Thumb Motor Performance is Greater for Two-Handed Grip Compared to Single-Handed Grip on a Mobile Phone

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The aim of this study was to determine if thumb motor performance varied between single-handed and two-handed grip for thumb tapping tasks on a mobile phone. A secondary aim was to determine if differences in phone movement variation and thumb flexion could account for variations in motor performance across the two grip configurations. Ten right-handed participants (5 males, 5 females) completed reciprocal thumb tapping tasks on an Apple iPhone 3® in a single-handed and a two-handed grip configuration while an active-marker motion capture system measured 3D kinematics of the thumb and phone. The results show that thumb motor performance was significantly greater for the two-handed grip configuration due to less phone movement variation compared to the single-handed grip configuration. Thumb flexion did not significantly vary across configurations. These data suggest that increasing support for the phone such as by using a two-handed grip could lead to increases in tapping performance. For example, increased performance would be expected when using phones that include a landscape mode and are wide enough to allow a stable two-handed grip.

INTRODUCTION

With the increased use of mobile phones, the design of the phone and keypad becomes increasingly important for promoting performance, user experience, and reducing strain on the musculoskeletal system. Users may choose to interact with their phone using one or two hands for reasons such as personal preference, multitasking, or possibly the need for additional support. Single-handed interaction requires using the thumb to reach the keys, and many users prefer to use their thumbs for two-handed interaction as well. The dual task of holding the phone and tapping with the thumb(s) introduces a challenge for designers since these tasks are not independent from one another (Trudeau et al., 2012a). The ergonomic benefits of using either a single or two-handed grip configuration are unclear. Information regarding user performance and posture for different grips during phone interaction could be useful for hardware designers and software developers wanting to promote user experience.

Several studies have investigated thumb performance for single-handed phone interaction. Keys located in the bottom right corner of the phone for right-handed users are consistently associated to higher muscular effort (Hogg, 2010), higher transition times and decreased accuracy (Park & Han, 2010a). Increased thumb motor performance has been found to be associated with smaller phones (Trudeau et al., 2012b) and with movements in the top right/bottom left orientation of the phone for right-handed users (Trudeau et al., 2012b; Karlson, 2008).

In a two-handed grip configuration the prehensile task is shared by both hands, which may have an impact on user performance and posture. Gustaffson et al. (2011) found lower muscle activity in the extensor digitorum muscle for two-handed grip on a phone compared to single-handed grip. They hypothesized that this result could be attributed to the need for increased stability. No other study has determined the impact of a two-handed grip on user performance and posture.

Therefore the aim of this study was to determine if thumb motor performance, as defined by the effective index of performance calculated from Fitts' Law, varies between single-handed and two-handed grips for thumb tapping tasks on a mobile phone. We expected that thumb motor performance would be greater in the two-handed grip configuration. As a secondary hypothesis, we expected that a greater motor performance in the two-handed grip configuration could be explained by less phone movement variation as well as a straighter thumb posture.

METHOD

A repeated measures experiment was conducted to verify the stated hypotheses. Kinematics of the thumb and phone were recorded as participants accomplished reciprocal thumb tapping tasks in a single-handed and a two-handed grip configuration (Figure 1). Measured variables were thumb motor performance, phone movement variation, and thumb interphalangeal joint flexion as an indicator of thumb flexion.

Participants & Tasks

Ten right-handed participants (5 males, 5 females) were recruited for this study and provided consent. Mean (±SD) age and right hand length were 27.0 ± 7.0 yrs and 18.7 ± 1.7 cm respectively. The Harvard School of Public Health Office of Human Research Administration approved all forms and protocols.

While holding a mobile phone in either a single-handed or two-handed grip configuration, participants accomplished trials that involved reciprocal tapping with their thumb between 2 keys on an Apple iPhone 3® (LINK TO SUPPLEMENTAL VIDEO). The emulated keys consisted of 3-ring binder reinforcement stickers (1.4 cm diameter) placed 2 cm apart, creating a 4 x 3 grid on the surface of the phone (Figure 1). The selection and presentation of the key pairs was randomized for every participant to achieve a representative sample of all the possible incoming tap directions for each key. For each trial, 6 seconds of data collection started once the subject indicated they were comfortable with the tapping task. The single-handed grip configuration involved holding the phone in the portrait orientation with the right hand and all keys were included in the tasks. To simulate realistic usage behavior, the two-handed grip condition involved holding the phone in the landscape orientation and the keys in the left-most column were excluded from the tasks. Participants were allowed to slightly adjust their grip between trials. Instructions to participants included to “complete the task as fast and with as much precision as possible”. Participants rested for 90 seconds after every 15 trials.

Figure 1: Single-handed grip configuration (top), and two-handed grip configuration (bottom).

Materials

An active-marker motion capture system (Optotrak Certus, Northern Digital Inc., Waterloo, Canada) obtained 3D thumb and phone kinematics. Clusters of three infrared light emitting diodes (IREDs) were attached to the phone, hand, proximal phalange of the thumb, and two markers were placed on the thumb nail (Figure 1). The 3D position of these IREDs was tracked at 100 samples per second, recorded to a personal computer, then digitally filtered with a low-pass, fourth order Butterworth filter with a 10 Hz cutoff frequency. For a given tap toward a specific key within a trial, the horizontal distance the thumb tip moved, the movement time from the previous tap, and the position of the thumb’s distal IRED were pulled from the continuous data at the instant that the tap was completed. The instant of a tap completion was defined as when the vertical (Z) position of the thumb’s most distal IRED relative to the phone reached a local minimum (with respect to time) with a relative horizontal position in the vicinity of the key.

Measured Variables

For each key within a trial, an across tap average movement time, average distance, average interphalangeal joint angle and an effective index of performance (IP_e) as an indicator of motor performance were calculated. According to ISO9241-9, the effective index of performance was calculated as $IP_e = ID_e/MT$, where MT and ID_e are the average movement time and effective index of difficulty, respectively (Fitts, 1954; Douglas et al., 1999; Soukoreff & MacKenzie, 2004; Wobbrock et al., 2008). ID_e was calculated as $ID_e = \log_2(A_e/W_e + 1)$, where A_e is the horizontal distance between both keys involved in the trial, and W_e is the effective target width, $W_e = 4.133*SD$. Here, SD is the standard deviation of the thumb tip IRED horizontal position on the phone's surface about the mean horizontal position for all taps on a specific key during the trial.

Phone movement variation was calculated as the sum of the standard deviations of the phone's angular inclination across all 3 axes of rotation. The phone's position was calculated using Euler angles with respect to a global stationary coordinate system. Thumb interphalangeal joint flexion was calculated for each tap using Euler angles based on the orientation of the thumb's distal phalange with respect to the proximal phalange's coordinate system.

Measured variables were averaged across trials for each grip configuration within participants. All data were processed using Matlab software (The Mathworks, Natick, MA).

Statistical Analysis

To test the hypothesis that thumb motor performance varied across grip configurations we used a repeated measures mixed ANOVA model with participant as a random effect (significance level $\alpha = 0.05$). To test the secondary hypothesis that variation in motor performance across conditions was due to phone stability and thumb flexion, we first determined if phone movement variation and thumb flexion were associated with motor performance by fitting a mixed multiple regression model with motor performance as the outcome and phone movement variation and thumb flexion as the predictors. We then conducted two separate repeated measures mixed ANOVAs to determine if phone movement variation and thumb flexion were significantly different across grip configurations. All statistical analyses were run using JMP Software (SAS Institute, Cary, NC).

RESULTS

Thumb motor performance varied significantly across grip configurations ($F = 65$, $p < 0.001$). Motor performance was greater for the two-handed grip configuration compared to the single-handed grip configuration (across participant averages of 13.2 ± 3.1 bits/sec and 12.0 ± 2.9 bits/sec respectively; Figure 2). Greater thumb motor performance was also significantly associated with both decreased phone movement variation and a more extended thumb (Table 1).

Phone movement variation varied significantly across grip configurations ($F = 488$, $p < 0.001$). Phone movement variation was lesser for the two-handed grip configuration compared to the single-handed grip configuration (across subject averages of 4.3 ± 3.2 deg and 8.7 ± 5.2 deg respectively; Figure 2). Thumb flexion was not significantly different across grip configurations (two-handed and single-handed across subject averages of 38.3 ± 20.0 deg and 36.5 ± 21.9 deg respectively; Figure 2).

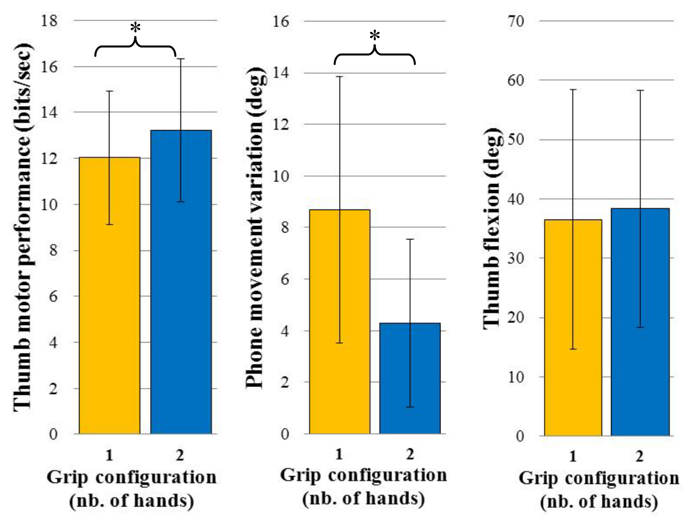

Figure 2: Across participant average thumb motor performance (left), phone movement variation (center), and thumb flexion (right) for the single-handed and two-handed grip configurations. Error bars indicate ± 1 SD.

TABLE 1: Parameter estimates for the mixed multiple linear regression model describing the association between motor performance (outcome) and phone movement variation and thumb flexion.

Predictor	$\hat{\beta}$ regression coefficient	SE[1]	p-value
Phone movement variation	-0.114	0.627	< 0.001
Thumb flexion	-0.038	0.015	< 0.001

[1]SE = standard error of the estimated parameter.

DISCUSSION

The results show that gripping the phone with two hands improves thumb motor performance over holding and operating the phone with a single hand, which supports the study's main hypothesis. The results further support the secondary hypothesis that this association may be due to less phone movement variation in the two-handed grip configuration. This is consistent with the results from Gustafsson et al. (2011) who hypothesized that the reduced extensor muscle activity they found for two-handed grip was due to increased phone stability. This result also makes sense on a motor control perspective. An unstable phone causes variable key locations, rendering a precise tapping task more difficult. A two-handed grip allows the non-active hand to stabilize the device, relieving the active hand from having to hold and position the phone, which increases the user's capacity to accomplish the precision thumb tapping task.

The results do not support the hypothesis that the two handed grip configuration favors a straighter thumb posture, which suggests that the association between grip configuration and motor performance found in this study may not be due to different mechanics involved in tapping with the thumb across conditions. Overall, users flexed their thumbs equally in both grip configurations, which might reflect the small size of the device and keys. A flexed thumb posture allows the user to tap with the tip rather than the palmar surface of the thumb, therefore reducing surface area. Park and Han (2010b) suggest that a flexed posture favors tapping accuracy, an association that has been observed in another study from our group as well (Trudeau et al., 2012a).

There were limitations to the methods of this study. First, the reciprocal tapping tasks did not reflect commonly performed tasks such as typing and Internet browsing. However, the tasks provided a convenient way of measuring motor performance using Fitts' Law and reflect the elemental tasks involved in commonly performed activities. In addition, the emulated keys were not functional. However, the stickers had tactile feedback which provided participants with sensory information about their accuracy. Since the key size was constant, the range of calculated indices of difficulty (ID_e) was not wide enough to determine a Fitts' regression model. Instead, for each grip configuration, we calculated effective indices of performance for tasks that involved different movement orientations and key distances. Next, we could not determine if performance differences could be attributed to visual obstruction from the thumb itself. However, we believe that this is an intrinsic characteristic of the grip configuration, which is the main independent variable of interest. Finally, no information on participant comfort/discomfort was collected in this study and therefore we cannot conclude on whether these parameters were affected by grip configuration or if they had an effect on performance.

These results suggest that stabilizing the phone by using a two-handed grip while tapping leads to increases in thumb motor performance. Consequently, increased tapping performance would be expected when using phones that include a landscape keyboard mode or phones that are wide enough to allow a comfortable two-handed grip while still allowing the thumbs to reach all keys and functions. Additional considerations such as friction on the back of the phone and device shape to ensure effective grip could also contribute to increased stability and performance.

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