The Effect of Age and Screen Sizes on the Usability of Smartphones Based on Handwriting of English Words on the Touchscreen

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Abstract

The aim of this study is to analyse the effect of age and screen sizes on the usability of smartphone touchscreens. With a total of 42 participants, we compare usability between two age groups [younger (20-39 years) and elderly (60+ years)] and two screen sizes [small (3.5”) and large (7”)]. Each participant is requested to write 10 English words using their finger on the touchscreen, with finger movement time (MT) and finger pressure (FP) as measures of usability. The results show us that elderly participants exhibit significantly longer MT, indicating less efficiency, but there are no significant differences in FP between the two age groups across the two screen sizes. The results also show us that small screen sizes lead to significantly harder FP, indicating less sensitivity, but there are no significant differences in MT between the two screen sizes across the two age groups. Given these results, designers should consider the response efficiency of elderly users and response sensitivity to small screen sizes in order to increase usability.

Keywords: Mobile computing; elderly; usability; smartphones; human-computer interaction.

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تأثير عمر المستخدم وحجم شاشات على سهولة استخدام الهواتف الذكية باستخدام كتابة الكلمات الإنجليزية على شاشة اللمس

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ملخص

الهدف من هذه الدراسة هو ايجاد مدى ملائمة شاشات اللمس للمستخدمين من كبار السن وذلك بالتحقق من تثير العمر (عمر المستخدم) والتحقق من تأثير استخدام احجام الشاشات المختلفة للأجهزة الخلوية الذكية، حيث يتم ذلك عند الكتابة على شاشات اللمس للأجهزة الخلوية الذكية. لإنجاز الهدف من الدراسة تم جمع البيانات المطلوبة للتجربة من 42 شخص شاركوا في التجربة وتم تقسيمهم الى مجموعتين حسب اعمارهم للمقارنة بين ادائهم لايجاد مدى ملائمة شاشات اللمس لكل من المجموعتين: المجموعة الأولى من الفئة العمرية ما بين (20–39 سنه) –المجموعة الثانية هي فئة كبار السن التي تزيد أعمارهم عن (60 سنه)، وايضا تم استخدام حجمين مختلفين من شاشات اللمس: حجم (3.5 انش – حجم صغير) وحجم (7 انش – حجم كبير). ولجمع البيانات من المشاركين في هذه الدراسة، لقد طلب من كل مشارك كتابة 10 كلمات إنجليزية باستخدام إصبع المشترك على شاشة اللمس، حيث تم استخدام الوقت المستغرق في الكتابة وقوة ضغط الأصبع عند الكتابة على شاشة اللمس كمقياس لايجاد مدى ملائمة شاشات اللمس بين المجموعتين.

أظهرت النتائج ان كبار السن كانوا أقل فعالية بفارق مهم من خلال طول الوقت المستغرق في الكتابة مقارنه مع الفئة العمرية ما بين (20–39)، لكن لم يكن هناك فارق مهم بين المجموعتين في قوة ضغط الاصبع على شاشات اللمس في كلا الجهازين. ومن حيث ايجاد تأثير حجم شاشات اللمس على المستخدمين من كلا المجموعتين، اشارة الدراسة إلى أنه استخدام الشاشات ذات الحجم الصغير يحتاج الى قوة ضغط أكبر في الكتابة مما يدل على انه الاستجابة في الأجهزة الصغيرة للمستخدمين أقل مقارنة مع الشاشات الكبيرة وخصوصا للمستخدمين من كبار السن، ولم يكن هناك فروقات مهمه في الوقت المستغرق بين الحجمين.

نتائج هذه الدراسة توصي مصممي شاشات اللمس أن يأخذوا بعين الاعتبار فعالية استجابة كبار السن وقدراتهم الحركية ومدى استجابة شاشات اللمس لهم – خصوصا شاشات اللمس صغيرة الحجم – وذلك لزيادة سهولة استخدام وملائمة شاشات اللمس لكبار السن.

Introduction:

The popularity of smartphones has been increasing rapidly over the years, and such devices have now become an integral part of everyday life for people all over the world (Boulos et al., 2011; Aldhaban, 2012). In the UK alone, it has been estimated that approximately 71% of adults owned a smartphone in 2016, which has increased significantly from 39% in 2012 (Ofcom, 2015; 2017). Similar increases have been reported internationally (Poushter, 2016; Sanakulov & Karjaluoto, 2017). By definition, smartphones are:

‘A cellular telephone with built-in applications and Internet access. Smartphones provide digital voice service as well as text messaging, e-mail, Web browsing, still and video cameras, MP3 player, video viewing and often video calling. In addition to their built-in functions, smartphones can run myriad applications, turning the once single-minded cell phone into a mobile computer’ (Krouse, 2012, p. 732).

Hence, smartphones offer users access to vast range of applications at the palm of their hands, providing users the benefit of engaging with these applications easily, even when ‘on the go’. Indeed, the ever-increasing popularity of smartphones has been evidenced by the use of these devices in place of alternative technologies such as desktop computers and laptops, which reflects the convenience, accessibility and mobility of smartphone devices (Clarke, 2013; Page, 2013).

Smartphones can be of particular benefit to elderly users (Plaza et al., 2011; Al-Showarah, 2015). Most notably, such devices can aid elderly users in staying connected with family, friends and other individuals in a convenient and low-cost manner (Chen et al., 2013). Smartphones can also play an important role in the safety and security of elderly users (Mallenius et al., 2007). For example, safety alarm applications and location services on smartphones can allow elderly users to instantly obtain emergency support when needed. Additionally, smartphones can offer memory aids such as appointment alarms and reminders, which would be beneficial to elderly users with age-related memory loss (Plaza et al., 2011). Moreover, smartphones can offer elderly users the opportunity to engage with mentally stimulating applications such as ‘brain training’ games and exercises, which could enhance their cognitive functioning (Chen et al., 2013).

Despite the benefits, few smartphones and applications are designed to meet the cognitive, sensory and motor abilities of the elderly (Zhang and MacKenzie, 2007; Leitão, 2012; Salman et al., 2017). In general, older age is associated with a decline in each of these abilities. To illustrate, older age has been associated with the following impairments: decline in cognitive resources such as reduced working memory capacity and information processing speed; decline in sensory abilities such hearing loss and reduced vision; and decline in motor abilities such as slowness of movement due to loss of muscle mass and arthritis (Caprani et al., 2012; Al-Showarah, 2015). In order for smartphone technology to be useful for the elderly, designers should consider such impairments and accommodate for them accordingly. For example, the decline in vision can be accommodated for by the use of large text and high contrast colours on the displays of smartphones (Fisk et al., 2009). If designed with the abilities of the elderly in consideration, smartphones can have the potential to aid the elderly in living independently and self-sufficiently, as well as enhance their quality of life. As such, the study of smartphone usability in the elderly is needed to help facilitate achieving such implications.

In existing studies, the elderly have demonstrated problems in using touchscreen-based technology. For example, studies have reported that elderly individuals exert harder pressure on touchscreen keyboard buttons compared to younger individuals, particularly when the keyboard buttons are small in size (Rogers et al., 2005; Stößel et al., 2009; Farage et al., 2012; Chen, 2013). It should be noted, however, that such studies of age differences have mainly been conducted in the context of devices other than smartphones. Namely, larger and purpose-built devices have tended to be of focus. There is therefore a need for research to focus on the usability of smartphones among elderly users, and this will allow recommendations to be established for the design of smartphones and applications that are suitable for the abilities of the elderly (Chen, 2013).

The present study addressed this need for research by examining effect of age on the usability of smartphones, measured via handwriting on the touchscreen. We considered two age groups: a younger age group and an elderly age group. Moreover, due to the variety of screen sizes that are available, the present study also examined the effect of screen sizes on the usability of smartphones. We considered two screen sizes: small and large. Since finger-based gestures are the most common mode of interacting with smartphones (Bhuiyan and Picking, 2009), such gestures were analysed in this study, specifically finger-based handwriting. By using this type of gesture, it was possible to determine the usability of smartphones by measuring finger movement time (MT) and finger pressure (FP), both of which are commonly used as indictors of usability (Rogers et al., 2005; Moffat and McGenere, 2010; Nicolau and Jorge, 2012; Findlater et al., 2013).

Based on the results of prior research concerning age and screen sizes, the following two hypotheses were formulated:

H^1: Elderly users will exhibit longer MT and harder FPthan younger users when handwriting words on the touchscreen.

H^2: The smaller screen size will lead to longer MT and harder FP than the larger screen size when handwriting words on the touchscreen.

To best of our knowledge, there has been no research conducted using handwriting on smartphone touchscreens to analyse the effect of age and screen sizes on the usability of smartphones. Therefore, the present study is the first to contribute understanding of this kind. Our study is also the first to use widely available small-screened smartphones, since existing studies have tended to use large and purpose-built devices when evaluating the effect age (Stößel et al., 2009). This contribution is important because small-screened smartphones might have the potential to be utilised effectively by the elderly if designed according to their abilities.

In summary, the results of the present study demonstrated that the elderly group exhibited significantly longer MT than the younger group, but the two age groups did not differ in terms of FP. In addition, the results demonstrated that smaller screen sizes led to significantly harder FP than larger screen sizes, but there were no significant differences between the two screen sizes in terms of MT. Hence, there was less efficiency in using smartphones with regards to elderly individuals, and less sensitivity in using smaller screen sizes.

In the remaining sections of this paper, the following will be presented: a review of related work regarding the effect of age and screen sizes will be provided in section 2; the methodology will be outlined in section 3; the experimental results will be presented in section 4; a discussion of the results will be provided in section 5; and the conclusion of the study will be outlined in section 6.

Related Studies

The usability of touchscreen devices is a relatively new field of research, only recently beginning to gain momentum. Within this field, a number of studies investigating the effect of age on the usability of touchscreen devices have been conducted. For example, one study examined the usability of a touchscreen device compared to a non-touchscreen rotary encoder device among two age groups; young adults aged 18-28 years and older adults aged 51-65 years (Rogers et al., 2005). In this study, usability was measured via the time required to complete a series of tasks, including moving a slider, selecting up/down buttons, selecting items from a list or drop-down list box, and scrolling. Overall, the older adults were slower to complete the tasks, whether completed on the touchscreen device or non-touchscreen rotary encoder, and completion time was especially slow when smaller buttons were involved.

In another study, the effect of age was examined in the context of a traditional desktop computer compared to a large touchscreen device (Findlater et al., 2013). The study involved a group of adults with an average age of 27.7 years, and a group of elderly adults with an average age of 74.3 years. Again, the time required for task completion was used an indicator of usability. Four tasks were of interest, specifically, pointing, dragging, crossing and steering. Moreover, pinch-to-zoom was an additional task of interest, but relevant to the touchscreen only. Similar results to the aforementioned study were obtained, whereby the older adults were slower to complete the tasks.

In a study focusing on elderly users, text-entry performance on landscape touchscreen keyboards was examined by the speed of inputting words. The results showed that the speed of the elderly adults was relatively slow (Nicolau and Jorge, 2012). An important point to note is that studies using completion time or speed as indicators of usability assume greater usability when fast, but assume less usability when slow (Rogers et al., 2005; Nicolau and Jorge, 2012; Findlater et al., 2013). Since elderly users have generally demonstrated slow completion time or speed in the studies that have been mentioned, the results suggest low usability of touchscreen technology for elderly adults.

Studies have also examined the effect of age by using force pressure as an indictor of the usability of touchscreen devices. To illustrate, the force pressure exerted by young adults and older adults has been compared in a study involving stylus pen-based interaction with a tablet computer (Moffat and McGenere, 2010). Upon examining the results, older adults were found to exert twice as much pressure as young adults. Here, lower force pressure was assumed to be an indicator of greater usability, whereas harder force pressure was taken to suggest low usability. The results therefore indicate that the usability of touchscreen technology was low for the elderly adults.

In contrast to the effect of age, there has been a scarcity of studies regarding the effect of screen size on the usability of touchscreen devices. In a review of studies published between 2000-2013 (Motti et al., 2013), only one study examining the effect of screen size was reported (Kobayashi et al., 2011). Specifically, the study measured the completion time of gestures on a small screen size compared to a large screen size among elderly users, where the gestures included dragging, tapping, pinching with panning, and pinching without panning. An iPad comprising a 9.7” screen represented a large screen size, whilst an iPod comprising a 3.5” screen represented a small screen size. The results demonstrated that the completion time of gestures was slower for the small screen size. Based on such results, the usability of larger screen sizes appears to be greater than smaller screen sizes.

To our knowledge, there has been one further study examining the effect of screen size on touchscreen usability (Stößel et al., 2009). The completion time of 42 gestures was compared for three screen sizes: 1) a small screen (1.8”); 2) a medium screen (3.6”); and 3) a large screen (7.2”). In addition to screen size, the study compared the completion time of young adults and older adults, finding that older adults were slower to complete the gestures, especially on small screen sizes. Similar results have been reported in studies assessing the force pressure exerted on keyboard buttons during text-entry tasks (Rogers et al., 2005; Farage et al., 2012; Chen, 2013). In these studies, elderly individuals have been found to exert harder pressure on keyboard buttons compared to their younger counterparts, especially for small-sized keyboard buttons.

There have also been recent results providing further support for the effect of screen size on touchscreen usability (Al-Showarah, 2015). To specify, two screen sizes of commonly used smartphones were compared for usability among younger and elderly adults: a 3.5” screen and a 7” screen. Analysis of the pressure exerted on the screens when completing finger-based gestures revealed that the larger screen size was more usable for the elderly adults, due to lower pressure being exerted. The present paper extends the research of Al-Showarah (2015) by examining the effect of age and screen sizes on the usability of smartphones, but it is different in the experimental design by using handwriting of English words on the touchscreen of smartphones.

Methodology

Apparatus

The apparatus comprised two mobile devices, which were selected to represent two screen sizes: small and large. The small size was intended to be typical of smartphones, which have screen sizes between 3” and 5.5”. The large size was intended to be typical of mini tablets, which have screen sizes of 7”. The following two devices were selected: 1) Samsung Galaxy Ace S 5830 (dimensions 112.4 x 59.9 x 11.5 mm, screen size 3.5”); and 2) Samsung Galaxy Tab 2 (dimensions 193.7 x 122.4 x 10.5 mm, screen size 7”). Therefore, the small screen size was represented by the Samsung Galaxy Ace S 5830, whilst the large screen size was represented by the Samsung Galaxy Tab 2.

In each device, we created an application that was used as a tool to allow the measurement of two indices that were required for the present research. More specifically, the application allowed the mesurement of finger movement time (MT) and finger pressure (FP), each of which will be described in more detail in section 3.5.

Participants

A total of 42 participants provided data for the study. Although larger samples are always desirable, this was a sizable sample considering the relatively lengthy experimental procedures involved in the study, lasting approximately 40 minutes for each participant. The number of male (19) and female (23) participants was almost equal, and we will consider the effect of gender in our future work. The participants were allocated to one of two age groups: a younger group, which consisted of 26 participants between 20-39 years of age [mean (M) = 26.73; standard deviation (SD) = 5.36]; and an elderly group, which consisted of 16 participants aged 60 years and over (M = 65.19; SD = 3.31). Such age groupings were based on the propositions of the World Health Organisation, according to which the elderly population consists of individuals aged 60 years and over (World Health Organisation, 2013). All participants were university students, university staff or individuals from the local community.

The average ring size of the younger group ranged between 58.89 mm and 61.14 mm, and ranged between 61.06 mm and 66.15 mm for the elderly group. Meanwhile, the level of experience of participants was measured by the average time spent using smartphones per day. This was between 3.08 hours and 3.17 hours for the younger group, and between 1.50 hours and 2.23 hours for the elderly group. As it is not easy to cover all levels of experience in one research study, we will try to consider different levels of experience in our future work.

Experimental Design

There were two experimental conditions: a small screen size condition and a large screen size condition. A between-subjects experimental design was used, there fore participants were each allocated to only one of these two conditions, rather than both. This was to minimise the impact of practice effects from experience with either of the experimental conditions. Each participant completed 6 experimental trials, and each trial required participants to handwrite 10 English words using their finger on the touchscreen. The 10 words were repeated across each of the 6 experimental trials. Therefore, there were a total of 2520 trials. An example of the handwritten words of a participant that completed the experimental trials is provided in Figure 1.

Figure 1. An example of the handwritten words of a participant.

As shown in Figure 1, the English words comprised basic-level vocabulary, which was intended to reduce linguistic ability barriers when completing the experimental trials. To clarify, the words involved in the experimental trials were: arm, cat, dark, grass, hi, jog, pun, queen, school, white. For any enquiries about the database of these words, or to obtain more information, please contact the first author on either of the email addresses provided in the title page.

Experimental Procedure

Participants individually completed the experimental trials. Firstly, each of the participants was seated at a table, ensuring the height and distance of the seating was adjusted to their comfort. Secondly, depending on the experimental condition to which the participants were allocated, either a small- or large-screened mobile device was placed flat on the table.

It was ensured that the screen of the device was faced upwards and oriented landscape at a distance of 10-15 cm from the table edge. This is similar to the orientation used in prior research (Nicolau and Jorge, 2012). In addition, it was ensured that each device was fixed on the table to avoid movement of the device that would influence the finger gestures on the touchscreens. Thirdly, the experimenter provided each participant with a description of the forthcoming experimental procedure, and also provided each participant with training regarding the forthcoming experimental trials. The training required participants to practice writing words on the touchscreen using their finger, which allowed them to become familiar with the experimental trials. Finally, each participant completed the 6 main experimental trials. In each trial, participants were required to write 10 English words using their finger on the touchscreen. Each word was repeated across the 6 trials. The participants were instructed to write the words according to how they would normally write words on a touchscreen, but were asked to avoid linking individual letters together. This is similar to the instructions given to participants in previous research (Zhang and MacKenzie, 2007; Teather et al., 2010; Al-Showarah, 2015).

Measures

As mentioned prevously, the two indices that were required for the present research were finger movement time and finger pressure. These indices were measured starting from finger touch-down to finger touch-up. In other words, these indices were measured starting from the time each participant placed their finger on the touchscreen to the time each participant removed their finger from the touchscreen.

Finger Movement Time (MT). MT was measured as the average time spent by each participant when writing 10 words across 6 trials (milliseconds). Similarly to previous studies, faster MT was assumed to indicate greater usability (Rogers et al., 2005; Nicolau and Jorge, 2012; Findlater et al., 2013). To clarify, faster MT refers to a lower average writing time in milliseconds. As a general rule, the lower the average writing time, the faster the MT. However, there is no threshold to differentiate faster MT from slower MT.

Finger Pressure (FP). FP was measured as the average pressure exerted on the touchscreen by each participant when writing 10 words across 6 trials (force pressure). Based on previous studies, we assumed that lower FP indicates greater usability (Moffat and McGenere, 2010). In this case, lower FP refers to a lower average force pressure. As another general rule, the lower the average force pressure, the lower the FP. Similarly to MT, there is no threshold to differentiate lower FP from higher or harder FP.

Experimental Results

T-tests were used to compare each age group and screen size on MT and FP. The average MT and FP values for each age group across the two screen sizes are summarised in Table 1. The average MT and FP values for each screen size across the two age groups are summarised in Table 2.

Table (1) Average MT and FP values for each age group across the two screen sizes

Measures	Younger Group		Elderly Group		p
	M	SD	M	SD	
MT (ms)	3084 ↓	869	3858 ↑	1211	*
FP (force pressure)	0.3501 ↓	0.1758	0.4831 ↑	0.2413	-

Note: - = p > 0.05, * = p < 0.05, ** = p < 0.001

Table (2) Average MT and FP values for each screen size across the two age groups

Measures	Small Screen Size		Large Screen Size		p
	M	SD	M	SD	
MT (ms)	3365 ↓	1088	3395 ↑	1074	-
FP (force pressure)	0.5815 ↑	0.1194	0.2031 ↓	0.0328	**

Note: - = p > 0.05, * = p < 0.05, ** = p < 0.001

3) Finger Movement Time (MT). The results comparing the effect of age on MT in Table 1 were as expected in the first hypothesis; the elderly group exhibited longer MT (3858 ms) than the younger group (3084 ms). The difference between the MT of the elderly group and the younger group was significant ($p < 0.05$).

The results for the effect of screen size on MT in Table 2 were not as expected in the second hypothesis: the large screen size led to longer MT (3395 ms) than the small screen size (3365 ms), and the difference was not significant ($p > 0.05$).

For ease of visualisation, the average MT for each age group and screen size is illustrated in a bar chart in Figure 2.

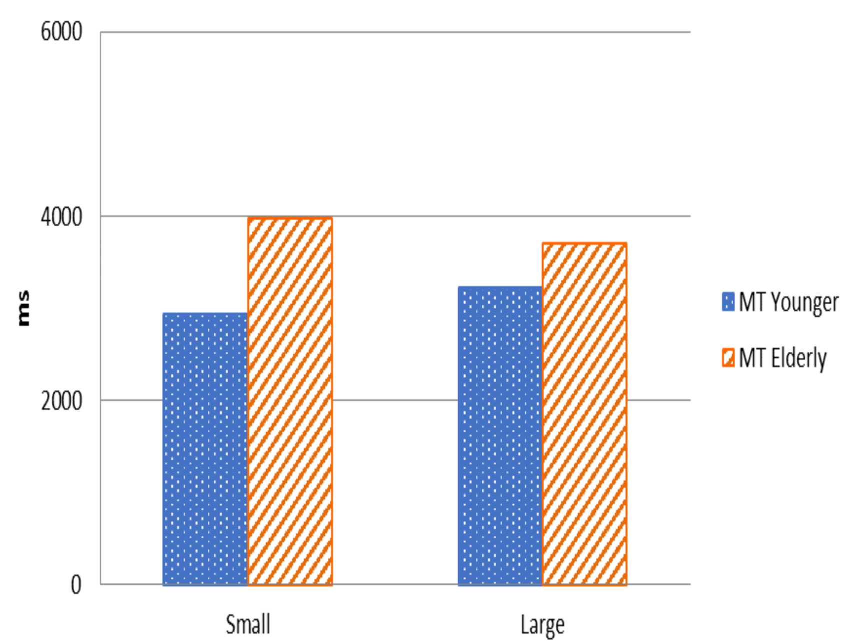

Figure (2) Average MT for each age group and screen size

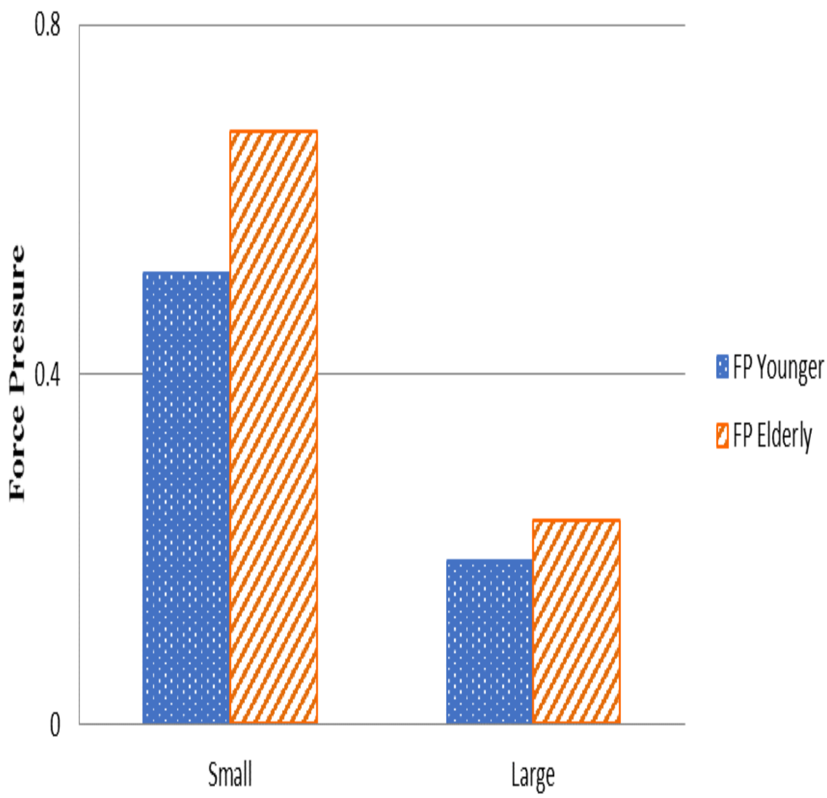

Figure (3) Average FP for each age group and screen size

Finger Pressure (FP). The results for the effect of age on FP in Table 1 were not as expected in the first hypothesis: the elderly group exhibited harder FP (0.4831 force pressure) than the younger group (0.3501 force pressure), but the difference was not significant ($p > 0.05$).

The results for the effect of screen sizes on FP in Table 2 were as expected in the second hypothesis: the small screen size led to harder FP (0.5815 force pressure) than the large screen size (0.2031 force pressure). The difference between the FP for the small screen size and the large screen size was significant ($p < 0.001$).

To simplify the visualisation of these results, the average FP for each age group and screen size is illustrated in a bar chart in Figure 3.

Discussion

The hypothesis regarding the effect of age on MT was supported by the results, since the elderly group exhibited longer MT than the younger group. Additionally, the hypothesis regarding the effect of screen size on FP was supported, since harder pressure was exerted on the smaller screen size compared to the larger screen size. However, the hypotheses regarding the effect of age on FP, and the effect of size on MT were not supported, since there were no significant age or size differences found with respect to these measures.

The longer MT of the elderly group indicates less efficiency in using smartphones compared to younger users. Our findings are in line with previous work examining the effect of age on the usability of touchscreen devices, where it has been shown that elderly individuals are generally slower in completing touch-based tasks (Rogers et al., 2005; Nicolau and Jorge, 2012; Findlater et al., 2013; Al-Showarah, 2015). As such, designers of smartphones and applications should consider the response time of elderly users, to increase efficiency of smartphone use for this group.

The harder FP exerted on small screen sizes indicates less sensitivity in using small screens, which is similar to previous work, where greater force has been exerted on small keyboard buttons (Rogers et al., 2005; Farage et al., 2012; Chen, 2013). Moreover, the result regarding the harder FP exerted on small screen sizes is also similar to previous work that demonstrated elderly individuals exert harder pressure on smaller screen sizes compared to larger screen sizes (Al-Showarah, 2015). Therefore, designers of smartphones and applications should consider response sensitivity when designing small touchscreens, to increase sensitivity to small-screened smartphones.

The lack of significant differences regarding the effect of age on FP suggests that age does not influence sensitivity, whilst lack of significant differences regarding the effect of screen size on MT suggests that screen size does not influence efficiency. This is different to other research, where elderly users have demonstrated harder pressure when interacting with touchscreen devices (Moffat and McGenere, 2010), and slower movement has been exerted on smaller screens (Stößel et al., 2009; Kobayashi et al., 2011; Motti et al., 2013). Thus, age may not be as relevant to FP, and screen size may not be as relevant to MT as previously thought. Since the lack of significant differences are the first results of this kind, further research should be conducted to examine their reliability.

Conclusion

The results of the study have provided insight into the effect of age and screen sizes on smartphone usability, measured via handwriting on the touchscreen. In terms of age, the results have demonstrated that elderly individuals are less efficient in using touchscreen smartphones than their younger counterparts, given the longer MT that was found for the elderly group. In terms of screen sizes, the results have demonstrated less sensitivity in using smaller screen sizes compared to larger screen sizes, given the harder FP that was exerted on the small touchscreen. The results collectively suggest that efforts should be focused on increasing the response efficiency of elderly users, and response sensitivity to small screen sizes. Such efforts would be useful in helping to promote the usability of smartphones among elderly individuals, and the usability of small-screened smartphones.

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