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Effects of touch target location on performance and physical demands of computer touchscreen use

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ABSTRACT

Touchscreen interfaces for computers are known to cause greater physical stress compared to traditional computer interfaces. The objective of this study was to evaluate how physical demands and task performance of a tap gesture on a computer touchscreen vary between target locations and display positions. Twenty-three healthy participants conducted reach-tap-return trials with touch targets at fifteen locations in three display positions. Mean completion time, touch accuracy and electromyography of the shoulder and neck extensor muscles were compared between the target locations and display positions. The results demonstrated that participants completed the trial 12%–27% faster with 13%–39% less muscle activity when interacting with targets in the lower area of the display compared to when tapping upper targets ($p < 0.05$). The findings suggest that proper target placement and display positioning can improve task performance and lessen physical demands of computer touchscreen interface use.

1. Introduction

The touchscreen interface has several specific advantages, such as direct interaction with what is shown on the display, faster target selection compared to mouse or stylus, and various modes of operation through multi-touch gestures (Cockburn et al., 2012; Kin et al., 2009). The direct interaction and the ability to conduct various operations with multi-finger gestures have made the touchscreen interface one of the main interfaces for mobile devices, such as smartphones and tablets. Although it has become popular for mobile devices, the touchscreen interface has not been widely used for desktop or notebook computers to date. Unlike interaction with mobile devices, which requires only finger and wrist movements, interaction with computer touchscreens often requires entire arm movements without hand or arm support, possibly constituting one of the key reasons that made the touchscreen interface less popular for computers (Al-Megren et al., 2015; Juan David et al., 2014; Shin and Zhu, 2011).

A touchscreen interface requires users to tap a certain target and conduct a touch gesture while looking at the target. Placing targets lower on a screen reduces arm elevation but increases neck flexion to look down at the target. In contrast, placing targets near eye height reduces neck flexion but it leads to greater arm elevation to reach the target. Common guidelines for computer workstations, such as ‘placing the keyboard at the height of elbow and the top line of display at or slightly below eye height’ (ANSI/HFES, 2007; OSHA, 2001), do not work for computer touchscreens. Recent studies have suggested some recommendations for users of computer touchscreens such as the use of sloped and extended armrests to minimize the duration of floating arm posture and alternating hands frequently to reduce cumulative fatigue on the dominant hand and arm (Kang and Shin, 2014; Shin and Zhu, 2011). While these recommendations may help users utilize computer touchscreens with less physical discomfort, there are still numerous understudied factors that may influence the physical demands of the interface.

An underexplored but potentially important factor in touchscreen interface design is the location of touch targets. The vertical and horizontal location of a target relative to a user may influence the movement and muscle activities of the upper extremities, as observed in studies of finger pointing tasks and light manual work (Schuldt et al., 1987; Sporrong et al., 1998). Performance in touch gestures such as tapping accuracy or task completion time may vary depending on where the target is located from the user, as reported in a study with a commercial standing kiosk (Leahy and Hix, 1990). Although findings in previous research suggest potential effects of target location on task performance and

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physical demands of computer touchscreens, there has been little research investigating the quantitative relationship between them.

The primary objective of this experimental study was to determine the effects of target location and display position on task performance and physical demands when interacting with a computer touchscreen. Task performance and physical demands were evaluated by quantifying touch accuracy, completion time and electromyography (EMG) of the shoulder and neck extensor muscles while conducting reach-tap-return trials. The study results can provide recommendations for proper touchscreen display location and target layout.

2. Materials and methods

2.1. Participants

Since handedness is known to influence touchscreen usage patterns (Kang and Shin, 2014), participants were recruited into three handedness groups (left handed, right handed, ambidextrous). Twenty-three participants (13 females, 10 males) with mean age of 20.6 (SD 2.0) years, body weight of 57.3 (SD 8.9) kg and height of 1.64 (SD 0.075) m participated in this laboratory experiment. According to the Edinburgh Handedness Inventory (Oldfield, 1971), they were classified as seven left-handers, nine right-handers, and seven ambidextrous participants. All participants had no physical difficulty conducting finger touch gestures on a computer touchscreen in a seated posture. Prior to data collection, each participant provided informed consent on a protocol approved by the institutional review board and was trained for finger touch gestures and task procedures.

2.2. Independent variables

The independent variables of this study were display position and target location. Each participant conducted reach-tap-return trials on fifteen targets when the display was at three different positions: ‘Far’, ‘Close’ and ‘Low’. In the ‘Far’ position, a 23″ touchscreen display (IPS236 V, LG Electronics, Korea) was tilted 15° from vertical, raised so that the top of the viewable area matched the participant's eye height, and placed at a distance where the participant could barely touch the top of the display's viewable area with fully stretched arms in a reclined sitting posture (Fig. 1). In the ‘Close’ position, the display was placed closer to the participant so that its lower edge was directly above the function key row of an external keyboard. The keyboard position was set for the participant prior to data collection so that the participant's elbows were flexed to 90° when the hands were resting on the keyboard. In the ‘Low’ position, the touchscreen was tilted 75° from vertical, lowered toward the keyboard height, and positioned at a location where the participant could touch the top of viewable area with full stretch. Once the initial setup was made in each condition, the participant was not allowed to make any further change and asked to keep the upper back reclined during the cyclic reach-tap-return trial of the condition. The order of presentation of the three display positions was randomized between participants.

With the display at each of the three positions, the participant conducted reach-tap-return trials on fifteen targets that were distributed in three rows by five columns with center-to-center horizontal and vertical gaps of 100 mm between targets. Targets with consecutive numbers were separated by rows or columns to minimize learning effects (Fig. 2). Each target has a ‘+’ mark of 15 mm by 15 mm, and the participant was asked to aim at the center of the target.

2.3. Data collection

Prior to the start of data collection, the participant was asked to adjust the chair and table height to position the keyboard so that the shoulders were relaxed, wrists were flat and elbows were flexed to 90° when the hands were resting on the keyboard. The keyboard was used as an origin point for the participant's hands during cyclic reach-tap-return trials. Ceiling lights were masked or repositioned to avoid screen glare.

With the display at each of the three positions, participants began reach-tap-return trials with the left hand first (‘left hand only’ condition). At a verbal command with the target number ‘1’, they first visually searched for target #1, identified its location within the display, lifted their left hand off the keyboard and reached the target, tapped the target with the index finger and made a visual mark on the display, and then placed their hand on the keyboard again and maintained sitting posture with both hands on the keyboard for 2–3 s. After the short pause, the second target number (#2) was called, and the task continued until all fifteen targets were tapped in ascending order with the same hand. After all fifteen targets were tapped, the cycle was repeated again. Next, the participants repeated the above with their right hand only (‘right hand only’ condition) and then with their preferred hand (‘preferred hand’ condition). In the ‘preferred hand’ condition, no restriction was enforced so the participants could choose any preferred hand and alternate hands between targets, if desired. The order of the three hand usage conditions was consistent for all participants.

While conducting reach-tap-return trials, EMG signals of the left and right shoulder muscles and neck extensors were recorded using a surface EMG system (Bagnoli 16-channel Desktop System, Delsys, U.S.A.). Two pairs of Ag-AgCl bipolar surface EMG sensors were attached bilaterally at the midpoint of a line connecting the acromion process and the spinous process of the 7th cervical vertebra (C7) to collect signals from the upper trapezius muscles (Hermens et al., 1999). For the neck extensors, EMG sensors were placed bilaterally at the midpoint of a line connecting the C7 and the mastoid process to collect signals from the splenius capitis muscles (Joines et al., 2006). Raw EMG signals were collected at 2000 Hz, bandpass filtered (10–500 Hz), full-wave rectified and then smoothed using the 2nd order low-pass Butterworth filter with a cut-off frequency of 6 Hz to generate linear envelope EMG. The linear envelope EMG data from each muscle were normalized to the maximum amplitude of the muscle, which was collected during maximum voluntary contraction (MVC) trials at the beginning of the experiment. The MVC EMG data of the shoulder muscles were collected in a seated posture as the participants exerted pull-up force against a stationary rigid handle by shrugging both shoulders with arms straight and pointing downward. Neck extensor MVC EMG data were collected while the participants attempted to rotate their head backward from a slightly flexed posture against a stationary cushion pad while sitting. MVC EMG of each muscle was collected twice, and the higher amplitude from the two trials was registered as the maximum amplitude of the muscle. A rest period of at least 2 min was given after each MVC trial to avoid fatigue development.

Simultaneously, with the EMG signals, the position and movement of the display, table, participants' hands and head were recorded using a motion capture system. Reflective markers were placed on their upper extremities and forehead as well as on the display and the table surface. Rigid bodies of the head, upper arms, forearms, hands, display and table were then constructed from the markers to track the coordinates of each body segment, the table and the display (Table 1). Since markers for the display were attached above the top edge of the display, the geographic center of