A Review of Age-Related Characteristics for Touch-Based Performance and Experience

Jing Liao, Jianan Lou, Qifei Wu, Min Zou, and Linfeng Zheng(✉)

Zhejiang University, Hangzhou, Zhejiang, China
zhenglinfeng@zju.edu.cn

Abstract. Touchscreens are considered as a friendly interface for elderly people. However, a gap between young users and older users was still observed in either interaction performance or user experience. Although previous studies have identified the gap is associated with age-related characteristics, most researches are focused on specific input or output elements. This heterogeneity of research subjects makes it difficult to understand, compare and to recommend proper techniques for a specific design. Accordingly, we provided a review, thoroughly describing the efforts on the touch-based system and the elderly population in the past decade and answering the following questions: (1) How to identify characteristics that sensitive to performance and experience? (2) How to accommodate for elderly's special interests? We also summarized the relevant design guidance, and provides novel perspectives of inclusive technical design for the elderly. Our work may enlighten those who is interested in the design of both hardware and software elements for the elderly.

Keywords: Elderly · Age-related characteristics · Touch-based system
Interaction performance · Interaction experience

1 Introduction

As a direct input, touchscreens eliminate control-display displacement, and are regarded to be able to reduce interaction time and boost accuracy. The older adults also have high subjective satisfaction and preference on touchscreens [1]. However, a gap between young users and older users was still observed in considerable experimental results of performance and self-reported experience [3].

The characteristics of older people relating to this gap are referred as age-related characteristics. Understanding the influence of age-related characteristics on performance are the prerequisites for setting design criteria for the older group [2]. Many researchers strived to explore relations of this heterogeneous group characteristics to behaviors and outcomes of interaction [1–11, 14, 15, 22–24, 29–41, 43–59]. Motti et al. reviewed experimental variables related to interaction performance and experience, i.e. the population involved, the kind of tasks that were executed, the apparatus, the input techniques, the provided feedbacks [3].

In this paper, we specified elderly's characteristics and determine factors (both experimental and practical) on performance and experience of using touchscreens. We summarized significant findings as design guidelines. Our work will guide for

J. Zhou and G. Salvendy (Eds.): ITAP 2018, LNCS 10926, pp. 279–296, 2018.
https://doi.org/10.1007/978-3-319-92034-4_21

researches on elderly-technology interaction in (1) design of empirical experiments exploring touch-based interaction; (2) implications of possible barriers during interaction; (3) approaches to improving technology experience.

This review is organized as follows: Sect. 2 describes metrics of interaction performance and experience and emphasizes the role of age-related characteristics as a primal cause of generation gap. Section 3 surveys the elderly centered touch-based interaction techniques and Sect. 4 assesses them and provides guidelines considering the special interests for elderly group. Finally, we concluded our work in Sect. 5. Detailed settings of experiments involved in literature are appended in the Appendix (Fig. 1).

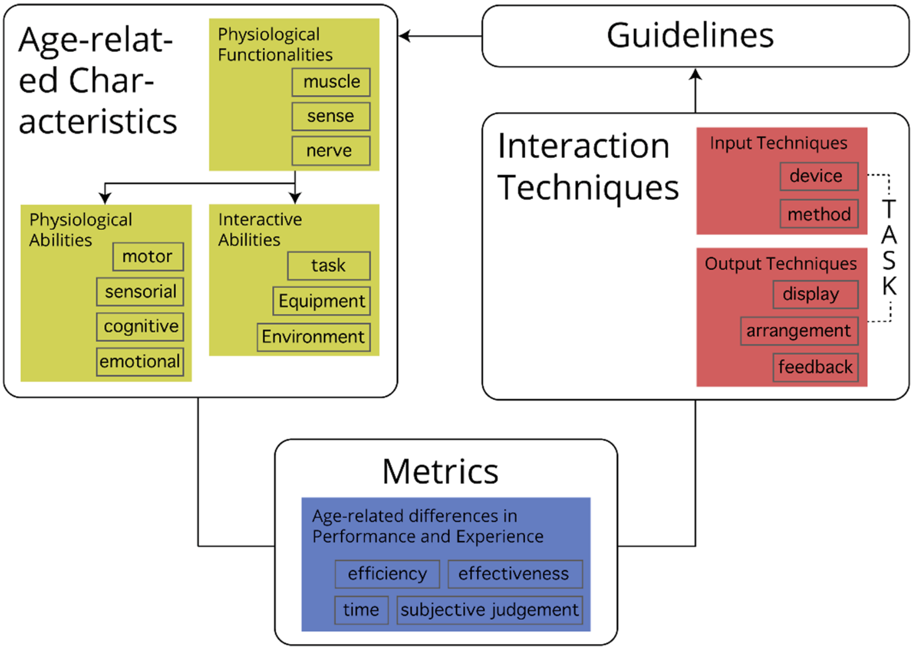

Fig. 1. Research paradigm of age-related characteristics and touch-based interaction

2 Age-Related Characteristics as a Primal Cause of Generation Gap in Elderly-Computer Interaction

A general conclusion is reached in human computer interaction community that users' abilities would strongly impact interaction performance and experience. We built a three-level of descriptions of aging characteristics: Physiological Functionalities, Physiological Abilities and Interaction Abilities, to explain physiological changes, effects of physiological changes and how these effects act during the elderly of using touch-based systems.

2.1 Three-Level Taxonomy of Age-Related Characteristics

Physiological Functionalities: Muscle, Sense and Nerve.
Muscle. Age-related muscular changes include declines in muscle strength and power [4–6], number and size of muscle fibers [7]. As a result, limb and finger tiredness are more frequently happened on older adults, particularly when working on devices i.e. tablet PC, where arms need to be kept in-air.

Sense. Aging may accompany with pathological changes in sensorial organs, such as opacities of the crystalline lens of the eye caused by cataract, local loss of visual function caused by diabetic retinopathy, and age-related macular degeneration (AMD) of the photosensitive cells at the retina [5]. These sensorial pathological changes may lead to degenerations of sensorial abilities required by interaction, then obstruct the elderly to use the general interfaces.

Nerve. Aging brings about neural changes, e.g. reduced speed of conduction of nerve signals [4, 7] and slower nerve signal processing [4], directly affecting motor, sensorial and cognitive abilities of older adults.

Physiological Abilities: Motor, Sensorial, Cognitive and Emotional.
Motor. In the context of touch-based interaction, motor degenerations include negative changes in strength, speed of upper limb muscles [5, 8], as well as reduced abilities, i.e. consistency of movement [5, 8, 9], coordination [9–11], endurance [6] and accuracy [5, 7]. Motor degenerations directly hindered older people in performing reaching, selecting, grasping, and gestural tasks [3, 5].

Sensorial. Primarily, sensorial degenerations in touch-based interaction are visual and tactile declines. Firstly, old people are at high risk of visual impairment incidents, reducing the depth-perception [6], field-of-view [7, 9], visual acuity [8], the ability to resolve detail [7, 9, 12], to detect [13] and focus on object [12], to discriminate color [5, 6, 9], to detect contrast [5, 9, 12, 14], and to estimate motion [9]. As vision being widely known as the main tunnel of perceiving external stimulus, difficulties in perception and utilization of visual feedbacks may be one of the important causes of poor performance of older people [15]. Secondly, tactile degenerations make older adults have difficulties in sensing the texture, quality and temperature of surfaces. Loss of tactile sensitivity may lead to not being able to rely on haptic interface to interact. Particularly, atrophic skin decreases the quality of fingerprint data, posing challenges on fingerprint-feature-based identification authentication [16, 17], which is widely used on smartphones.

Cognitive. Old adults have more difficulties in concentrating on tasks and filtering out irrelevant information [5, 11, 12, 18, 19], the abilities to know, understand and reason [11, 14], to respond [9, 10], to recall and learn [12, 22], to navigate [21, 23], and to recognize and use words [6, 12, 18]. However, higher-level cognitive abilities, i.e. visuospatial memory are less influenced by aging [24]. In general, declines in memory (both long-term and short-term [5, 9, 18, 19], and verbal memory [21]), processing abilities(e.g. visual processing) and intelligence (both fluid and crystallized) [3, 5], is three of significant cognitive degenerations. An interesting finding is that the fluid intelligence (the capacity to analyze, reason and solve problems) is widely considered to be decreased with age, while the crystallized intelligence (the ability to use skills, knowledge, and experience) is considered to be improved with age, because experiences tend to expand one's knowledge. But close relationships were determined between aging and declines in crystallized intelligence in e.g. pen interaction [5]. Cognitive abilities play an *increasingly* significant role in usability and acceptance of design for the elderly [20].

Emotional. Emotional degenerations of older adults are related to beliefs, attitudes, anxiety, fear, acceptability [9, 25, 26]. Older adults may have misconceptions that they cannot or do not use advanced technologies (e.g. computers, the Internet) [25]. A lack of beliefs in capability may prohibit some older people using technologies [27]. Fortunately, many emotional degenerations are highly related to computer literacy [9, 25, 26, 28]. Social media and social networks encourage older people using digital products and services, which improves their computer literacy [26, 28].

Interaction Abilities. Interaction abilities are physiological abilities associated with user performance and behaviors under specific experimental settings. By analysis of experimental results in literature, we found the interaction abilities rely on the task performed, the equipment and the task-being environment.

Task Dependency. Most studies observed age-related differences in, i.e. performance or behavior difference between younger group and older group. However, the measured ability is actually affected by task requirements defined in individual experiment. For instance, the efforts required by accomplishing tapping gestures is negatively related to the target size [29], but is positively related to the precision requirement [29, 30], the distance from the target [29] and complexity [31]. These factors interact with age and have complex effects on performance and experience.

Equipment Dependency. Equipment type, or interactive techniques may also have strong effects on practical interactions. Early touch-panels use capacitive touchscreen, which is prone to color distortions and becomes inaccurate when temperature or moisture changes. Thus, large studies conducted on capacitive touch-panels concluded that touch-based interaction is even worse than traditional mouse [32]. This contradict to outcomes yielded in subsequent experiments using high-stability and high-resolution touch-panels (e.g. Piezoelectric touchscreen and Infrared touchscreen).

Environment Dependency. The user being environments are into categorized in-virtuo (in the real environment, easy-to-control but poorly reflecting to the user's reality), in-situ (being able to provide high-realistic data, but may be highly biased by the observers and extremely costly) and in-simu (or in-sitro, a synthetic environment for a real environment to work under laboratory conditions of control) [33]. The closer to a real environment, more insights may yield from the experiments.

2.2 Metrics of Interaction Performance and Experience

Identifying evaluation metrics is of great significance, because metrics are practical for examining disparities between older and younger people and accessing experimental results of literature. In the context of touch-based interaction tasks, we defined the definition of time (both learning time and retention over time), effectiveness, efficiency and subjective judgement measures.

Time. Time can be considered as temporal duration required or related to perform pre-defined action(s). An action can be viewed as contact with the interface (e.g. reach and tap on a target) or any inclination provoked by interaction task (e.g. reaction). Elderly people may encounter difficulties in either performing an action or becoming aware of performing the action.

Effectiveness. Error, including error rate (or accuracy), error severity, recovering from errors, is a common measure of interaction effectiveness. Effectiveness could be evaluated at different levels. Take text entry task as example, the minimum string distance (MSD) can be used to evaluate sentence-level errors (incorrect word or word order), occurrence of insertions, substitutions and omissions to evaluate character-level errors.

Efficiency. Simply, the efficiency metric can be mathematically explained as an indicator of effectiveness per unit time. In previous example of text entry, efficiency metric can be the word-per-minute (wpm).

Subjective Judgements. Subjective judgements can be qualitative (e.g. interview) or quantitative (e.g. questionnaire). A general method is to ask participants to do self-evaluations on task-specific measures. Particularly, subjective results are not always consistent with objective measures. For instance, elder users may prefer an awkward way (poor measure of time, effectiveness or efficiency) to interact [34].

3 Studies on Elderly Centered Touch-Based Interaction Techniques

In this section, we discussed effects of input and output domains of touch-based interaction techniques on interaction according to tasks, to have deep examinations into consistencies and inconsistencies in elderly interaction performance and experience.

3.1 Interaction Tasks in Touch-Based Systems

The interaction task can be a good variable when analyzing designs of interaction for the elderly. Firstly, well-defined interaction tasks are good simulations of processes of interaction in real contexts. Secondly, the interaction performance and experience is highly related to tasks to be finished. Thirdly, most of retrieved literatures have clear definitions on the experimental task, so comparing these experimental results based on the interaction task is available.

Target Acquisition (TA). As one of the of the most basic manipulation, TA has been the most theoretically and experimentally studied. A typical TA movement consists of two control phases: (1) an initial large and quick directing phase and (2) a later small and slower acquiring phase [31]. Older adults may face more challenges in either (1) or (2) phases with respect to distinct contexts. Three problems of on-screen interaction are identified to be more challenging for older people: First, the fat finger' problem in finger-based selection task. The finger, hand, or arm may occlude part of, or even the whole target [35, 36]. Second, the 'slipping' in stylus-based selection. Older adults are easily slipping away from a target when tapping on smooth screen [37]. Third, difficulties in small targets selection [5, 35], because a more precise tapping is required to successfully select a target. Interestingly, target size also has detrimental influence on the efficiency of cognitive processes involved in the target acquisition task, especially for the elderly [38].

Text Entry (TE). TE has also been widely studied. It is particular challenging for older adults because of the nature of high complexity. The performance of text entry is highly affected by keyboard design [34, 41], predict system [34], nature of task [42, 43], and the workstation configuration [44]. Besides, TE performance has close relationships with user pre-experience [40]. Generally, older adults require more intuitive and easy-to-use entry method [34].

Keyboard Layout. Visual layouts and techniques do not improve TE performance, or even have negative effects [34, 39]. The input accuracy has no relationships with the familiarity of QWERTY layout [40]; Also, the input speed is found to be strongly related to previous QWERTY experience rather than keyboard layout [40]. Still, a carefully-designed keyboard, e.g. visual-adaptive keyboard, may provide comfortable and natural typing experience [41]. Additionally, old users can be benefited from adaptions that was hide from the interface. Findlater et al. designed a visual-adaptive keyboards that reshuffle layout of keys and a non-visual-adaptive keyboard that do not change visually rectangular layout but increase the chance that the user will press one visual key but output a different letter [41]. The non-visual-adaptive keyboard provided both typing speed and efficient/easy-to-use/preferred improvements [41].

Predict Variant and Working Condition. Surprisingly, old users are the least satisfied with Predict Words variant keyboard, and they performed comparable or even worse in general regarding input speed and error rate [34]. The reason suggested by self-report is that the text predict is too complex and need more practice in order to correctly use it. As for effects of typing in stationary or mobile condition, the text input speed decreases, the error rate and mental workload increases when user is walking [44].

Real Scenario Tasks (In-Situ Usage). Real scenario tasks can be defined as complete interaction 'transactions' happening in daily work, i.e. sending an email. Two problems may lead to a gap between experimental results and practical usage. The first problem is task inconsistency. Take TE as example, it can be divided into three in-situ tasks, copy, compose and describe [42]. Most in-vitro experiments asked participants copy sentences, but we think-and-write rather frequently than copy in practical conditions. Actually, older adults were found to pause more frequently during the fixed time allowed for typing (in self-judgement, they were also reported to spend more time thinking than younger adults) [42]. In other words, the difference between two age groups in speed of typing as being caused by longer inter-key times, e.g. thinking, not the actual tap times. The second problem is difficulties in controlling and determining variables in real scenario tasks. However, underlying factors may be identified since results are limited to less assumptions. For instance, the use of hands leads to increasing both time and error rate for older people, while it has no effects on the young [43]. But only a few studies considered this variant in experiments.

3.2 Input Techniques for Touch-Based Systems

Input techniques can be device-based (smartphones, tablets, tablet PCs, and table-size touchscreens), or method-based (finger-based and stylus-based techniques). A considerable of studies have thoroughly examined the input devices and methods for the older adults [7, 45, 46]. Most studies evaluated common techniques as tap, multi-tap, long-press, drag, drag-and-drop and free-drawing. Many novel input methods have also been proposed, e.g. Steadied-Bubbles [47] and SWABBING [48].

3.3 Output Techniques for Touch-Based Systems

Display: Size, Color, Contrast, Fonts. The effects of display size [29, 49], orientation [50], color [34], contrast [51, 52] and fonts [14, 53] were examined and were identified to have significant influence on performance and subjective evaluations.

Arrangement: Layout, Information Architecture. Arrangements strongly affect navigation task [20, 31, 54, 55], e.g. keyboard layout is strongly related to identifying location of keys [39]. Besides, arrangement of interface elements (information architecture) has a significant influence on speed, mental load and satisfactory during web browsing [31, 55].

Feedback: Visual, Acoustic, Tactile and Multimodal Feedback. Few studies conclusively discussed effects of output feedbacks on elderly. After examining relevant literature, we found many inconsistencies in findings. Although popular opinion is that providing feedback from these ‘absent’ channels will enhance user performance and satisfaction, and results of many empirical studies validated this hypothesis. However, some studies found that either visual (older adults were less sensitive to visual feedbacks [35]), auditory, or haptic feedback do not act important as expected on older users. We discussed these effects case-by-case, because each type of feedback has typical effects on interaction.

Visual Feedback. Visual feedback is usually designed to aid in pointing [29], navigation [54] and entry tasks [34]. The hovering techniques and the long-press on touchscreen, for instance, either help users affirming whether the desired target is accurately pointed, or suggest the possible behaviors after the target is selected. Another type of visual feedback is aimed at modeling feeling that naturally generated by other modalities, i.e. when clicking on a button, it looks like a real button is pressed. This type of visual feedbacks is widely used in computers, mobile devices and virtual environments [56]. But for older users, studies did not recommend the mechanism of creating pseudo-haptic feedback [57] through visual channel, especially in onscreen text entry task [34].

Acoustic Feedback. The auditory feedback is usually used as secondary channel to facilitate visual feedbacks. The presentation of multimodal feedback with auditory signals via a touch screen device enhances performance and remark of older adults [58]. Besides, auditory feedback can be designed to provide implications on word to be typed. For instance, introducing an enhanced auditory feedback (EAF) for Korean language entry task can provide subtle phonetic auditory feedback with the use of acoustic phonetic features of human speech [59]. Another potential of auditory feedback is to elicit emotions of users, based on evidence of the systematic relationships between acoustic features and emotions felt [60]. Providing pleasant sounds in augmented artifacts and interfaces is able to make the task slightly easier, to leave users feeling more in control [60], and to mitigate negative effects of tactile feedback of increasing cognitive efforts [29].

Tactile Feedback. One of the weakness of touchscreens typing is the lack of tactile feedback as provided from physical keyboard [8]. Researchers tried to compensate for this nature by providing proper haptic feedbacks, however, completely exploring these parameters is very complicated and of high cost of sensors and actuators at present. On the other hand, effects of providing feedbacks on touchscreen is also inconclusive. Some studies found haptic feedbacks aid performance, particularly for elderly and blind users [29, 58, 61, 63, 64]. One the other hand, haptic feedbacks were found to provide fewer help and to distract attention or affect older adults' stable grasp of the device [29, 59, 65]. That tactile feedbacks being so tricky is related to subjective satisfactory nature of sensitiveness and the currently incomplete simulation of physical feedbacks. Even if provided a small but unnaturally force, it will have strong negative effects on performance; as for satisfaction, significantly worse than those without tactile feedbacks [65]. Therefore, detailed design guidelines are needed in the design of haptic feedback. Nishino et al. provided a design guideline specific for implementing mutually discriminable tactile stimuli in practical applications [61]. But this guideline is still not sufficient for supporting designing efficient and natural haptic responses.

Multimodal Feedback. Multimodality has been recommended for elderly-technical system interaction for many years, conclusively for: (1) various modalities could compensate disadvantages more than interfere between each channel [62]; (2) various modalities can accommodate more characteristics of users and environments [66, 67]; (3) human's natural ability on utilizing and integrating between multimodalities is little affected by aging [66]. However, some studies show multimodal feedbacks yield worse performance than a unimodal feedback, if some modalities, e.g. improper tactile feedback, that has negative effects on performance are combined [68, 69]. And these negative effects of multimodal feedback may be gender-related [70].

4 Guidelines for Interaction Design on Elderly People

4.1 How to Identify Characteristics that Sensitive to Performance and Experience?

According to results of literature examination, effects of age-related characteristics on interaction performance and experience are summarized in Table 1. Contradictory results are labeled as '?', implying the effects have not been determined.

Table 1. Effects of age-related characteristics on performance and experience of touchscreen (+: increase; –: decrease)

		Time	Effectiveness	Efficiency	Subjective Judgement	Remark
Motor degenerations	Strength	?	–	–	?	
	Speed	+	?	–	–	
	Consistency	+	?	–	?	
	Coordination	+	?	–	–	
	Endurance	?	?	?	–	
	Accuracy	+	?	–	–	
Sensorial degenerations	Depth-perception	?	?	–	?	
	Field-of-view	+	?	–	?	
	Tactile	?	–	–	–	
	Detail resolve	+	–	–	?	
	Motion detect	+	–	–	?	
	Color discrimination	?	?	?	–	
	Contrast detect	?	?	–	–	
Cognitive degenerations	Concentration and Respond	+	?	–	?	
	Know, Understand and Reason	+	–	–	?	
	Recall	+	–	–	?	
	Learn	+	–	–	–	
	Navigate	+	?	–	–	retain previous strategies
	Recognize and use words	?	–	–	?	
Emotional degenerations	Attitude	?	?	–	–	based on results of surveys
	Belief	?	?	–	–	
	Anxiety	?	?	–	–	
	Fear	?	?	?	–	
	Acceptability	?	?	?	–	

According to Table 1, effects of motor and sensorial degenerations have been the most fully studied. It is reasonable, considering a large volume of the geriatrics studies provided implications on research. Although effects of many cognitive degenerations are identified, the underlying mechanisms remain a mystery. As Zhou et al. described in [20], the feature of big fonts, big buttons, large displays, and loud volume, is just the tip of the iceberg; below the water lie design modifications that reduce old adult's cognitive demands. Effects of emotional degenerations on performance and experience are not clear, and are also need to be further examined.

4.2 How to Accommodate for Elderly's Special Interests?

Based on the experimental results and the analysis of the literature, we summarized the approaches for accommodating the needs of the elderly:

Focus on Ability Rather Than Attribute. Age-related degenerations can be biological or chronological [24]. Chronological age is not enough for describing the age-related characteristics [71]. Vocal degenerations for instance, chronological vocal degenerations show strong relationships with aging, while biological vocal degenerations can be affected by overuse of vocal, consumption of tobacco and alcohols, psychological stress etc. [24]. We encourage focus on biological age-related degenerations in user backgrounds.

Consider Specific Tasks and Environments and Focus on Usage in Real Scenarios. Most studies conduct experiments under laboratory environments. The findings and recommendations are somewhat questionable when guiding for design in real scenarios because user performance and experience are highly dependent on experimental tasks and environments (Sect. 2.1).

Facilitate Learning of Interaction. Although having more barriers during interaction, the difference between the young and the elderly could be reduced with inclusive design approaches. Additionally, along with popularity of social media and social networks, effects of emotional degenerations are fading (Sect. 2.1). Older people are becoming increasingly interested in learning novel techniques for the purpose of entertainment, communication, social support etc. [26–28]. Designing solutions to help them learning is of great significance.

Be Prudent on Novel Interaction Techniques. Particularly, interaction performance and experience of older adults are highly related to the acceptance of technology. According to Zhou's acceptance model [20], a lack of knowledge on computers and experience may impede computer usage of the older adults. Low acceptance of older adults is also related to anxiety, diffidence and fear during interaction [11, 51].

Reduced Functionalities and Assistive Techniques for Special Needs as Secondary. Most of the researches focus on age-related difference during the interaction process. However, this gap also exists in learning to control and react to touch-based devices. For instance, the young adults and old adults show different learnability in navigation [21] and text entry tasks [34]. Unlike Millennials, older adults are not born with computer and the Internet. Tutorials or guidelines for general users probably not sufficient for an elder to get familiar with novel techniques. Learning to use assistive techniques will be a painstaking process for older people.

5 Conclusion

Building a thorough map of effects of age-related characteristics on touch-based interaction system become the crux of design for the elderly. In this work, we provided a literature review, specifying elderly's characteristics and determined factors (both experimental and practical) on performance and experience of using touchscreens. We also summarized the relevant design guidelines, and provided some novel perspectives of the inclusion design of technologies for the elderly. Research on elderly cognitive process during interaction, learning of interaction, and elderly-friendly feedbacks, remain the under-explored areas. This stimulates curiosity for future studies.

Acknowledgement. This paper is supported by the National Natural Science Foundation of China (61303137), the National Science and Technology Support Program (2015BAH21F01) and the Art Project for National Social-Science Foundation (15BG084).

Appendix

See Table 2

Table 2. Experiment settings in literature

Reference	Equipment	Task	Sample size (old + mid + young)	Age mean/SD	Environment
Chen 2017 [J]	21″ 1920×1080 touchscreen PC	One-directional-pointing; multi-directional-pointing, dragging-and-dropping	18(−) + 18 + 18	68.7/4.7	
Rodrigues 2016 [J]	Samsung ATIV Smart PC Pro 11.6″	Five variations of QWERTY entry: COLOR, WIDTH, PREDICT_WORD, SHIFTED, SIZE_INVISIBLE	20(5M15F) + 0 + 0	–/–	
Cáliz 2016 [C]	Szenio 10.1 capacitive multi-touch	Tap; Double tap; Long press; Drag; Scale up; Scale down and One-finger rotation in game	50(25M25F) + 0 + 0	–/–	
Smith 2015 [J]	Motorola Droid 4, FlexT9 Text Input suite, Version XT9, Version T9WRITE, Dragon Version 2	Physical QWERTY, onscreen QWERTY, tracing, handwriting and voice	25(9M16F) + 0 + 25	68.8/7.4	

(*continued*)

Table 2. (*continued*)

Reference	Equipment	Task	Sample size (old + mid + young)	Age mean/SD	Environment
Motti, 2015 [J]	Galaxy Note II (WXGA 1280×720 Super AMOLED); Galaxy Note 10.1(WXGA 1280×800 LCD)	Drag-and-drop	24(−) + 0 + 0	72.25/5.8	
Alshowarah 2015 [d]	Samsung Galaxy Ace S 5830, HTC wildfire, Samsung Galaxy Tab 2, Samsung Galaxy Note 10.1	–	22(−) + 31 + 50	–/–	
Acarturk 2015 [J]	iPad	Usability test on iPad use and email services	5(3M2F) + 0 + 5	72/2.35*	
Zhou 2014 [J]	Apple iPod Touch (3.5 in., 480×320), Dell Streak (5 in., 800×480), Samsung Galaxy Tab (7 in., 1024×600), Apple iPad (9.7 in., 1024×768)	Four daily task related to entry	32(7M25F) + 0 + 0	67.2/5.53	In-situ
Wulf 2014 [C]	iPad, 9.7″ 1024×768	Tap; drag; pinch; pinch-pan; rotate left and rotate right	20(9M11F) + 0 + 20	71.85/5.13	
Rodrigues 2014 [C]	Samsung ATIV Smart PC Pro 11.6″	–	–	–	
Muskens 2014 [C]	iPad 2.0	Four existing applications and one prototype	14(−); 12 (7M5F)	~69/–	Iin-simu
Motti 2014 [J]	Galaxy Note II (WXGA 1280x720 Super AMOLED), Galaxy Note 10.1 (WXGA 1280x800 LCD)	Drag-and-drop in a puzzle game	24(8M16F)	74.25/5.8	In-simu
Barros 2014 [C]	HTC Titan 4.7′, HTC Radar 3.8′	Vertical swipe; horizontal swipes; tap	9(2M7F); 9 (5M4F); 9(−)	80.7/–; 76.4/–; 84.4/–	
Schlick, Jochems 2013 [J]	Elo resistive 17″ TFT LCD(model 1715, 1280×1024)	Pointing; drag-and-drop	30 + 30 + 30	65.47/4.08	
Leah 2013 [C]	Apple iPad 3, Apple laptops	Pointing; dragging; crossing; steering	20(−) + 0 + 20	74.3/6.6	
Hwangbo 2013 [J]	4.3″ Android smartphone	Pointing	22(9M13F) + 0 + 0	70.55/–	

(*continued*)

Table 2. (*continued*)

Reference	Equipment	Task	Sample size (old + mid + young)	Age mean/SD	Environment
Nicolau, 2012 [C]	HTC Desire and ASUS Transformer TF101 Tablet	QWERTY entry	15(4M11F) + 0 + 0	79/7.3	
Mertens 2012 [M]	HP TouchSmart tm2-1090eg, 12.1 in. capacitive multi-touch, 1280×800	A new direct input technique based on swiping called swabbing	15(−) + 0 + 0	73.56/–	
Vella 2011 [C]	15″ TFT display, 1024×768	Clicking; dragging; clicking; magnetization	8 + 16 + 19 + 26 + 28	–/–	
Nishino 2011 [C]	A self-designed system on touchscreen	–	85(-) + 0 + 0	–/–	
Leung 2011 [j]	–	Icon usability test	18(−) + 18	–/–	
Bradley, 2011 [c]	Samsung Galaxy Tab	Daily tasks	–	–/–	in-situ
Moffatt 2010 [C]	Wacom Cintiq 12WX, 12.1″ pen tablet, 1280×800; Cintiq Classic pen	Pointing	12(6M6F) + 0 + 12	73/–	
Lepicard 2010 [C]	Dell Tablet PC Latitude XT2, 12.1″ inch LCD monitor,	Target selection	24(−) + 0 + 36	76.5/8.2	
Fezzani 2010 [J]	Apple Macintosh; Wacom DIP digitizer tablet; wireless pen	Pointing	14(6M8F) + 0 + 14	66.9/4.0	
Vigouroux 2009 [C]	15″ laptop, 1024×768 TFT display	Clicking; clicking and magnetization	15(7M5F3W) + 0 + 0	–/–	
Tsai 2009 [C]	ASUS MyPal A730W compatible PDA	Continuous-touch digit input	45(17M28F) + 0 + 0	67.6/–	
O'brien 2008 [J]	Dell 600-MHz Pentium 3	4 keyboard shapes, 3 keyboard arrangements text entry	24(−) + 0 + 24	69.67/4.27; 67.17/3.54; 68.33/2.88; 69.17/4.88	
Moffatt 2008 [C]	Fujitsu LifeBook T3010D Tablet PC	Tap; glide; entry	12(4M8F) + 0 + 12	72/–	
Moffatt 2007 [C]	Fujitsu 12.1″ tablet, 1024×768; inductive pen	Multi-dimensional tapping; menu	12(4M8F) + 12(3M9F) + 12	62.1/–, 76.3/-	

(*continued*)

Table 2. (*continued*)

Reference	Equipment	Task	Sample size (old + mid + young)	Age mean/SD	Environment
Li 2007 [C]	Hewlett-Packard iPAQ 5450, touch screen QWERTY keyboard	QWERTY text entry	63(20M43F) + 0 + 0	49.8/18.8	
Lee 2007 [C]	PDA(ASUS A730), Cell phone(Dopod 818)	Tasks in realistic environment	5(−) + 5 + 5	67.9/3.8	In-situ
Asano 2007 [J]	NTT DoCoMo P901i	Access all mobile Web sites and perform a task specific to each Web site	–	65.4/–	
Arning 2007 [C]	Toshiba Pocket PC e740, LCD-screen (Iiyama TXA3841, TN, 15″ 1024×768	"Create a new entry" and "change an existing entry")	32(16M16F) + 32 + 32	58.2/6	
Hourcade 2006 [C]	Compaq iPAQ 3950 PocketPC, 320×240; pen	Tap; touch	20(−) + 20 + 20	–/–	

References

1. Hertzum, M., Hornbæk, K.: How age affects pointing with mouse and touchpad: a comparison of young, adult, and elderly users. Int. J. Hum. Comput. Interact. **26**(7), 703–734 (2010)
2. Arning, K., Ziefle, M.: Barriers of information access in small screen device applications: the relevance of user characteristics for a transgenerational design. In: Stephanidis, C., Pieper, M. (eds.) UI4ALL 2006. LNCS, vol. 4397, pp. 117–136. Springer, Heidelberg (2007). https://doi.org/10.1007/978-3-540-71025-7_9
3. Motti, L.G., Vigouroux, N., Gorce, P.: Interaction techniques for older adults using touchscreen devices: a literature review. In: Proceedings of the 25th Conference on L'Interaction Homme-Machine, pp. 125–134. ACM, Talence (2013)
4. Chen, J., Or, C.: Assessing the use of immersive virtual reality, mouse and touchscreen in pointing and dragging-and-dropping tasks among young, middle-aged and older adults. Appl. Ergon. **65**, 437–448 (2017)
5. Hourcade, J.P., Berkel, T.R.: Simple pen interaction performance of young and older adults using handheld computers. Interact. Comput. **20**(1), 166–183 (2008)
6. Neerincx, M.A., Cremers, A.H.M., Kessens, J.M., van Leeuwen, D.A., Truong, K.P.: Attuning speech-enabled interfaces to user and context for inclusive design: technology, methodology and practice. Univ. Access Inf. Soc. **8**(2), 109–122 (2009)
7. Taveira, A.D., Choi, S.D.: Review study of computer input devices and older users. Int. J. Hum. Comput. Interact. **25**(5), 455–474 (2009)
8. Smith, A.L., Chaparro, B.S.: Smartphone text input method performance, usability, and preference with younger and older adults. Hum. Factors **57**(6), 1015–1028 (2015)

9. Holzinger, A., Searle, G., Nischelwitzer, A.: On some aspects of improving mobile applications for the elderly. In: Stephanidis, C. (ed.) UAHCI 2007. LNCS, vol. 4554, pp. 923–932. Springer, Heidelberg (2007). https://doi.org/10.1007/978-3-540-73279-2_103
10. Vigouroux, N., Rumeau, P., Vella, F., Vellas, B.: Studying point-select-drag interaction techniques for older people with cognitive impairment. In: Stephanidis, C. (ed.) UAHCI 2009. LNCS, vol. 5614, pp. 422–428. Springer, Heidelberg (2009). https://doi.org/10.1007/978-3-642-02707-9_48
11. Leung, R., McGrenere, J., Graf, P.: Age-related differences in the initial usability of mobile device icons. Behav. Inf. Technol. **30**(5), 629–642 (2011)
12. Asano, Y., Saito, H., Sato, H., Wang, L., Gao, Q., Rau, P.-L.P.: Tips for designing mobile phone web pages for the elderly. In: Jacko, J.A. (ed.) HCI 2007. LNCS, vol. 4550, pp. 675–680. Springer, Heidelberg (2007). https://doi.org/10.1007/978-3-540-73105-4_74
13. Gruber, N., Mueri, R.M., Mosimann, U.P., Bieri, R., Aeschimann, A., Zito, G.A., Nef, T.: Effects of age and eccentricity on visual target detection. Front. Aging Neurosci. **5**(2), 101 (2013)
14. Lee, C.-F., Kuo, C.-C.: Difficulties on small-touch-screens for various ages. In: Stephanidis, C. (ed.) UAHCI 2007. LNCS, vol. 4554, pp. 968–974. Springer, Heidelberg (2007). https://doi.org/10.1007/978-3-540-73279-2_108
15. Suleyman, A.S.: Effects of age on smartphone and tablet usability, based on eye-movement tracking and touch-gesture interactions. Doctoral Thesis (2015)
16. Modi, S.K., Elliott, S.J., Whetsone, J., Kim, H.: Impact of age groups on fingerprint recognition performance. In: 2007 IEEE Workshop on Automatic Identification Advanced Technologies, pp. 19–23. IEEE (2007)
17. Lanitis, A., Tsapatsoulis, N.: Quantitative evaluation of the effects of aging on biometric templates. IET Comput. Vis. **5**(5), 338–347 (2011)
18. Taljaard, D.S., Olaithe, M., Brennan-Jones, C.G., Eikelboom, R.H., Bucks, R.S.: The relationship between hearing impairment and cognitive function: a meta-analysis in adults. Clin. Otolaryngol. **41**(6), 718–729 (2016)
19. Barrantes, S.S.: Some aspects of ICT accessibility, usability and design methods with the young elderly (2006)
20. Zhou, J., Rau, P.-L.P., Salvendy, G.: Use and design of handheld computers for older adults: a review and appraisal. Int. J. Hum. Comput. Interact. **28**(12), 799–826 (2012)
21. Ziefle, M., Bay, S.: How to overcome disorientation in mobile phone menus: a comparison of two different types of navigation aids. Hum. Comput. Interact. **21**(4), 393–433 (2006)
22. Vella, F., Vigouroux, N., Rumeau, P.: Investigating drag and drop techniques for older people with cognitive impairment. In: Jacko, J.A. (ed.) HCI 2011. LNCS, vol. 6764, pp. 530–538. Springer, Heidelberg (2011). https://doi.org/10.1007/978-3-642-21619-0_65
23. Etcheverry, I., Terrier, P., Marquie, J.-C.: Assessing web interaction with recollection: age-related and task-related differences. Comput. Hum. Behav. **28**(1), 11–22 (2012)
24. Acartürk, C., Freitas, J., Fal, M., Dias, M.S.: Elderly speech-gaze interaction. In: Antona, M., Stephanidis, C. (eds.) UAHCI 2015. LNCS, vol. 9175, pp. 3–12. Springer, Cham (2015). https://doi.org/10.1007/978-3-319-20678-3_1
25. Morris, A., Goodman, J., Brading, H.: Internet use and non-use: views of older users. Univ. Access Inf. Soc. **6**(1), 43–57 (2006)
26. Vošner, H.B., Bobek, S., Kokol, P., Krečič, M.J.: Attitudes of active older Internet users towards online social networking. Comput. Hum. Behav. **55**, 230–241 (2016)
27. Dell, P., Marinova, D.: Are they acting their age? Online social interaction and identity in the elderly. In: Modsim International Congress on Modelling & Simulation Land Water & Environmental Management Integrated Systems for Sustainability, vol. 364, no. 3, pp. 2700–2706 (2007)

28. Wandke, H., Sengpiel, M., Soenksen, M.: Myths about older people's use of information and communication technology. Gerontology **58**(6), 564–570 (2012)
29. Hwangbo, H., Yoon, S.H., Jin, B.S., Han, Y.S., Ji, Y.G.: A study of pointing performance of elderly users on smartphones. Int. J. Hum. Comput. Interact. **29**(9), 604–618 (2013)
30. Grabowski, P.J., Mason, A.H.: Age differences in the control of a precision reach to grasp task within a desktop virtual environment. Int. J. Hum Comput Stud. **72**(4), 383–392 (2014)
31. Liao, M.J., Wu, Y., Sheu, C.F.: Effects of perceptual complexity on older and younger adults' target acquisition performance. Behav. Inf. Technol. **33**(6), 591–605 (2014)
32. Farhadi-Niaki, F., Etemad, S.A., Arya, A.: Design and usability analysis of gesture-based control for common desktop tasks. In: Kurosu, M. (ed.) HCI 2013. LNCS, vol. 8007, pp. 215–224. Springer, Heidelberg (2013). https://doi.org/10.1007/978-3-642-39330-3_23
33. Portet, F., Vacher, M., Golanski, C., Roux, C., Meillon, B.: Design and evaluation of a smart home voice interface for the elderly: acceptability and objection aspects. Pers. Ubiquit. Comput. **17**(1), 127–144 (2013)
34. Rodrigues, E., Carreira, M., Goncalves, D.: Enhancing typing performance of older adults on tablets. Univ. Access Inf. Soc. **15**(3), 393–418 (2016)
35. Tsai, W.-C., Lee, C.-F.: A study on the icon feedback types of small touch screen for the elderly. In: Stephanidis, C. (ed.) UAHCI 2009. LNCS, vol. 5615, pp. 422–431. Springer, Heidelberg (2009). https://doi.org/10.1007/978-3-642-02710-9_46
36. Zhou, J., Rau, P.L.P., Salvendy, G.: Older adults' text entry on smartphones and tablets: investigating effects of display size and input method on acceptance and performance. Int. J. Hum. Comput. Interact. **30**(9), 727–739 (2014)
37. Moffatt, K.A., Mcgrenere, J.: Slipping and drifting: using older users to uncover pen-based target acquisition difficulties. In: International ACM Sigaccess Conference on Computers and Accessibility, pp. 11–18. ACM (2007)
38. Fezzani, K., Albinet, C., Thon, B., Marquie, J.C.: The effect of motor difficulty on the acquisition of a computer task: a comparison between young and older adults. Behav. Inf. Technol. **29**(2), 115–124 (2010)
39. Cuaresma, J., MacKenzie, I.S.: A study of variations of Qwerty soft keyboards for mobile phones. In: Proceedings of the International Conference on Multimedia and Human-Computer Interaction, pp. 126.1–126.8. International ASET, Inc., Ottawa (2013)
40. Nicolau, H., Jorge, J.: Elderly text-entry performance on touchscreens. In: Proceedings of the 14th International ACM SIGACCESS Conference on Computers and Accessibility, pp. 127–134. ACM, Boulder (2012)
41. Findlater, L., Wobbrock, J.: Personalized input: improving ten-finger touchscreen typing through automatic adaptation. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 815–824. ACM, Austin (2012)
42. Nicol, E., Komninos, A., Dunlop, M.D.: A participatory design and formal study investigation into mobile text entry for older adults. Int. J. Mobile Hum. Comput. Interact. **8**(2), 20–46 (2016)
43. Lepicard, G., Vigouroux, N.: Touch screen user interfaces for older subjects. In: Miesenberger, K., Klaus, J., Zagler, W., Karshmer, A. (eds.) ICCHP 2010. LNCS, vol. 6180, pp. 592–599. Springer, Heidelberg (2010). https://doi.org/10.1007/978-3-642-14100-3_88
44. Yatani, K., Truong, K.N.: An evaluation of stylus-based text entry methods on handheld devices in stationary and mobile settings. In: International Conference on Human Computer Interaction with Mobile Devices and Services, pp. 487–494. ACM (2007)
45. Motti, L.G., Vigouroux, N., Gorce, P.: Improving accessibility of tactile interaction for older users: lowering accuracy requirements to support drag-and-drop interaction. Procedia Comput. Sci. **67**, 366–375 (2015)

46. Mclaughlin, A.C., Rogers, W.A., Fisk, A.D.: Using direct and indirect input devices: attention demands and age-related differences. ACM Trans. Comput. Hum. Interact. **16**(1), 1–15 (2009)
47. Moffatt, K., McGrenere, J.: Steadied-bubbles: combining techniques to address pen-based pointing errors for younger and older adults. In: International Conference on Human Factors in Computing Systems, CHI 2010, pp. 1125–1134. ACM, Atlanta (2010)
48. Mertens, A., et al.: Model based processing of swabbing movements on touch screens to improve accuracy and efficacy for information input of individuals suffering from kinetic tremor. In: Hippe, Z.S., Kulikowski, J.L., Mroczek, T. (eds.) Human – Computer Systems Interaction: Backgrounds and Applications 2. Advances in Intelligent and Soft Computing, vol. 98, pp. 503–522. Springer, Heidelberg (2012). https://doi.org/10.1007/978-3-642-23187-2_32
49. Jin, Z.X., Plocher, T., Kiff, L.: Touch screen user interfaces for older adults: button size and spacing. In: Stephanidis, C. (ed.) UAHCI 2007. LNCS, vol. 4554, pp. 933–941. Springer, Heidelberg (2007). https://doi.org/10.1007/978-3-540-73279-2_104
50. Wulf, L., Garschall, M., Klein, M., Tscheligi, M.: The influence of age and device orientation on the performance of touch gestures. In: Miesenberger, K., Fels, D., Archambault, D., Peňáz, P., Zagler, W. (eds.) ICCHP 2014. LNCS, vol. 8548, pp. 583–590. Springer, Cham (2014). https://doi.org/10.1007/978-3-319-08599-9_86
51. Sciarretta, E., Ingrosso, A., Volpi, V., Opromolla, A., Grimaldi, R.: Elderly and tablets: considerations and suggestions about the design of proper applications. In: Zhou, J., Salvendy, G. (eds.) ITAP 2015. LNCS, vol. 9193, pp. 509–518. Springer, Cham (2015). https://doi.org/10.1007/978-3-319-20892-3_49
52. Chen, W.: Gesture-based applications for elderly people. In: Kurosu, M. (ed.) HCI 2013. LNCS, vol. 8007, pp. 186–195. Springer, Heidelberg (2013). https://doi.org/10.1007/978-3-642-39330-3_20
53. Muskens, L., van Lent, R., Vijfvinkel, A., van Cann, P., Shahid, S.: Never too old to use a tablet: designing tablet applications for the cognitively and physically impaired elderly. In: Miesenberger, K., Fels, D., Archambault, D., Peňáz, P., Zagler, W. (eds.) ICCHP 2014. LNCS, vol. 8547, pp. 391–398. Springer, Cham (2014). https://doi.org/10.1007/978-3-319-08596-8_60
54. Barros, A.C.D., Leitão, R., Ribeiro, J.: Design and evaluation of a mobile user interface for older adults: navigation, interaction and visual design recommendations. Procedia Comput. Sci. **27**, 369–378 (2014)
55. Bergstrom, J.C.R., Jans, O.H.M.E.: Age-related differences in eye tracking and usability performance: website usability for older adults. Int. J. Hum. Comput. Interact. **29**(8), 541–548 (2013)
56. Witt, H., Lawo, M., Drugge, M.: Visual feedback and different frames of reference: the impact on gesture interaction techniques for wearable computing. In: International Conference on Human Computer Interaction with Mobile Devices and Services, pp. 293–300. ACM (2008)
57. Ott, R., Thalmann, D., Vexo, F.: Haptic feedback in mixed-reality environment. Vis. Comput. **23**(9), 843–849 (2007)
58. Lee, J.-H., Poliakoff, E., Spence, C.: The effect of multimodal feedback presented via a touch screen on the performance of older adults. In: Altinsoy, M.E., Jekosch, U., Brewster, S. (eds.) HAID 2009. LNCS, vol. 5763, pp. 128–135. Springer, Heidelberg (2009). https://doi.org/10.1007/978-3-642-04076-4_14
59. Park, Y., Heo, H., Lee, K.: Enhanced auditory feedback for Korean touch screen keyboards. Int. J. Hum Comput Stud. **73**, 1–11 (2015)

60. Lemaitre, G., Houix, O., Susini, P., Visell, Y., Franinovic, K.: Feelings elicited by auditory feedback from a computationally augmented artifact: the flops. IEEE Trans. Affect. Comput. **3**(3), 335–348 (2012)
61. Nishino, H., Goto, R., Fukakusa, Y., Lin, J., Kagawa, T., Yoshida, K., Nagatomo, N.: A touch screen interface design with tactile feedback for practical applications. Int. J. Space Based Situated Comput. **3**(1), 8–21 (2013)
62. Pitts, M.J., Burnett, G., Skrypchuk, L., Wellings, T., Attridge, A., Williams, M.A.: Visual–haptic feedback interaction in automotive touchscreens. Displays **33**(1), 7–16 (2012)
63. Üzüm, B., Göktürk, M.: The effect of vibrotactile feedback on novice older adults in target selection tasks. In: Robertson, M.M. (ed.) EHAWC 2011. LNCS, vol. 6779, pp. 171–179. Springer, Heidelberg (2011). https://doi.org/10.1007/978-3-642-21716-6_18
64. Hoggan, E., Brewster, S.A., Johnston, J.: Investigating the effectiveness of tactile feedback for mobile touchscreens. In: Conference on Human Factors in Computing Systems, CHI 2008, Florence, Italy, April, vol. 2008, pp. 1573–1582 (2008)
65. De Boeck, J., Vanacken, L., Coninx, K.: Target Acquisition with force feedback: the effect of different forces on the user's performance. In: Altinsoy, M.E., Jekosch, U., Brewster, S. (eds.) HAID 2009. LNCS, vol. 5763, pp. 11–20. Springer, Heidelberg (2009). https://doi.org/10.1007/978-3-642-04076-4_2
66. Schierholz, I., Finke, M., Schulte, S., Hauthal, N., Kantzke, C., Rach, S., Sandmann, P.: Enhanced audio-visual interactions in the auditory cortex of elderly cochlear-implant users. Hear. Res. **328**, 133–147 (2015)
67. Huyse, A., Leybaert, J., Berthommier, F.: Effects of aging on audio-visual speech integration. J. Acoust. Soc. Am. **136**(4), 1918–1931 (2014)
68. Faeth, A., Harding, C.: Emergent effects in multimodal feedback from virtual buttons. ACM Trans. Comput. Hum. Interact. **21**(1), 1–23 (2014)
69. Köpsel, A., Majaranta, P., Isokoski, P., Huckauf, A.: Effects of auditory, haptic and visual feedback on performing gestures by gaze or by hand. Behav. Inf. Technol. **35**(12), 1044–1062 (2016)
70. Park, E., Joon, K., Pobil, A.P.D.: The effects of multimodal feedback and gender on task performance of stylus pen users. Int. J. Adv. Robot. Syst. **9**(3), 1 (2012)
71. Motti, L.G., Vigouroux, N., Gorce, P.: Ease-of-use of tactile interaction for novice older adults. In: Zhou, J., Salvendy, G. (eds.) ITAP 2015. LNCS, vol. 9193, pp. 463–474. Springer, Cham (2015). https://doi.org/10.1007/978-3-319-20892-3_45