Cognitive, Perceptual, Sensory and Verbal Abilities as Predictors of PDA Text Entry Error and Instructions Across the Lifespan

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Abstract. Sixty-three participants (range from 18 to 85 years of age) completed 4 data entry tasks on an HP iPAQ 5450 via a touch-screen QWERTY keyboard, as well as a battery of neuro-cognitive tests. Entry errors and assistance required by participants were coded into categories. Multiple regression analyses revealed that episodic memory was the strongest predictor for stand-still errors and commission errors, while sensory abilities was the strongest predictor of omission errors. We suggest that raining sessions that familiarize older adults with the functions of specific keys (e.g. Spacebar and Backspace) and structure of the keyboard, complemented with visual or auditory feedback provided by the keyboard as methods to improve text entry accuracy.

Keywords: Human-Computer Interaction, PDAs, aging, text entry errors.

1 Introduction

Personal Digital Assistants (PDAs) are portable and powerful devices that offer many of the functionalities of standard PCs, such as a calendar book, contact list and internet capabilities. In addition, a range of software applications can be added that could potentially be used to assist older adults. For example, mobile computers can be a lifeline for those with memory problems accompanying normal aging, such as serving as reminders to take medication at specific times [15] or function as a way finding systems [11]. It can also provide a portable means of communicating with family, friends and healthcare providers.

However, issues relating to data input have been highlighted as an ergonomics problem that arises from such mobile computing devices [2]. It is documented in the literature that older adults make more text entry errors [4, 8, 9] that are attributed to declining sensory, perceptual, motor and cognitive functioning that accompany healthy aging [7, 14, 17]. Although recent developments have been successful at decreasing target acquisition errors [19, 23, 30] that are hypothesized to arise from poor visual and motor functioning, text entry is rarely perfect. In order to complement the effective use of these text entry developments, we need to support older adults users by developing training procedures that familiarize them with text entry, as well as specify design guidelines of the keyboard that are suited to the capabilities of these users.

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The first objective of the present study was to explore the types of text entry errors made and the assistance required to correct these errors. Three studies have categorized transcription errors (on a normal-sized keyboard) as substitution, intrusion, omission, and transposition [13, 21, 22]. These errors have been interpreted as reflecting perceptual confusion, failure to monitor the phrase sequence, and faulty assignment of movement specification [20]. On a handheld computer, Wright and colleagues [31] noticed that the most common error was to omit spacing between words among older adults. This was thought to reflect unfamiliarity with the keyboards. Errors resulting from wrong pressure and tapping the wrong letter were also noted. These errors have been attributed to arise from difficulties in visually discriminating among certain letters on the touch-screen keyboard. However, no empirical validation was provided for these speculations. In addition, no study has reported what types of instructions would be required to assist with text entry.

To explore the underlying sensory abilities and cognitive processes that may explain the occurrence of these errors and instructions, we employed a battery of neuro-cognitive tests to explore the predictive power of sensory-perceptual abilities, perceptual speed, episodic memory and verbal intelligence on the types of text entry errors and help instructions. One study has tied text entry performance to these abilities. Czaja and Sharit [9] demonstrated that visuomotor skills and memory predicted typing errors above and beyond computer experience. However, only the total number of errors was used as the dependent variable. Thus, the second objective of our present study will be to establish an empirical link between these abilities and different types of entry errors and instructions.

2 The Present Study

2.1 Methods

2.1.1 Participants

Sixty-three healthy community-living adults (43 women; 20 men) participated in this study. Participants ranged from18 to 85 years of age, with an average age of 49.8 (*SD* = 18.8) years.

2.1.2 Apparatus

A Hewlett-Packard iPAQ 5450 handheld computer running on Microsoft Windows® for Pocket PC 2002 was used for this experiment. The screen measured 2.26 inches wide by 3.02 inches tall and had a transflective LCD (64, 000 colors). A touch screen QWERTY keyboard was available for data entry that occupied approximately 1/3 of the area of the screen. The alphabets and number keys on the keyboard measured 3mm by 4mm in size.

2.1.3 Cognitive Tests

We employed a battery of standardized neuro-cognitive tests for assessing sensory abilities, perceptual speed, episodic memory and verbal intelligence [listed in Table 1]. Each selected test is the golden standard for assessing the abilities described and has been shown to have high validity and reliability. For more detailed descriptions of each test, refer to [12, 27].

2.1.4 Procedures

Each participant entered a series of short phrases in the PDA using a stylus via a QWERTY keyboard while sitting next to the experimenter. Information required for text entry tasks remained in view for the duration of each task. Button-presses and stylus interactions with the PDA, as well as all communications between the participant and the experimenter, was recorded by a Hitachi DZ-MV380A digital video camera.

After completing the PDA tasks, the experimenter administered the battery of neuro-cognitive tests listed in Table 1.

All text entry errors as well as help-requests and instructions were transcribed and coded from the video records. Errors were coded according to the criteria described by Wobbrock and Myers [29]. Each error was grouped into one of the following 7 categories:

DOUBLE: creating an unnecessary duplicate character after a target character
WORD: omitting characters within words or whole words in the designated phrase
LANDING: landing on keys adjacent to the target key
LAYER: unnecessarily switching between the upper/lower case layer of the keyboard (e.g. by pressing SHIFT or CAP lock)
CASE: entering a target character in the wrong case (i.e. creating a lowercase letter when it is supposed to be in uppercase, or vice versa)
IRRELEVANT: creating irrelevant characters in relation to the designated phrase.
NEEDED: deleting characters that are relevant to the designated phrase

Based on the video records, we also grouped all participant requests for help/information, confirmation or clarification into the following 9 categories:

LOCATE: showing participants the location of the keys/buttons
FUNCTION: explaining the use of a particular key
TYPO: pointing out to participants that there is either a missing character in the word or an extra unneeded letter in the word
ERASE: instructing Ss to erase/delete unwanted info
CONFIRM: experimenter validates that a key is correct when the participant asks
RULES_W: explaining rules of using a word processor
RULES_K: explaining rules of using a keyboard
KEY: instructing participants to press a specific key/button
REMIND: reminding participants the designated phrase to be entered

2.2 Results

The data was screened for outliers, defined as any value that was more than 3 standard deviations away from the average. Each outlier was replaced with a value 3 standard deviations either above or below the mean. For ease of visual display, the results are shown in 3 groups, each with an equal number of participants: younger adults (18-39 years), middle-aged adults (40-60 years), and older adults (61-85 years).

Table 1. Performance on the neuro-cognitive tests and results of regression analyses that used participant's age as a predictor

Neuro-cognitive tests	Age Group			R^2 Age	Ability
	Y	M	O		
	M	*M*	*M*		
Sensory abilities					
HSI [5]	23.14	22.40	26.33	.08*	auditory sensitivity
CSI [6]	11.38	11.80	12.71	.04	color discrimination ability
Snellen eye chart [1]	9.05	7.43	7.33	.33*	visual acuity
Perceptual-Motor					
TMT† [25]	22.10	40.01	49.81	.08*	motor speed
DSST† [18]	128.14	156.99	174.52	.36*	perception
Stroop† [12]					attention and inhibition
Word Reading	35.95	36.86	38.62	.02	
Color Naming	48.24	50.94	55.86	.23*	
Incongruent	79.52	91.35	105.95	.20*	
Episodic Memory					
RAVLT⌂ [16]					episodic memory
List A: 1st recall	8.48	8.14	7.00	.11*	
List A: 2nd recall	12.67	12.31	9.67	.17*	
List A: 3rd recall	14.90	14.40	10.95	.22*	
List B recall	8.00	6.12	5.67	.16*	
List A: Short delay	9.86	10.22	6.05	.14*	
List A: Long delay	11.00	9.66	6.10	.24*	
Verbal ability					
NAARTЖ [3, 28]	29.95	22.57	22.00	.13*	vocabulary

* indicates p < .05 Ж indicates number of words pronounced incorrectly
† completion time ⌂ indicates number of words correctly recalled

2.2.1 Neuro-cognitive Tests

A principle components analysis using a Varimax rotation confirmed that each test loaded on its respective factor. Table 1 displays the neuro-cognitive test performance across the 3 age-groups, as well as the age-related effects for each test component. In summary, performance on these tests was comparable to results obtained in previous research [12, 16, 28] indicating that our sample consisted of a group of cognitively healthy adults.

2.2.2 Data Entry Errors

Table 2 shows the summary for each type of text entry errors, as well as R^2 with age. The strongest age-related effect was found for typing words in an incorrect case, with older adults making 3 times more of these errors than younger adults. Older adults were also twice as likely to delete needed characters and to type in duplicate characters (presumably reflecting unsteadiness in applying pressure to the keyboard) compared to younger adults. Errors that involved landing in adjacent keys and errors that created unneeded characters showed no significant age-related effects. Younger adults made as many landing errors as older adults. It is possible that in fact older adults made Landing errors due to hand unsteadiness while younger adults were less cautious with entering text perfectly because they had the knowledge on how to reverse these errors.

Table 2. Basic descriptive statistics of each of the error types from each age group and the relationship between age and performance on each of the errors

Entry Errors	Age Group			R^2 Age
	Y	M	O	
	M	*M*	*M*	
Case	1.76	3.89	5.48	.23**
Double	.62	1.35	1.55	.15*
Irrelevant	2.19	2.70	3.85	.05
Landing	2.29	.72	2.19	.00
Layer	1.29	1.34	2.84	.09*
Needed	4.52	5.20	8.19	.12*
Word	.49	.62	.84	.07*

* indicates p < .05
** indicates p < .01

Table 3. Basic descriptive statistics of each of the instruction types from each age group and the relationship between age and performance on each of the instructions

Entry Ins	Age Group			R^2 Age
	Y	M	O	
	M	*M*	*M*	
Confirm	.20	1.02	1.97	.26**
Erase	0	.49	1.39	.38**
Function	.19	1.23	2.85	.40**
Key	.38	1.96	5.78	.36**
Locate	.08	1.51	4.54	.49**
Remind	.81	1.44	3.93	.41**
Rules_K	.33	1.05	3.01	.29**
Rules_W	0	.65	2.02	.25**
Typo	.29	.69	1.32	.20**

** indicates p =< .01

To identify the distinctiveness of the data entry error types, a principle components analysis with a Varimax rotation of the factors was conducted. The analysis revealed 3 distinct groupings, interpreted as Standstill (Double, Layer and Case), Commission (Irrelevant and Landing) and Omission (Word and Needed) errors.

2.2.3 Text Entry Instructions

Regression analyses with each instruction type on age revealed that age accounted for up to 50% of the variance in the data. Older adults required a substantially greater number of each type of help than the other participants [Table 3], suggesting that older adults were less familiar with the functions and location of keys. Among the request for location of a key, the Spacebar and Backspace were the most common. In the Rules_K category, the most common explanations given included telling participants that the Caps Lock must be off in order to use the Backspace key. For the Key category, the frequently given phrase is to press the Shift key to switch layers to see the hidden symbols on the number line.

A principle components analysis with a Varimax rotation was conducted to explore the distinctiveness of the types of text entry instructions. The analysis revealed 3 distinct factors, interpreted as Keyboard (Function, Key, Confirm and Locate), Rules (Rules_W and Rules_K) and Phrase (Erase, Typo, and Remind).

Table 4. Cross-correlations between entry errors and entry instructions

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Entry Errors																
1. Case	/															
2. Double	.37**	/														
3. Irrelevant	-.03	.11	/													
4. Landing	.05	-.12	.27*	/												
5. Layer	.35**	.39**	.03	.09	/											
6. Needed	.12	.20	.22	.29*	.17	/										
7. Word	.30*	.20	-.02	.06	.12	.38**	/									
Entry Instructions																
8. Confirm	.29*	.44**	.27*	-.10	.30*	.13	.23	/								
9. Erase	.29*	.44**	.19	.03	.28*	.21	.27*	.50**	/							
10. Function	.40**	.27*	.20	-.02	.30*	.33**	.31*	.44**	.49**	/						
11. Key	.54**	.49**	.20	.02	.62**	.33**	.35**	.59**	.52**	.70**	/					
12. Locate	.38**	.39**	.36**	.05	.34**	.36**	.24	.51**	.53**	.77**	.80**	/				
13. Rules_W	.31*	.36**	.29*	.20	.31*	.39**	.32*	.57**	.67**	.57**	.60**	.68**.	/			
14. Rules_K	.52**	.47**	.14	.05	.69**	.44**	.16	.43**	.43**	.59**	.79**	.62**	.59**	/		
15. Remind	.24	.49**	.30*	.18	.51**	.39**	.22	.36**	.50**	.35**	.60**	.69**	.59**	.62**	/	
16. Typo	.43**	.39**	.15	.01	.20	.36**	.40**	.3***	.50**	.44**	.42**	.47**	.61**	.53**	.42**	/

* indicates p < .05

** indicates p =< .01

Table 5. Regression of entry errors and instructions on neuro-cognitive components

	Standstill	Commission	Omission	Keyboard	Rules	Phrase
Verbal intelligence	-.11	-.11	.03	-.19	.00	-.16
Sensory abilities	-.19	.05	-.27*	-.22	-.10	-.25*
Perceptual-motor	.19	.07	.23	.03	.12	.33*
Episodic memory	-.41**	-.33*	-.02	-.32*	-.50*	-.16

† each number represents a standardized beta coefficient
* indicates p < .05
** indicates p =< .01

2.2.4 Relationship Between Text Entry Error and Instructions

All inter-correlations among the types of text entry instructions were significant, and these relationships ranged from moderate to strong [displayed in Table 4]. Very few significant inter-correlations were found among types of text entry errors, suggesting that there may be clusters of mistakes that participants make (i.e. making one type of error are also linked to making more of other types of errors). In particular, individuals that made more Double errors also made more Case and Layer errors. Participants that deleted Needed characters also made an increased number of Word errors, suggesting problems in monitoring text entry progress. Medium-sized correlations were found across text entry instructions and errors, suggesting that individuals making any types of entry errors required external instructions in assisting with task completion. Landing errors were shown to be not significantly related with requiring any extra help. One reason for this is that Landing errors follow a curvilinear trend with age, and a fundamental requirement for computing correlations is that both variables must fit a linear model.

2.2.5 Relationship of Errors and Instruction Categories with Neuro-cognitive Components

Multiple regression analysis was conducted to explore the predictive nature of the neuro-cognitive components on each error and instruction grouping. Better episodic memory was related to making less Standstill and Commission errors, and Keyboard and Rules instructions [Table 5]. This confirmed earlier speculations that monitoring phrase sequence is important in making correct entries. As expected, participants who forgot explanations of instructions given earlier were more likely to require these instructions again.

Poor sensory abilities predicted a greater number of Omission errors, while both worse sensory and perceptual-motor abilities were found to be related to requiring a greater number of Phrase instructions. These instructions were mainly related to pointing out to participants that there was a mistake in the entry and to correct this mistake. Poorer sensory abilities explained the failure to detect mistakes made in the entry. The increase of these instructions is also likely due to slower responses by the participants, whereby then the experimenter had to repeat the instructions several times because it was inferred that the participant did not hear or understand the instructions.

Verbal abilities were not a significant predictor of any categories of error or instruction. Although older adults were performing worse than younger adults on text entry and required more recovery instructions, aging is associated with improved verbal abilities. Older adults may have been able to use their verbal abilities to compensate for the negative effects of sensory and cognitive declines, thus attenuating the relationship.

3 Discussion

One of the major findings from this study reveals that not all types of errors are committed equally by older adults, and that they require all various types of instructions to assist in undoing these errors. In particular, the most frequent errors involved typing characters in the incorrect case. Poor episodic memory performance is one of the causes for the greater number of Case errors among older adults. These errors are most likely to arise when older adults forget to turn off Caps Lock to type lower case characters. In order to counteract this memory-related deficit, one recommendation would be to alert the user, either using visual or auditory cues, that the Caps Lock button is on when the entered characters are not at the beginning of a sentence.

Another explanation for why older adults make more of these errors may be due to the structure of the keyboard. The organization of layers (i.e. upper and lower case) seen in keyboards is often employed because the available space on the screen is very small on PDAs. The keyboard often requires the use of special function keys to access certain numeric and punctuation characters. It is known that moded styles of interaction can be confusing to users [24, 26] and this effect may be magnified with users who are unfamiliar with this type of arrangement. This is exemplified in the requests for Rules_K instructions by older adults (e.g. turn off Caps Lock to see the lower case characters). It appears that older adults are not familiar with rules associated with function-related keys upper case characters. Explicitly incorporating this type of instructions during the training sessions may ease confusion.

Hand unsteadiness and pressure-related errors were also noted among the participants. One input alternative to address these errors is for keys to be selected by removing the pen from the screen rather than by tapping [19]. However, this method is most likely to slow down typing significantly and is not particularly useful for users that do not have these problems. One suggestion would be to add this option under the input devices and allow the user to activate this option if desired.

One difficulty in entering text on a PDA is that it does not allow simultaneous monitoring of the keyboard and entered text. Thus, it is difficult to detect whether there are missing letters in the entry (Omission errors). For older adults, this is found to occur more frequently and that poorer sensory abilities are likely to magnify this relationship. There is evidence that adding non-speech sounds can enhance the usability of numerical keypads on small computer touch-screens [4] but the auditory feedback provided by the keyboard will depend on the noise levels in the working environment. An alternative would be to provide a visual indication that a character is missed, such as blinking the screen.

In terms of helping instructions, one of the common requests from older adults is to point out the location of the Spacebar and Backspace key. This group of participants was also more likely to ask for it again even after receiving the instructions earlier.

Previous research has demonstrated that older adults are able to learn new skills; they just take longer than younger adults [10]. Developing training sessions that include instructions that specifically point out the location of these 2 keys can prove helpful. Also, enabling the key to show a reminder when the key is pressed (e.g. a bubble showing SPACE for the Spacebar key) can help older adults in learning the keys better after the training session.

As explained in the Introduction, pocket computers can be simple to use and highly informative reminding devices, and as such could offer useful support to older people at work and elsewhere. The findings in this study indicate that declines in sensory and cognitive abilities impede accurate text entry. Suggestions are provided that may reduce text entry errors among older adults. However, the suggestions provided are based on findings obtained from a combination of statistical techniques and observations made during the study. Future usability studies will be needed in order to ascertain whether these guidelines and suggestions can indeed improve text entry for older adults.

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