INPUT RATES FOR A ONE-HANDED INPUT DEVICE (OHAI) FOR CHINESE TEXT ENTRY

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As computer technology has become ubiquitous in nature, designers must develop text-entry methods that can accommodate a variety of devices, cultures, and languages. This paper presents a study evaluating a One-HAnded Input (OHAI) device developed for mobile text-entry in Chinese. The device is a chorded keyboard system on which text is entered in Chinese using the *pinyin* system. Participants trained with the device for 10, 1-hour sessions. Their text-entry rates and their rate of input for individual chords were measured after each session. The Power Law of Practice was used to predict input rates after 100 hours of training. Predicted input rates approximate 16 characters per minute, approaching *pinyin* input rates on conventional keyboards. Input rates for individual chords were also measured in order that future iterations of the software may associate the most commonly used characters with the fastest-to-execute chords. The study also suggests several potential future improvements to the OHAI system, such as augmenting the software with an autocompletion system.

INTRODUCTION

As the use of mobile technology increases, research in mobile text entry is flourishing, due at least in part to the fact that user needs are not currently being met by many mobile devices (Soukoreff, 2001). As the environment where computers are used changes, so to are we seeing a change in the population that uses them. An additional challenge for designers is to develop devices that can accommodate the range of cultures and languages in which the device will be used.

The One-HAnded Input (OHAI) device was developed in order to address these issues in text entry. The device operates under the theory of a chorded keyboard, described by Wickens (1998) as a device "in which individual items of information are entered by the simultaneous depression of combinations of keys, on which the fingers may remain." Advantages of a chorded keyboard system include (1) a reduction of required movement, making the chording board less susceptible to repetitive stress injury or carpal tunnel syndrome, and (2) after extensive practice, chording keyboards have been found to support more rapid word transcription processing than the standard typewriter keyboard, possibly due to reduced movement-time requirements (Seibel, 1964; Barton, 1986). On the disadvantage side, the primary cost of the chording keyboard is in the extensive learning required to associate the finger combinations with their corresponding actions (Richardson, et al., 1987).

There is a wide range of variety in the design of chorded keyboards. Chorded keyboards have been developed that vary along such dimensions as the number of hands used to operate the device (one vs. two), the number of buttons on the device, the shape of the device, and the number of chords available to the user. Each of the aforementioned advantages and disadvantages will likely vary with the specific design of the device.

The OHAI can be used in conjunction with a software system to enter text in either English or Chinese. Because the OHAI can be used with only one hand, and because it can conceivably be designed to rest in one's palm, it offers an option to address the users' need for mobile text entry devices. It could be used in conjunction with many mobile devices and with devices that have tight restrictions on available space.

There is also a need for devices that can be tailored to different cultures and languages. Numerous difficulties arise when entering text in a non-alphabetic language, such as Chinese. *Pinyin,* an official Chinese phonetic alphabet based on Roman characters, is used by 97% of computer users in China for daily input (Wang, et al., 2001). The system of software accompanying the OHAI is based on *pinyin*, but it addresses one of the bottleneck problems associated with the *pinyin* system and conventional keyboards. Because most Chinese characters are homophonic with many others, after typing the *pinyin* for a character, the user must choose and select a character by typing an identifying number, e.g. "2". This requires removing the hands from the "home row" and an accompanying shift of visual attention, as only a little over 30 percent of computer users claim to be able to touch type on the numeric keys; both of which contribute to slower typing rates (Wang, 2001). Because the hands are never fully removed from the OHAI device, this time cost is eliminated.

The study presented here was designed to gain some measure of the rate of text entry obtainable within a specified training period with the device, and some investigation of the learning curve over this time period. In addition, in order to make future improvements in the device and its software we hope to obtain some information regarding the relative difficulties of executing the individual chords.

METHOD

Participants

Subjects in the experiment were bilingual students enrolled in the Chinese Language program at their high school. All except one of the participants rated their reading and writing ability in Chinese as "good" or "excellent." Additionally, all but one of the participants rated their ability to use *pinyin* as "good" or "excellent." (Interestingly, the two participants who rated themselves as "fair" in one of the above two criteria performed in the top third of the group in their ability to use the device.) The age of the participants ranged from 14 to 18 years with an average of 16.27 years. Seven males and four females took part in the study.

The students were not paid for their participation, but were given a "reward" with an approximate value of $10 for coming each day. Prizes were given to the three participants with the fastest input rates at the end of the study.

Design

The study consisted of 11 participants, each receiving a total of 10 hours of practice time using the OHAI device and data-entry software. These 10 hours were broken into 5, 2-hour sessions, given over five consecutive days save for a two-day break over a weekend between the third and fourth day. To assess the data entry and error rates of the participants, each participant was given a chording test (measuring rates of chord execution) and a transcription test after each hour of practice (twice per training session).

Apparatus and Procedure

The OHAI device (Figure 1) was an ergonomically designed handset. On the device were five buttons, each positioned to be easily depressed with a given finger. The device therefore allowed for 31 different chords to be selected. The selection of a chord began when a participant depressed one of the buttons, and the execution of the chord occurred when the participant released the depressed buttons simultaneously. This allowed for self-correction of chord selection, prior to execution, if the wrong buttons had been originally depressed.

The OHAI handset worked in conjunction with a software program designed specifically for the nature of the device. The software presented the participant with a grid containing all of the possible chords, which remained on the screen while the device was being used (Figure 2). Each box of the grid also contained the character that would be executed if the corresponding chord was selected. The program provided visual feedback to the participants by highlighting the grid box that would be selected if they released the chord that was currently being depressed.

The grid screens were organized in a menu-like hierarchy. The first grid screen displayed the initial consonant phonemes for all Chinese characters (Figure 2). Once one of these phonemes was selected the second grid screen presented the all of the relevant vowel phonemes that lead to a real character. The third grid screen then allowed the user to select the tone of the character. The final grid screen listed all of the characters with the same pronunciation, determined by the *pinyin* string they had entered. The user then chose the desired character. The position of the chords remained constant throughout all of the grid screens, while the corresponding characters were naturally different in each grid screen.

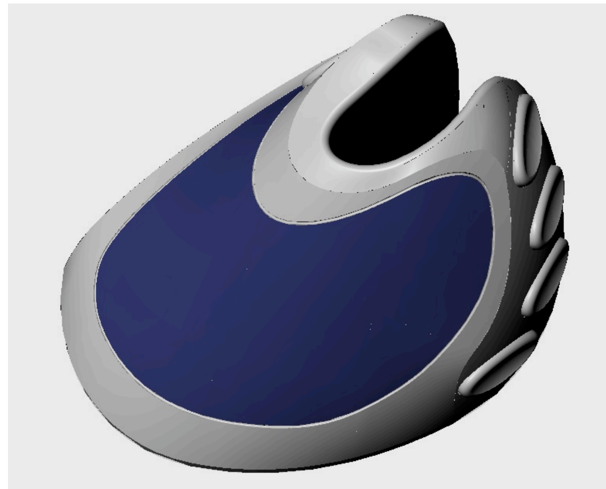

Figure 1. The OHAI device.

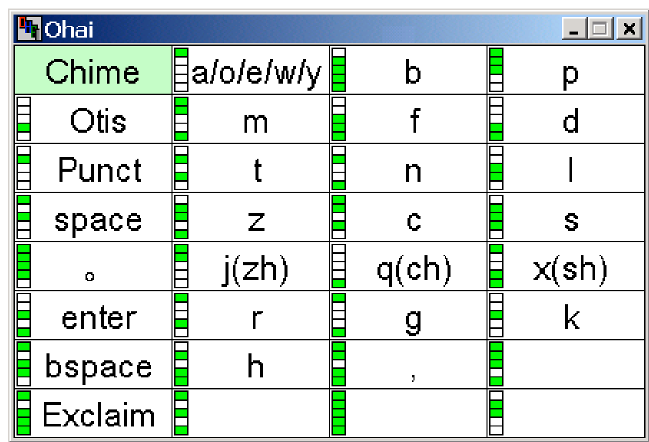

Figure 2. Initial grid screen for the OHAI *pinyin* typing program. The column on the left of each box represents the chord that must be executed in order to select that box. The top square of the column represents the thumb and the bottom square represents the "pinky" finger. For example, in order to select "space," the thumb and middle finger must be depressed and released simultaneously.

During each session participants first played one or two games designed to teach the chording combinations for approximately 10 minutes. For the next 10 minutes, they used a program that measured their entry rates for each chord combination. The next 30 minutes were spent with participants using a tutor program in which they were asked to transcribe sets of characters or short sentences. Finally, they used a testing program in which they were asked to transcribe full sentences. Times were recorded for each sentence from the point the participant entered the first character to the point at which they had entered a string of the same length as the target sentence. An adjusted characters-per-minute measure was calculated by dividing the number of correctly entered characters by the time taken to type the entire phrase. Participants were then given a 10-minute break, subsequent to which they repeated the same procedure of program usage.

RESULTS

Power law of Practice

The Power Law of Practice was applied to the data in order to extrapolate text-entry rates beyond the ten measurements obtained.

The Power Law of Practice has been used extensively to examine the learning curves of all types of skilled behavior, both cognitive and sensory motor (Card, Moran, and Newell, 1983). It states that the time to do a task decreases proportional to a power of the amount of practice as given by the following relationship:

> *The time T_n to perform a task on the nth trial follows a power law: $T_n = T_1 n^{-b}$ where T_1 is the time to do the task on the first trial and b is a constant.*

Text input data

The power law was used to predict the mean adjusted characters per minute based on the mean for the eleven participants after each hour of training. The best-fitting curve gives $T_n = 3.647n^{-0.315}$ (See Figure 3). The proportion of variance in the data accounted for by the power law (R^2) is 0.94. Figure 4 depicts the predicted learning curve extended to 100 hours of training. After 100 hours of training, the average characters per minute rate is predicted to approach 16 characters per minute.

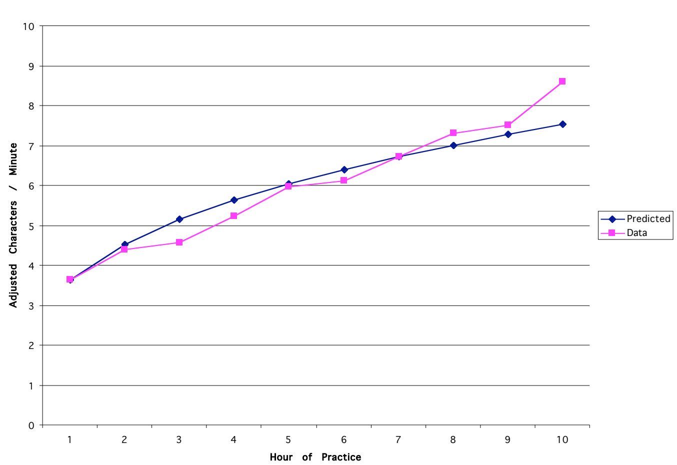

Figure 2. The learning curve as predicted by the power law of practice and the empirical data for the initial ten hours of practice ($T_n = 3.647n^{-0.315}$, R^2 = 0.94).

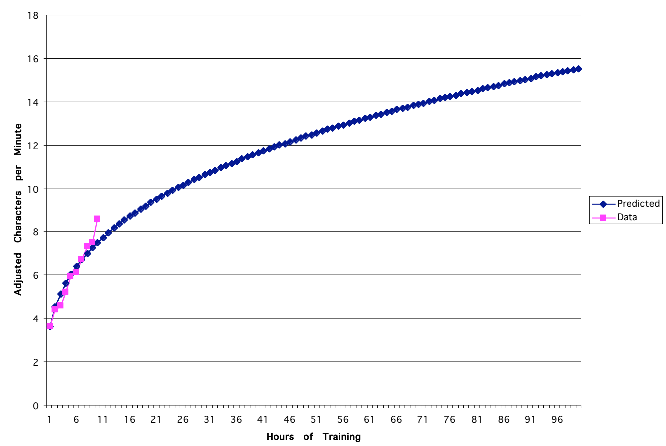

Figure 4. Learning curve up to 100 hours of training as predicted by the Power Law of Practice ($T_n = 3.647n^{-0.315}$, R^2 = 0.94).

The data used in the calculation of the power law were based on the mean adjusted characters per minute after each hour of training collapsed across all eleven subjects. However, it should be noted that each individual showed the same basic pattern in his/her data, which corresponds to the pattern predicted by the power law of practice (see Figure 4). Participants' rates of entry ranged from 2.5 to 6.5 adjusted characters per minute after the first day of training (first two hours of practice) to 4.95 to 13 adjusted characters per minute after the last day of training (last two hours of practice) with mean adjusted characters per minute of 4.03 and 8.07, respectively.

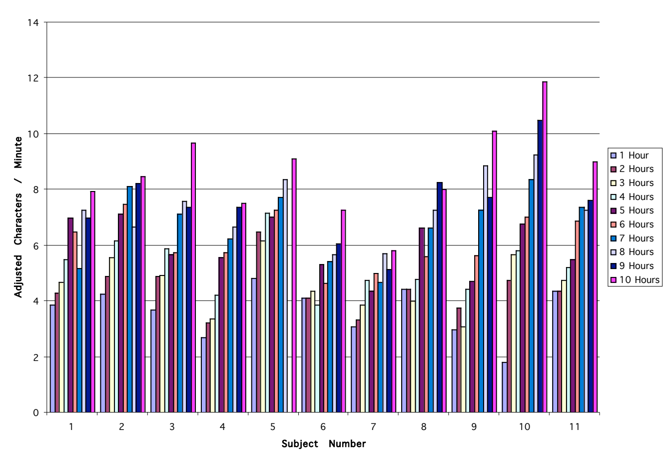

Figure 4. Mean adjusted characters per minute after each day of training (two hours) for each individual subject, depicting the same general trend in improvement over the course of the study.

Error and Omission Rates

The average rate of errors and omissions was 1.507 characters per 30-character sentence, or 5%. Statistical analysis showed that there was no significant change in error rate for each individual across the ten hours of practice F(9,72) = 0.55, $p < 0.66$.

Chording data

The time for participants to complete each individual chord was measured during the testing phases of each session. The program highlighted a chord combination, and the users' task was to execute that chord as quickly as possible. The time for each chord is therefore a combination of the mental mapping of the highlighted chord to the appropriate finger combination, and the physical execution of the finger presses and release.

A theoretical minimum time required to locate a cell on the grid and execute its relevant chord was calculated according to the Power Law of Practice; $T_n = 2.534n^{-0.353}$ (See figure 5). The proportion of variance in the data accounted for by the power law (R^2) is 0.98.

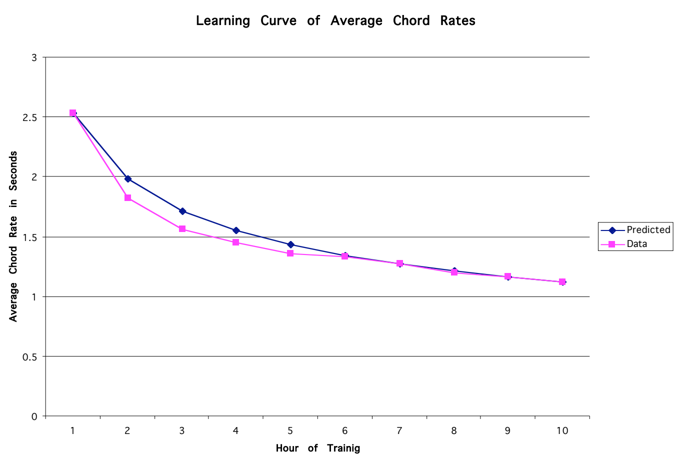

Figure 5. Average chord rate data and Power law of practice curve for the 10 hours of training. ($T_n = 2.534n^{-0.353}$, R^2 = 0.98)

By extrapolating on this learning curve we predict that the average chord execution time would approach 0.5 seconds after 100 hours of practice on the grid and handset. (See Figure 6.)

The chording-rate data were also examined by individual chords. As expected there were found to be significant and lasting differences in the execution speeds of the various chords. For instance, averaged over all 10 testing sessions, the chord with the fastest execution time was the single depression of the thumb at 1.02 seconds, followed closely by the depression of the pinky finger at 1.09 seconds. The slowest chord to execute was the combination of all fingers except the ring finger, with an average execution time of 2.09 seconds.

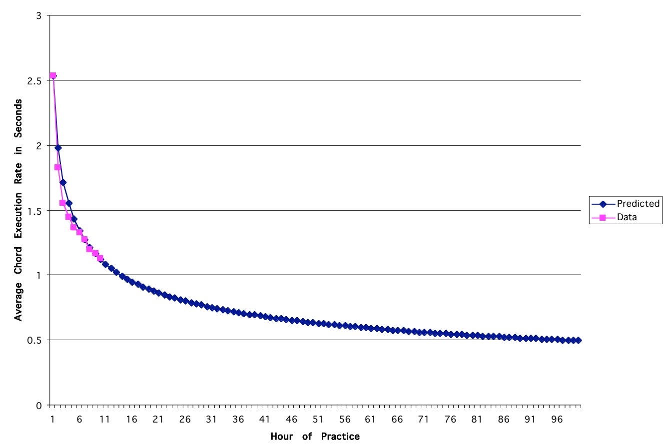

Figure 6. Average chord rate data and Power law of practice curve extrapolated to 100 hours of training. ($T_n = 2.534n^{-0.353}$, R^2 = 0.98)

The chords were ranked by average execution rate, and across all of the training hours the majority of chords maintained similar places in the execution speed ranking-list. However, the relative differences in the execution rates decreased as participants improved on the chording skill. After the first two hours of training the difference between the fastest and slowest chords was 2.28 seconds. After the last two hours of training the difference was reduced to 0.65 seconds.

DISCUSSION

The data predict a text-entry rate of 16 cpm after 100 hours of practice. This rate is slower but within the same range as *pinyin* text-entry using a conventional keyboard (approximately 21 cpm, depending on the system used, Wang et al., 2001). This is very promising, particularly since the device is operated with only one hand.

The predicted input rates are based on the Power Law of Practice, and it is important to note that the power law should be interpreted with certain caveats. For one, it may not cover all aspects of learning. It does not describe the acquisition of knowledge in long-term memory or apply to changes in the quality of performance. Quality does improve with practice, but it is measured on a variety of different scales, such as percentage of errors. Second, the Power Law of Practice may not hold at the extreme ends of extrapolation. For example, according to the power law, people never cease to improve at a task, although their rate of improvement will decrease. Therefore, predicted performance after a very large number of practice hours and for tasks with physical limitations to improvement should be interpreted with some trepidation.

There are also caveats that suggest that future iterations of the system might show improved text-entry rates. One use of the data regarding the average time to execute individual chords is a redesign of current software. Future iterations of the device will attempt to match the most frequently used characters with the fastest-to-execute chords.

Also, the current system does not take advantage of many advances in *pinyin* systems. Most *pinyin* programs do not have the users write out words one character at a time, rather the programs provide the most common words that start with the selected character. To accomplish this in the OHAI program would mean adding one more level of grid screens to the menu hierarchy. This would result in one word being entered in approximately 130% to 150% of the time required to enter one character. Since the average word in Chinese is about 2.5 characters this change could increase input rates by close to 100%, effectively doubling the characters entered per minute. It is fair to assume that adding one more level to the grid screen hierarchy would not dramatically change the shape of the learning curve calculated from this experiment; although it would presumably raise the curve. Therefore the predicted average input rates for the new program would be around 16 characters per minute after 10 hours of practice, and 30 characters per minute after 100 hours of practice. Some *pinyin* programs go one-step further and present users with the most common phrases that start with the word selected, further increasing the potential input rates with the device.

Future work will focus on evaluating the device augmented with the aforementioned suggested improvements, associating the most frequently used characters with the fastest-to-execute chords, and incorporating an autocompletion system. Additionally, current work is underway to develop a device to be used in conjunction with portable digital assistants (PDA's). It will be interesting to examine whether the chord execution rates reported here apply to the device as it is adapted for use with PDA's. Although we expect to see changes in the time to execute individual chords, we also expect the relative ranking of the individual chord execution rates to show little deviation. The relative ranking of the fastest-to-execute chords should provide a good starting point for the development of new one or two-handed chorded keyboards, and this information is freely available from the authors.

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