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Cervical spine biomechanics and task performance during touchscreen computer operations

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A B S T R A C T

The effects of different touchscreen interface designs on operators' task performance and cervical spine biomechanics were investigated in the current study. Fifteen male participants performed "Whac-a-Mole" type of visual target pinpointing tasks on a touchscreen monitor with different display sizes, icon sizes, icon colors and task difficulties. Participants' task performance, cervical spine biomechanics and upper extremity muscle activities were recorded and compared. Results demonstrated that an oversized desktop touchscreen monitor and small icons generated negative impacts on participants' task performance and biomechanical measurements. Lighter icon color and more difficult task requirement generated worse task performance but had limited impact on cervical spine biomechanics. In addition, when using an oversized touchscreen monitor, the impacts of icon size and task difficulty seem to be magnified. Our results demonstrated that a more human-oriented interface design could help improve task performance and reduce neck and upper extremity injuries while operating touchscreen monitors.

Relevance to industry: In this study we investigated how a number of different design factors could influence task performance as well as cervical spine biomechanics when using touchscreen monitors. Knowledge gained from the current study could help the design of future applications that involve finger touching operations on touchscreen monitors.

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1. Introduction

Touchscreen interfaces are becoming ubiquitous with the increasing use of touchscreen monitors and mobile devices such as smart phones and tablets. It is estimated that more than 360 million tablets will be sold worldwide by year 2016 (Young et al., 2013). Among recent laptop computer sales, the ones with touchscreen functions also accounted for a significant portion of market share (Woollacott, 2013).

Previous investigations have shown that the use of computers and mobile digital devices is highly associated with the high prevalence of neck pain (Hakala et al., 2006; Berolo et al., 2011). In the general population, neck pain affects 30–50% of adults (Carroll et al., 2008) and this rate is even higher among frequent computer users (Eltayeb et al., 2009). The Bureau of Labor Statistics (BLS) reported that on average, work-related neck pain requires 11 days away from work (BLS, 2012). The cost of neck pain is also significant, one study showed treatment for neck and back problems accounted for nearly $90 billion dollars in healthcare expenditure in the United States in 2005 (Martin et al., 2008); another study estimated the direct cost related to neck pain were $185.4 million dollars in Netherlands in 1996 (Borghouts et al., 1999). Despite its high cost, the reoccurrence of neck pain is observed at 50–80% within five years after its first occurrence (Côté et al., 2008).

Previous studies demonstrated that the design of computer interface has a profound impact on human performance (Karwowski et al., 1994). Some of the most important design variables include: screen sizes (Jones et al., 1999), icon sizes (Huang and Lai, 2008), the color and contrast level of icons (Bzostek and Wogalter, 1999), the viewing angle and distance (Grandjean et al., 1984) and task difficulty (Orvis et al., 2008). Standards such as ISO-9241 (Ergonomics of Human-Computer Interaction) and ANSI/HFES 100 (Human Factors Engineering of Computer Workstations)

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were developed based on the existing findings to provide guidelines for the design and development of desktop and laptop computers. However, few studies explored the effect of interface parameters on the touchscreen devices, due to its recently gained popularity. Therefore, there is a strong and urgent demand in understanding the effect of touchscreen related design features on human health and performance. In addition, previous studies have shown that desktop touchscreen usage could generate higher body discomfort (especially in the neck and shoulder region) and physical loads compared to traditional display monitors (Shin and Zhu, 2011; Kang and Shin, 2014). However, it remains unclear of how touchscreen interface parameters would influence cervical spine biomechanics.

The objective of the current study was to investigate the influence of different interface designs on operators' task performance and their cervical spine biomechanics. Based on the existing literature (Jones et al., 1999; Huang and Lai, 2008; Bzostek and Wogalter, 1999; Orvis et al., 2008) changes of graphic interface parameters may alter operational performance when using non-touchscreen computers. Therefore, we suspected that changes of touchscreen interface settings would influence task performance and the cervical spine biomechanics. Specifically, we hypothesized that oversized touchscreen display, relatively smaller icon size, lower contrast level (i.e. between icons and the background display) and more difficult task will generate negative influences on users' operational and biomechanical performance. Results of the current study may help develop future guidelines for the design of touchscreen interfaces.

2. Methods

2.1. Participants

Fifteen male participants were recruited from the student population of West Virginia University and surrounding residents. Their averaged age, height and weight were 27.2 years (SD 2.6), 171.8 cm (SD 4.7) and 70.8 kg (SD 5.9) respectively. All participants were required to have at least two years of experience using touchscreen electronic devices (e.g. smartphone, tablet, etc.) and only right-handed males were recruited in order to eliminate the potential influence of sex and handedness. During the recruiting process potential participants reported their handedness, during the data collection their handedness was also verified by finishing the Edinburgh Handedness Inventory (Oldfield, 1971). Finally participants with any type of MSD that required physician visits during the past 24 months were excluded. The current research protocol was approved by the Institutional Review Board of West Virginia University.

2.2. Apparatus

Bipolar surface electrodes (Bagnoli, Delsys, Boston, MA, USA) were used to collect electromyography (EMG) data from bilateral C4 paraspinal, deltoid and brachioradialis muscles with a sampling frequency of 1024 Hz. Three dimensional (3D) movement data were collected using an eight-camera optical motion sensing system (Vicon Motion System, Oxford, UK) with a sampling frequency of 100 Hz. A total of nine reflective markers were placed over the front, back and side of head (Young et al., 2012; Zhou et al., 2015), the left and right shoulders (on the most dorsal points of the clavicle bones) and the C7, T12 and S1 vertebrae (Fig. 2(a)–(c)). The Nexus software (Vicon Motion System, Oxford, UK) was used for the data collection.

A custom-made computer program was built using Matlab Graphical User Interface (GUI) language (Matlab, 2011; MathWorks, Natick, MA, USA) to enable the testing environment. A computer workstation (Intel® Core ™ 2 Duo CPU @ 2.53 GHz, 4 GB Memory with Windows 7 installed) with a 23-inch (16:9 wide screen) touchscreen monitor was used as the testing device.

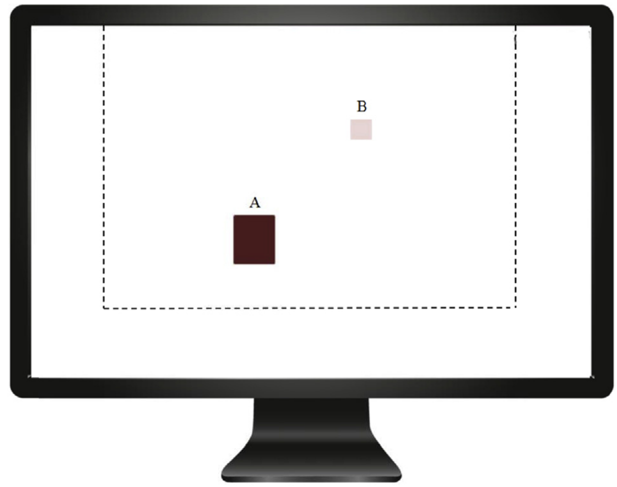

Fig. 1. An illustration of the testing program: dashed line indicates the display area for the small screen size condition while the large screen condition uses the entire display area of the screen; 'A' shows a large icon with darker red color, and 'B' shows a small icon with lighter red color. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.3. Independent variables

A total of four independent variables were included in the current study, and they were: (1) screen size (SCREEN), it has two levels: 51 × 29 cm and 38 × 21 cm. These sizes were determined such that the smaller display has ~50% of the display area of the larger screen and the dimensions are both ~16:9. The smaller screen size was enabled by adjusting the display area on the same touchscreen monitor (Fig. 1). (2) icon size (ICON), it has two levels: 1.46 × 1.46 cm and 3.64 × 3.64 cm (Fig. 1). The small icon size represent roughly the size of a finger tip and the large icon size was determined through a pilot study such that the icon is easy to pinpoint without significant refined motion adjustment. (3) icon color (COLOR), it has two levels: dark red (RGB value: 140, 0, 0) and light red (RGB value: 255, 160, 160) (Fig. 1). The red color was selected based on feedbacks from a pilot study, as it tends to generate better contrast with the white background; the light red was selected so that it is significantly lighter than the dark red, yet still clear to identify from the background. (4) task difficulty (DIFFICULTY) has two levels: 1 s of target refresh rate (later referred as the "easy" condition) vs. 0.85 s of target refresh rate (later referred as the "hard" condition). The difficulty levels were determined through the same pilot study such that the high refresh rate (i.e. 0.85s) will create a clear sense of urgency and the low refresh rate (i.e. 1s) still requires participants to be fully concentrated.

2.4. Protocol

Upon arrival, experimental procedures were first explained to the participants, and then a 5-min warm-up session was provided to allow participants become familiar with the tasks and computer setups. EMG electrodes were then placed to the designated locations using double-sided tapes. For the C4 paraspinal muscle, electrodes were placed bilaterally ~3 cm away from the midline of the spinal column at C4 level (Ning et al., 2015), the deltoid

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