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Effect of elastic touchscreen and input devices with different softness on user task performance and subjective satisfaction ☆

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ABSTRACT

This study explored the relationship between the softness of two output displays (glass and elastic surfaces) and three direct input devices (fingertip and two types of styli, with acrylic and rubber tips) in terms of user task performance and satisfaction in tapping tasks. In a within-subjects experiment, 44 participants were asked to play a touch-based game as quickly and accurately as possible across combinations of the two independent variables. After finishing tasks in each condition, they filled out an evaluation questionnaire regarding tactile satisfaction, which addressed perceived feeling of pressing down on the surface, pleasantness, helpfulness, finger fatigue, and degree of elasticity. The results of this experiment show a main effect of touchscreen type on task performance, whereas input device type shows main effects on both task performance and satisfaction. Measures of five key sub-factors of subjective satisfaction are explained, and the practical implications of these findings are discussed.

1. Introduction

To provide users with a pleasant tactile experience when using mobile touchscreen devices, designers and developers have considered sensory feedback and material properties (such as texture and hardness) as important factors in the design process (Klatzky and Lederman, 1992, 1993). With the widespread use of direct-touch mobile devices such as smartphones, tablet PCs, mobile handheld game consoles, and car navigation systems, users have accepted touch-based interactions with a stylus or the fingers as the natural method of handling such devices (Wintergerst et al., 2010). In general, the employment of haptic sensing and feedback delivered via vibrations and pressure can offer the benefit of alerting the user to critical events while gaining support for hand–eye coordination tasks (Biggs and Srinivasan, 2002; Mulgund et al., 2002; Hale and Stanney, 2004). A variety of mechanical vibrations with piezoelectric actuators, voice coils, and other actuators have been developed in designing tactile feedback for mobile touch surfaces (Fukumoto and Toshiaki, 2001; Poupyrev et al., 2002; Poupyrev and Maruyama, 2003). However, despite the rising popularity of touch-based devices, the lack of dynamic tactile feedback when pressing soft buttons rendered graphically on a hard-surface touchscreen still poses a problem (Buxton et al., 1985; Lee and Zhai, 2009; Bau et al., 2010).

Vibration features such as duration and intensity are closely related not only to functionality, but also to affective impression (Seebode et al., 2013). The use of mechanical vibrotactile actuation with current electromagnetic or piezoelectric actuators faces an inevitable conflict: it can be difficult for users to perceive weak vibrations with low amplitude, and high strength vibrations with high amplitude can be rated as unpleasant for delivering too strong a force against users' fingertips (Brown et al., 2005; Bau et al., 2010). In addition, users can easily become finger-fatigued when tapping repeatedly on the same spot of hard-surface glass display with the same finger postures to ensure that the correct buttons were pressed (Hale and Stanney, 2004). Another problem is that the display using mechanical vibrations is limited in its ability to create rich tactile sensation for users who want to explore its surface texture by active rather than passive touch. In other words, the tactile sensation of mechanical vibrations is created indirectly through vibration of the entire touch surface, which transfers the vibration induced by electrostatic force on an intermediate object to the fingertips, thereby offering tactile feedback to the non-moving fingers pressing against the surface of the screen. In contrast, electrovibration (Mallinckrodt et al., 1953; Bau et al., 2010) can create a rubbery sensation by modulating friction between the surface and skin of the moving fingers, thereby directly actuating the fingers.

In an effort to deliver high-quality user experience with high-fidelity tactile sensations, thereby allowing users to feel what they

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are doing, a number of researchers have strived to develop new display technology such as "TeslaTouch" (Bau et al., 2010), "Senseg Tixel™ (2011)," and "Tactus Intelligent Surface™ (2013)," which have recently gained special attention at the international Consumer Electronic Show. TeslaTouch and Tixel technology represent a radical development, in that they enable users to feel various virtual textures displayed on the screen through changes in surface friction; however, tactile feedback for pressing buttons, target acquisition, and "press and hold" interactions cannot be implemented with the two electrostatic friction-based technologies when the finger remains stationary on the surface or when the finger touch and displacement should be mapped to virtual elements with rapid movements. Such actions can be supported by mechanical actuation, although both electrotactile and vibrotactile displays have pros and cons as mentioned above. Unlike TeslaTouch and Tixel, Tactus can provide completely transparent physical buttons that dynamically appear and disappear on a flat touchscreen, allowing application-based control. In addition to the efforts of professionals, users themselves have also tried to attach different types of screen protection to the surfaces of their devices, such as glossy or matte films, which protect the screen from scratches and allow the user to feel a high-quality texture at low cost. To meet these demands, 3M™ released soft and matte Mobile Shield protectors made of a shape-memorizing material (polyurethane), which has excellent flexibility and resiliency that allows the protector to easily return to its original shape even when the user constantly touches the surface with a rigid probe.

In addition to display technology, it is important to focus on interactions through direct input devices that involve a sense of touch (Forlines et al., 2006). As new models of mobile tablets, smartphones with large screens, and compatible styli have been released, users are given more opportunities for elaborate manipulation; for example, note-taking, sketching, and painting using styli are more convenient. Given this trend, it is important to understand three aspects of typical touch interactions involved in creative activities such as drawing and handwriting: (1) "hand and tool," (2) "tool and surface," and (3) "hand and surface" interactions (Sulaiman and Blandford, 2004). Drawing or writing on the surface of mobile devices with styli is similar to doing so with pen on paper in the real world. This implies that adding haptic cues such as softness, hardness, or stiffness to both the input device and the output display can mimic the surface texture properties of traditional drawing tools, enhancing tactile experience. In spite of the importance of providing a rich tactual experience, most newly released styli have been improved in terms of functional benefits (such as palm rejection and increased precision) and redesigned aesthetic features (in order to make them a natural fit for note-taking) without taking into account subjective satisfaction. It is therefore necessary to consider differences in the material properties of both touch-based screens and input devices.

In light of the importance of this somewhat neglected area, the present study was carried out to examine the effects of an elastic touchscreen and input devices with different degrees of softness on user task performance and subjective evaluation. In particular, the degree of hardness/softness of the surface of the touchscreen and pen-based input devices was manipulated in order to present alternative approaches for the design of touch surfaces without using any form of mechanical actuation. The finger was used to provide a performance baseline. Considering the difference of the hardness/softness of the touchscreen and devices, both behavioral and self-report data were gathered in a lab experiment measuring task performance while playing a tapping-based game, along with subjective satisfaction of pressing down on the surface, pleasantness, helpfulness, finger fatigue, and degree of elasticity. The importance of tactile sensation cannot be overemphasized; touch perception, which can affect user emotions, enables the user to detect a product's usefulness and usability (Keinonen, 1998). In this respect, the findings of the current study help designers and developers to understand the human factors underlying direct touch-based interaction, informing the design of haptic products that provide a pleasant tactile experience.

The remainder of this paper is organized as follows: Section 2 provides a literature review on soft-surface touchscreens, input devices, and measures of touch-based interaction. Section 3 then explains the methodology used in this study. The findings and results are described in Section 4, followed by the discussion and conclusions in Section 5. Finally, I end with a discussion of the limitations of this work and suggest topics for future studies.

2. Literature review

2.1. Soft-surface touchscreen

Recently, a wide range of approaches have been suggested in which a layer of the touchscreen display is deformed, and virtual textures are created to provide users with a natural and pleasant feeling of physical feedback. According to Shi et al. (2008), users tend to have a preference for soft, light-weight, or elastic materials, ranking factors important in providing a pleasant feeling in the following order: the degree of softness, the degree of elasticity, temperature, and texture. One of the recommended design strategies is to design products endued with brand-new sensations, which attract touch and appeal to users. Therefore, the present study explored touch interfaces constructed using soft and elastic materials to provide a pleasant touch sensation.

A number of studies have focused on the development of soft-surface touch interfaces that can be controlled by the fingers. The "GelForce" interface, developed by Vlack et al. (2005), can detect the strength and direction of forces applied to its elastic body, which consists of a CCD camera and two layers of colored markers embedded in transparent silicone rubber. To enrich user interaction on the touchscreen surface, Noguchi et al. (2013) proposed a multi-touch tabletop interface, named "WrinkleSurface," comprised of a transparent urethane soft-gel sheet (3.5-mm-thick) attached to the surface of an acrylic panel. WrinkleSurface was designed as a novel input device that can detect finger orientation and enable users to perform various motions including push, thrust, and twist (clockwise and counterclockwise), along with the conventional motions of tap, drag, and pinch. They also focused on evaluation of the soft-surface touchscreen by measuring user performance in a target-acquisition task. Despite application of elastic materials on the surface, neither the GelForce nor the WrinkleSurface interface was applied in handheld devices, in contrast to the surface used in the current study.

Unlike GelForce and WrinkleSurface, "ForceTile" and "PhotoelasticTouch" are tangible tabletop interfaces for which small objects made of transparent elastic materials are used as input devices. In the case of ForceTile, Kakehi et al. (2008) implemented three interactive applications with the tile interface, which consists of a transparent acrylic case filled with an elastic body: (1) a photo viewer for changing and resizing displayed images, (2) a multi-touch interaction (pinching and stretching) for adjusting the scale of images in accordance with the intensity and direction of the force, and (3) entertainment in which the application was controlled by the magnitude and direction of the applied force. Sato et al. (2009) developed the PhotoelasticTouch tabletop system with emphasis on the importance of several design elements including non-body-worn equipment, shape flexibility, visual transparency, and varying input styles. Three practical applications were also presented for this system: (1) a force-sensitive touch panel, (2) a tangible face application, and (3) a paint application. In