Applied Ergonomics 60 (2017) 207–219

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Innovation & evaluation of tangible direct manipulation digital drawing pens for children

Tai-Hua Lee*, Fong-Gong Wu, Huei-Tsz Chen

Department of Industrial Design, National Cheng Kung University, 1, Ta-Hsueh Road, Tainan, Taiwan, 70101, Taiwan

ARTICLE INFO

Article history:
Received 31 March 2015
Received in revised form
18 November 2016
Accepted 27 November 2016
Available online 10 December 2016

Keywords:
Direct manipulation
Digital drawing pen
Children
Drawing

ABSTRACT

Focusing on the theme of direct manipulation, in this study, we proposed a new and innovative tangible user interface (TUI) design concept for a manipulative digital drawing pen. Based on interviews with focus groups brainstorming and experts and the results of a field survey, we selected the most suitable tangible user interface for children between 4 and 7 years of age. Using the new tangible user interface, children could choose between the brush tools after touching and feeling the various patterns. The thickness of the brush could be adjusted by changing the tilt angle. In a subsequent experimental process we compared the differences in performance and subjective user satisfaction.

A total of sixteen children, aged 4–7 years participated in the experiment. Two operating system experiments (the new designed tangible digital drawing pen and traditional visual interface-icon-clicking digital drawing pens) were performed at random and in turns. We assessed their manipulation performance, accuracy, brush stroke richness and subjective evaluations. During the experimental process we found that operating functions using the direct manipulation method, and adding shapes and semantic models to explain the purpose of each function, enabled the children to perform stroke switches relatively smoothly.

By using direct manipulation digital pens, the children could improve their stroke-switching performance for digital drawing. Additionally, by using various patterns to represent different brushes or tools, the children were able to make selections using their sense of touch, thereby reducing the time required to move along the drawing pens and select icons (The significant differences ($p = 0.000$, $p < 0.01$) existed in the manipulation times for drawing thick lines using the crayon function of the two (new and old) drawing pens (new 5.8750 < old 10.7500)). The addition of direct manipulation movements to drawing operations enhanced the drawing results, thereby increasing the children's enjoyment of drawing with tangible digital drawing pens.

1. Introduction

Contemporary artists have also adopted a digital approach because of its high convenience, and the drawing software provides numerous functions that can be easily tested (Chu, 2004; Flatters, et al., 2014). I/O brush (Fig. 1) developed by Ryokai et al. (2004) at the MIT Media Lab used a camera to capture static or dynamic images of the surroundings and converted the images into brush drawings on the screen. They preserved the brushed pigment feature found in traditional drawings. Voodoo Sketch(Fig. 2) developed by Block et al. (2008) incorporated the "holding the brush in one hand and the palette in the other" concept from traditional drawing, and presented the system interface as a palette. Suzuki et al. (2008, 2009) took advantage of the users' experience in using ordinary pens to enhance the manipulation capability of the digital pens. They included the use of direct movements, such as shaking, rotating, and swinging or waving, in pop up menus to help users to draw.

To develop children's drawing behaviors, the ability to freely employ various drawing techniques and produce images is worthy of exploration (Jolley and Rose, 2008; Toomela, 2003; Trautner, 2008; Martin and Velay, 2012). Additionally, children's drawing abilities and skills are closely related to the other general abilities they possess, such as cognitive abilities (Morra, 2002). Recent studies have used drawings produced by children to shape and collect opinions regarding the development of computer programs

* Corresponding author.
E-mail address: hihiei@yahoo.com.tw (T.-H. Lee).

http://dx.doi.org/10.1016/j.apergo.2016.11.014
0003-6870/

Fig. 1. I/O brush. Note: Fig.1 From Ryokai, K., Marti, S., and Ishii, H. (2004). *I/O brush: drawing with everyday objects as ink*. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (Vienna, Austria, April 24–29, 2004). CHI '04. ACM, New York, NY, 303–310.

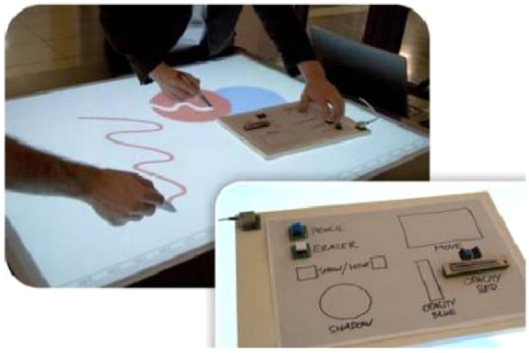

Fig. 2. Voodoo Sketch. Note: Fig.2 From Block, F., Haller, M., Gellersen, H., Gutwin, C., & Billinghurst, M. (2008). *VoodooSketch: extending interactive surfaces with adaptable interface palettes.* Paper presented at the Proceedings of the 2nd international conference on Tangible and embedded interaction.ACM. 55–58.

and as references for academic curricula and computer technology (Xu et al., 2009). Additionally, the age of children using computers is gradually declining, and the time that they spend on computers is increasing (Straker et al., 2009; McPake et al., 2013; Antle, 2013). Computers have slowly become a new medium for children to produce drawings (Ostler et al., 1996; Martin and Velay, 2012).

Current studies on digital drawing pens for children have incorporated the advantages of traditional drawings methods using pencils and paper into digital drawing systems (Suzuki et al., 2008; Xin et al., 2011). From an ergonomics perspective, Wu and Luo (2006) concluded that the most suitable diameter for styluses was 8 mm, which was also the most appropriate size for written input. Goonetilleke, Hoffmann, and Luximon (2009) suggested that pencils measuring 7.9 mm in diameter were the most suitable for kindergarten students. Digital drawing pens and traditional pencils and paper are significantly more in tune with natural postures and muscle movements (Matthews and Seow, 2007). The sense of touch is the most widely distributed, in the five senses of the human body. Touch is also the leading sense among the group of joint human perceptions (Prytherch and McLundie, 2002). When the sight and hearing functions are occupied, people can use touch, the sense of pressure, and vibrations indicate the positions and other information. Therefore, systems that can respond to the users' two hands or hand movements (Hinckley and Sinclair, 1999; Hinckley et al., 2016) and incorporate touch-based functions is suggested to potentially enable users to engage in superior and simpler manipulations (Buur et al., 2004).

The stability of a child's posture can affect their muscles' performance, when they were drawing (Miyahara et al., 2008). Children aged between 4 and 7 are drawing development occurs later in the post-schematic stage; the drawing becomes the most direct method to communicate (Siegler and Alibali, 2005). The ability to identify shapes and figures through touch generally exceeds that by sight (Zhang et al., 2003; Yuan, 2001; Zhang, 2001).

Graphical user interface (GUI) features simple and stable movements. However, it is relatively more difficult to operate using the pen-input method Apitz and Guimbretière (2004). In addition, because it contains a diversity of functions and requires users to constantly think, users are easily interrupted during the drawing process (Nijboer et al., 2010). Spindler, Hauschild, and Dachselt (2010) recommended that handheld physical devices be used for users to click and operate the functions found in the GUI of drawing systems. The concept of Tangible User Interface (TUI) was introduced with the goal of enabling users to interact with digital systems using physical objects, reducing the amount of time needed for them to learn about the said systems (Ishii and Ullmer, 1997). It is claimed that compared with GUIs, TUIs are more intuitive and enable users to issue commands quickly and effectively by using natural body movements made in daily life (Dixon et al., 2010; Lee and Ishii, 2010).

Presently, direct manipulation-based digital drawing developments have mostly focused on adult cognition. They fail to consider that children use a lesser range of functions than adults. The adult design principles may not apply to children because their needs, skills, and expectations all differ (Hanna et al., 1997; Gilutz et al., 2003). Focusing on the theme of direct manipulation, in this study, we proposed a new and innovative tangible user interface (TUI) design concept for a manipulative digital drawing pen. We selected the most suitable tangible user interface for the target group (children between 4 and 7 years of age). In a subsequent experimental process we compared the new designed tangible digital drawing pen with the traditional visual interface-icon-clicking digital drawing pens.

2. Co-creating the direct manipulation drawing pen

2.1. Identifying current drawing behavior system functions

2.1.1. Method

In this study, we visited a kindergarten and observed a drawing instruction in one kindergarten class (12boys, 13girls, and 4–7 years old) for 2 h. We recorded the teaching methods employed in the class, the drawing tools, the children's usage habits, and other unique situations. For the second part of the study, we introduced tablet PCs to the children, and had them operate the simple Microsoft Paint drawing software for 20 min. The goal was to understand how they used existing digital drawing software. Additionally, we asked experts to complete questionnaires we had prepared. The goal was to obtain professional opinions from art teachers who were the most familiar with the users (21 children's art teachers, all of whom were female and 19 years of age or above). The questionnaire items were as follows:

(1) Children performing traditional drawing: What drawing tools were the children given? How many different types and sizes of colored pens were given to the children? Given more than two drawing tools, which did the children favor? How many different colors were the children given to work with? Which methods do you think could help the children express their emotions?