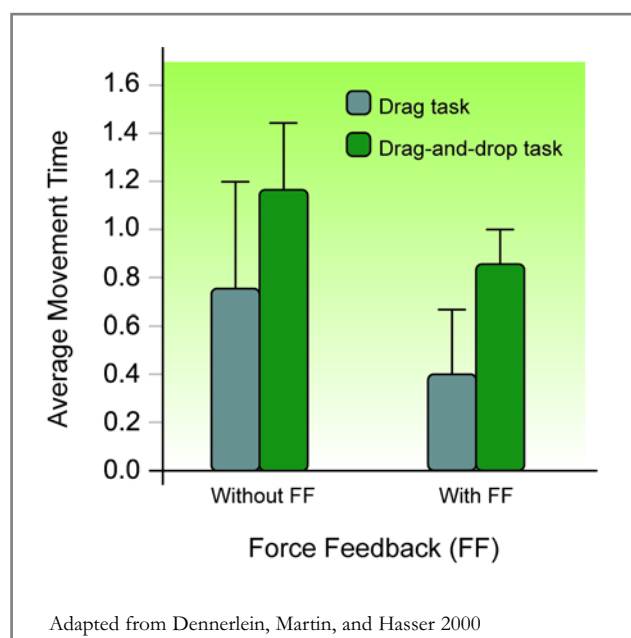
Dennerlein, Martin, and Hasser (Dennerlein, Martin, and Hasser 2000) studied how a force feedback mouse could improve the movement time performance of two common interactions on a Windows-based GUI. In testing, the user task included a force field that helped users stay on a line and target locations more accurately and quickly. The report documents a 52% improvement in movement time for a drag task and 25% improvement time for a combined drag-and-drop task when force feedback is enabled.

Additional research by Hasser and others (Hasser et al 1998) and Hwang and others (Hwang et al 2003) reinforces the Dennerlein, Martin, and Hasser 2000 findings. Results reported in the Hwang study are of particular note because they intro-

duce the concept of multiple targets, and testing was performed with motion-impaired, physically disabled users. Findings indicate that haptic feedback provides the greatest performance improvement for users who are the most disabled.

Other investigators have studied whether the specific type of haptic sensation has a significant impact on performance during Fitts-type tasks. This research is important because many interfaces with tactile feedback use the modality simply to convey warnings or other binary notifications (for example, a pager motor uses vibrotactile feedback to convey a single bit of information).

A good example is the work of Doshier and Hannaford (Doshier and Hannaford 2005) who developed a fingertip tactile display and presented users with vibrotactile haptic effects that varied in amplitude, wave shape, and duration during interaction with haptic icons. The authors report that observed throughput was positively correlated with tactile effect amplitude, with bit rate improvements of as high as 50%. They also report that rough feedback has a lower threshold of detection than smooth feedback. These findings indicate that tactile feedback can convey significant quantities of information and use does not need to be confined to simple notifications.



## Absence of Tactile Feedback

Other researchers have investigated the question of how removing tactile feedback affects user performance. This question is of particular interest in the area of touch-panel technologies, which are rapidly replacing mechanical key interfaces in a variety of HCI applications.

Several authors in the early and mid 1980s compared error rates and typing performance between mechanical keyboards and membrane keypads. Membrane keypads have no kinesthetic travel, but do provide tactile feedback in the form of raised key edges. Roe and colleagues (Roe, Muto, and Blake 1984) and Loeb (Loeb 1983) found that skilled touch-typists recovered their throughput (error rate and typing speed) on a membrane keypad after some learning. However for non-skilled typists, there was no learning effect and these typists remained consistently less efficient on the membrane keypad than on the mechanical one.

An extensive study of the value of auditory feedback on typing throughput for flat touchscreens was carried out by Bender (Bender 1999). Conducting detailed user studies, he examined the effects of auditory feedback duration and key size. Findings included that auditory feedback alone could not recover performance losses associated with movement time (time to move between keys) and contact time (time spent in contact with each key). However, auditory feedback did reduce error rates, especially for small key sizes. Bender concluded that for touchscreens that do not provide tactile feedback, it is important to provide some type of auditory feedback and to make keys as large as possible.

A more relevant issue for tactile feedback on modern touch surfaces is the difference in input performance between a mechanical keyboard and a touchscreen for high throughput tasks. This question was studied by Barrett and Krueger (Barrett and Krueger 1994), who compared the typing performance of both skilled and unskilled operators on both a mechanical and a touchscreen keyboard.

Their study took care to identify learning effects associated with the touchscreen by having the same subjects repeat a basic typing task five days in a row. The authors analyzed the inter-key duration, as well as the number of corrected and uncorrected errors, to arrive at an error-adjusted throughput measure for both keyboards for each day of the study. It was determined that non-expert users learned to operate the touchscreen over the course of the study, but by the fifth day, still had a 10–15% throughput advantage when using the mechanical keyboard vs. the touchscreen.



For expert users, there was no observed learning effect, and in fact these operators maintained a mechanical keyboard throughput advantage of approximately 50% during the study. This result and the results from Loeb and from Roe, Muto, and Blake indicate that tactile feedback is an essential feature of high performance keyboard input.

## Multimodal Feedback

Tactile feedback is just one of three important senses used in HCI; visual and auditory feedback are both far more common. In the context of multimodal feedback (using more than one sense), haptics has been shown to complement sight and sound, providing additive gains in objective task measures.



A multimodal system developed by Akamatsu, Sato, and MacKenzie (Akamatsu, Sato, and MacKenzie 1994) provided vibrotactile and auditory feedback to users during a Fitts-type drag-and-drop task. The authors report small performance improvements due to bimodal (audio and visual or tactile and visual) and trimodal (audio, tactile, and visual) over visual feedback alone.

Multimodal feedback is often cited as an enabling technology for users with low vision or other sensory disability. A detailed study conducted at the Bascom Palmer Eye Institute in conjunction with the Georgia Institute of Technology (Jacko et al 2003) compared the Fitts-type performance improvement of multimodal feedback for normal users to users with macular degeneration. The study found that, in all cases, unimodal auditory or tactile feedback and multimodal auditory and tactile feedback increased task performance for subjects with 20/20 vision (the control group). Other groups with vision ranging from 20/20 to better than 20/100 received significant benefit from any non-visual feedback (auditory or tactile) but also registered significant gains for bimodal and trimodal feedback.

Another feedback strategy is to substitute one sensory channel for another. For example, a tactile cue could provide users with information about a remote sensor or event. Debus and others (Debus et al 2001) developed a sensory substitution interface for a telerobotic task that could provide kinesthetic and/or vibrotactile feedback to the operator. The feedback provided was based on a force sensor on a remote robot arm that indicated to the operators how close they were to a target force level. The investigators reported that, relative to visual feedback alone, kinesthetic feedback reduced errors by 65%, vibrotactile feedback reduced errors by 38%, and the two combined reduced errors by 77%. These findings show that, although kinesthetic feedback can produce significant performance improvements, lower cost vibrotactile feedback also has value in increasing user task performance.

Cockburn and Brewster (Cockburn and Brewster 2005) examined the issue of multimodal feedback and target acquisition in a Fitts-type study. They compared the target acquisition performance of combinations of audio, tactile, and “pseudo-haptic” feedback. Using the simple

Windows interface, they slowed the cursor when it came near a target, resulting in a sticky interaction. They reported modest performance gains from audio and tactile feedback, similar to Akamatsu, Sato, and MacKenzie, and significant gains from sticky feedback. Additional gains were realized by combining the modalities, but the authors caution that engaging too many modalities in a non-complementary manner actually reduces task performance due to sensory noise.

## User Satisfaction

Research conducted by Immersion Corporation on both tactile feedback touch panels and on vibrotactile mobile phones indicates that, when users are given a choice between HCI with visual feedback and one with visual and tactile feedback, they express a strong preference for the latter. These results were reported along with similar work performed by Visteon (Serafin et al 2007).

Together, these studies demonstrate that, when users are shown both tactile and non-tactile automotive touch panel interfaces and asked to express a preference, the tactile display is strongly preferred. This may be because non-tactile interfaces do not provide the mechanical confirmation that most users expect when pressing a button.

In the mobile phone domain, work at Motorola (Chang and O’Sullivan 2005) investigated user preference for tactile feedback in conjunction with audio. Users were presented with two phones, one with audio-only feedback and one with bimodal audio-haptic feedback. The authors reported that of the 42 subjects, 35 indicated they prefer a mobile phone with haptic feedback over one without.

Recently published work by Brewster, Chohan, and Brown (Brewster, Chohan, and Brown 2007) examines the value of adding tactile feedback to a smartphone-type device to provide button press confirmation for text entry. Subjects were asked to enter a series of poems on the device in a laboratory setting and on a moving subway train. Corrected and uncorrected error rates indicated that the feedback provided some improvement in both situations. Subjects were also given a modified NASA TLX workload assessment for the train task in which they subjectively evaluated cognitive

loading with and without tactile feedback. Results indicated that subjects strongly preferred tactile feedback in every category, and further, that the presence of tactile feedback reduced their cognitive load.

The user preference studies cited above discuss feedback implementations that are non-invasive in that they provide users with information, but do not directly control user movements. In these scenarios, users typically perceive tactile feedback as providing additional information, confirmation, or other enhancement.

To understand if tactile feedback that forced users' motion would be as well received, Forsyth and MacLean (Forsyth and MacLean 2006) investigated the use of invasive kinesthetic feedback in a simulated driving task. In this study, subjects used a haptic knob as the primary steering interface in a driving simulation. Subjects were provided with either no feedback, path deviation feedback, or feedback that actively steered them as they approached corners. After performing several trials with each type of interface, users were asked about their preferences regarding the presence or absence of feedback and preferred type of feedback. Results showed that users not only preferred feedback overall, but that a majority of subjects felt more in control when actively guided by it.

## Non-visual Interaction

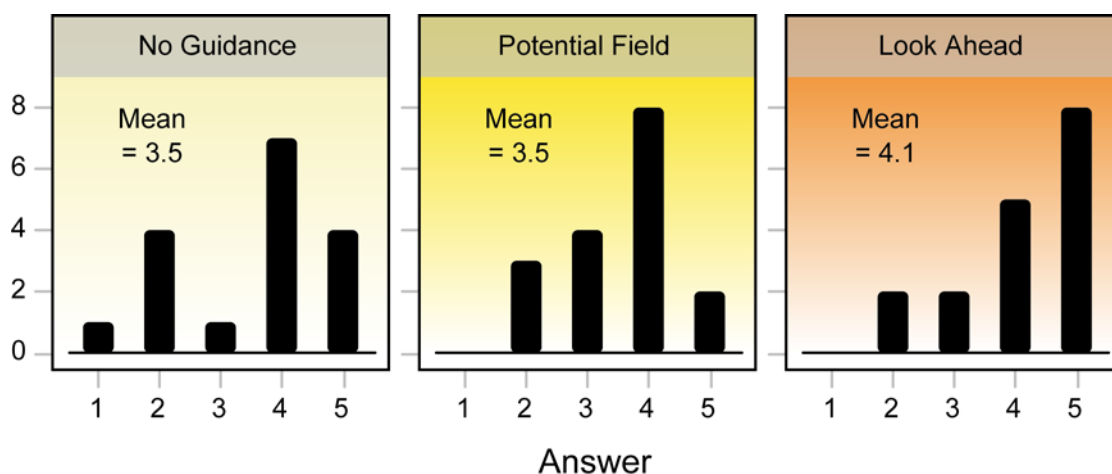
Haptic stimulation has several unique properties that make it ideal for communicating certain types of information:

- **Private information:** haptic feedback is silent, non-visual, and individually communicated (not broadcast)
- **Warnings or alerts:** haptic feedback can be distinctive and unanticipated, helping users to re-focus their attention
- **Confirmations:** haptic feedback can provide intuitive verification of an action

## Privacy

Numerous authors have proposed the use of tactile feedback as a basis for private, non-verbal communication. Sherrick (Sherrick 1991), Lindeman and others (Lindeman et al 2003), Tan and others (Tan et al 1999), and Van Erp and others (Van Erp et al 2005) have investigated the communication capacity of the tactile channel for complex messages in a completely non-visual, non-auditory setting.

Van Erp and colleagues (Van Erp et al 2005, and Van Veen and Van Erp 2001) present various investigations into the use of spatially distributed vibrotactile feedback to provide non-visual information to users while they



**Subject responses: What level of control did you feel you had over the vehicle? (1 = No Control 5 = Complete Control)**

Adapted from Forsyth and MacLean

execute other tasks. One of the goals of this research was to evaluate tactile feedback for use in providing private, low-cognitive load information to military and civilian first responders. The authors demonstrated that tactile feedback is useful and functional even under extreme 6 g-force loading conditions experienced during aerobatic maneuvers (Van Veen and Van Erp 2001). In another study (Van Erp et al 2005), subjects used information presented on a vibrotactile belt to navigate a series of waypoints while operating either a helicopter or a military watercraft. Subjectively, the results indicate that touch is a highly effective secondary communication channel that leaves the visual sense able to better attend to other control issues.



During investigation of the Tadoma non-visual, non-auditory communication method in which a deaf-blind person feels the movement of the lips and vibrations of the vocal cords, Tan and others (Tan et al 1999) developed a three-finger tactile feedback device suitable for Tadoma-like communication. They report that using only three amplitudes and three frequencies, equivalent performance to human Tadoma communication is possible. Findings show that a communication rate of 12 bps is not insignificant and easily supports rich non-verbal, non-visual communication. This work is consistent with other researchers investigating purely tactile communications. Brewster and Brown (Brewster and Brown 2004) for example, proposed a novel vibrotactile language whereas Van Erp and Spapé (Van Erp and Spapé 2003) showed that untrained subjects can distinguish among a variety of purely tactile melodies.

## Alerts

The notion of haptic feedback as a secondary or supplemental information source has been carefully

investigated by Lindeman and others (Lindeman et al 2003). The researchers asked subjects to locate a specific letter from a dynamically updated jumble of letters. Subjects were assisted by various visual and vibrotactile cues. Results indicate that visual cueing is dominant, providing a 30% average performance increase. However vibrotactile cueing also provided a 12% performance increase, making it a viable option if visual cueing is not

feasible, such as when the user is visually occupied. This finding is consistent with the work of Van Erp and others (Van Erp et al 2005) and demonstrates the value of tactile feedback as a useful means to refocus the user's attention.

Tactile feedback for secondary information was taken a step further by Poupyrev, Shigeaki, and Jun (Poupyrev, Shigeaki, and Jun 2002) and Poupyrev and

Shigeaki (Poupyrev and Shigeaki 2003), where the authors proposed that tactile feedback can function as a peripheral awareness interface as described by Buxton (Buxton 1995). The idea behind a peripheral awareness interface is to provide sensory stimulation on a subconscious or peripheral level, which leaves the user's primary focus on another task. These studies note that, in mobile contexts, users are often preoccupied with tasks such as walking, driving, or even participating in a business meeting, and that these scenarios provide the perfect context for non-visual tactile communication.

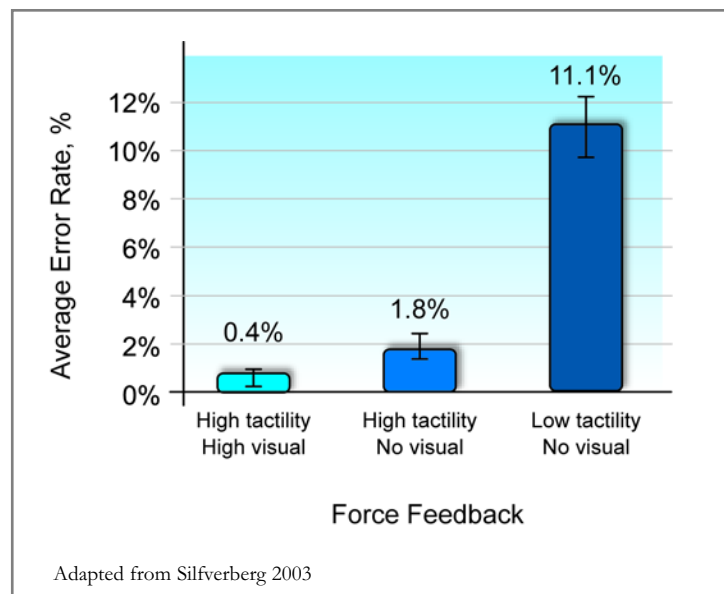
The authors investigated the advantage of this tactile feedback for a scrolling task on a PDA, a typical task performed by mobile users. Quantitatively, subjects performed on average 22% faster with tactile feedback. Users' subjective responses indicated that they preferred the tactile feedback device, not because of performance improvement, but because it was perceived to supply a better user experience.

## Confirmation

The use of tactile feedback in mobile devices has also been demonstrated by other researchers. Nashel and Razzaque (Nashel and Razzaque 2003) proposed providing button simulation using tactile feedback on touchscreen-based smartphones. They noted that such phones do not provide as satisfying a user experience without the mechanical feel of buttons (also often noted as a limitation of the forthcoming Apple iPhone)<sup>1, 2, 3</sup>. The idea of adding tactile feedback to mobile devices has been presented in the literature as early as 2001 by researchers at NTT DoCoMo (Fukumoto and Sugimura 2001), who distinguished between feedback felt by the hand that holds the device and feedback felt by the fingertip in contact with the screen. They noted that these two operating modalities each have their own benefits, depending on context.

Research published by Nokia (Silfverberg 2003) also reinforces the value of tactile feedback in mobile scenarios. In this work, subjects performed a numeric entry task on a mobile phone where each digit was prompted visually by a computer screen. Subjects performed the task with both a high tactility phone (rough mechanical buttons) and a low tactility phone (smooth mechanical buttons) with and without visual observation of the physical keypad. (Note that no programmable haptic feedback was involved in this study.) The results indicate that with direct visual information, the phone tactility made no statistical difference. However, in the absence of visual information, subjects were 25% slower and made over six times as many errors (see figure).

The commercial advantage of using tactile feedback as a non-visual confirmation is highlighted in a white paper produced by NCR Corporation (NCR 2004). NCR is a leading manufacturer of point of sale (POS) systems found in many retail locations including supermarkets and department stores. POS systems have been migrating to conventional touchscreen-based interfaces to provide dynamic displays capable of handling complex multilevel transactions. However NCR human factors researchers discovered that operator performance of touchscreen interfaces is lower than for mechanical interfaces for a variety of high-throughput transactions (for example, a supermarket check-out stand), resulting in a lower transaction rate. The researchers postulate that a key factor affecting this performance difference is the lack of tactile feedback in the conventional touchscreen-based solution.



<sup>1</sup> La Gesse, David. 2007. Touch-screens Lack That Keyboard Touch. U.S. News & World Report, February 8. [http://www.usnews.com/usnews/biztech/davesdownload/archive/070208/touchscreens\\_lack\\_that\\_keyboar.htm](http://www.usnews.com/usnews/biztech/davesdownload/archive/070208/touchscreens_lack_that_keyboar.htm)

<sup>2</sup> Lee, Nicole. 2007. Samsung SCH-W559: CNET editors' take. CNET, February 22. [http://reviews.cnet.com/Samsung\\_SCH\\_W559/4505-6454\\_7-32330269.html](http://reviews.cnet.com/Samsung_SCH_W559/4505-6454_7-32330269.html)

<sup>3</sup> Will Touchscreens Leave the Keys Behind? 2007. Cellular News, February 2. <http://www.cellular-news.com/story/21748.php>



## Other Benefits of Haptics

Beyond performance, user satisfaction, and communication of non-visual information, there are additional benefits associated with tactile feedback in HCI. These benefits are most clearly articulated by MacLean (MacLean 2000):

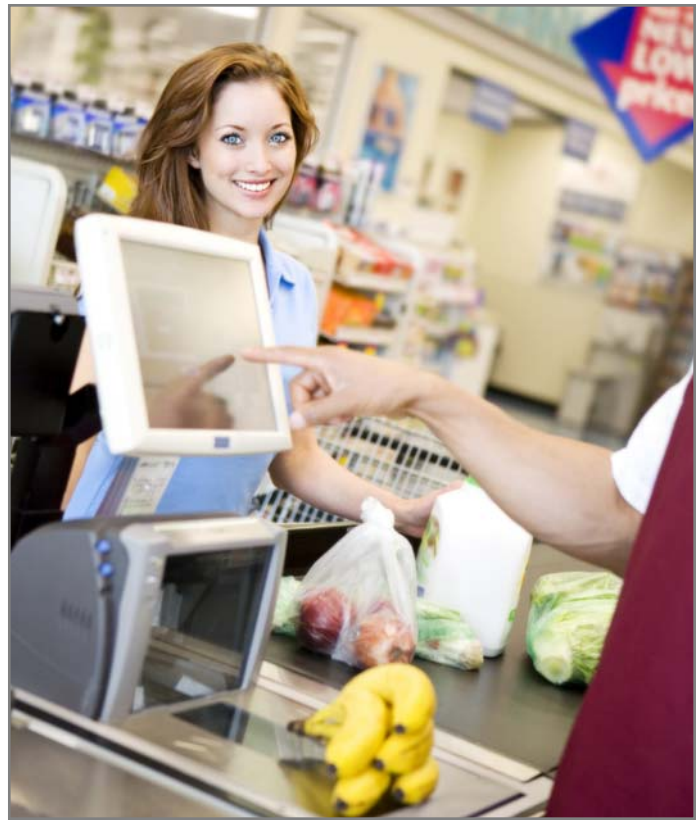
**Reconfigurability.** Computer-controlled tactile feedback is dynamic and can be easily adjusted to the user interaction state. Examples include modifying the number of detents on a knob to reflect different selection criteria or using dynamically configurable button arrays for POS systems.

**Continuous Control.** Tactile feedback provides immediate information to users during task execution, allowing them to modify their behavior to more effectively execute the task or to leverage the additional information for another purpose.

**Affective Computing.** Haptic feedback, because of its intimacy, can add missing social context in situations where typical feedback or social cues are absent. One example is a child's plush toy that responds to how it's being treated through use of an actuator (motor) that emits growling or purring vibrations.

**Comfort and Aesthetics.** In many interactions, tactile feedback is expected. When the interface does not provide it, users may become irritated or confused. Mauter and Katzki (Mauter and Katzki 2003) discuss this expectation related to automotive interfaces.

**Dealing with Complexity.** There are numerous situations where human task performance suffers due to overly complex procedures or visual sensory overload. Tactile feedback can help to offload the visual channel for the operator, reducing stress and improving efficiency.



## Summary

There are many scenarios where the addition of touch feedback provides high value as a private, bi-directional communication channel between a single user and a computer. The research presented in this white paper shows that tactile feedback can make users more efficient and also reduce their error rate and stress levels. The addition of tactile feedback also increases user satisfaction. In the author's view, tactile feedback is a tremendous and underused source of productivity gain for many applications within modern society.

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