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A compatible chord code for inputting elements of Chinese characters

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Abstract

A compatible chord code for inputting elements of Chinese characters (ECC) to computer was proposed. It capitalized on the graphic compatibility between ECC and chord combination of keys (CCK) on a single-handed chord keyboard with five keys. Experimental results showed that the proposed compatible chord code was better than a code that randomly mapped ECC onto CCK with respect to learning time and response time. Explicit indication of the graphic compatibility between ECC and CCK did not enhance memorizing the compatible code. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Compatibility; Chord keyboard; Chinese character inputting; Elements of Chinese characters; Chord combinations of keys

1. Introduction

The keyboard is the primary input device of computer. The standard keyboard, referred to as the "QWERTY" keyboard, was developed to type English using the English language over 100 years ago. It was designed according to the principle of spatial allocation, where characters are entered through single keys in sequence. The layout of the QWERTY keyboard has been criticized for its poor ergonomic design (Noyes, 1983a, b; Conrad, 1965; Kroemer, 1992; McMulkin, 1994; Beddoes, 1994; Gopher, 1988). Many new sequential keyboard layouts have been developed since 1909 (Noyes, 1983a, b; Conrad, 1965; Kroemer, 1992; McMulkin, 1994; Beddoes, 1994; Gopher, 1988). Although some of them are better than the QWERTY keyboard with respect to ergonomic features, the market has not accepted them. Noyes (1983a) concluded that the development of a more efficiently arranged layout should remain purely an academic exercise.

Because innovations of the sequential keyboard have failed to gain acceptance, an alternative keyboard was developed according to the principle of chord, where pressing a combination of keys simultaneously (Noyes, 1983b) enters a character. A chord keyboard has several advantages. It offers the option of using one or two hands. Unlike a sequential keyboard, a chord keyboard can be operated with a single hand. The competitively small size of a chord keyboard enhances its portability and potential usability in hostile environments. Empirically, chord keyboards are also better than QWERTY keyboards in inputting alphabetic languages with respect to inputting speed and ease of learning (Conrad, 1965; Kroemer, 1992; McMulkin, 1994; Beddoes, 1994; Gopher, 1988). Moreover, because these chord keyboards are designed according to the principle of "chord" rather than "spatial allocation", using a chord keyboard has no negative impact on the skills required when using the QWERTY keyboard. Therefore, users of the QWERTY keyboard may accept chord keyboards more easily than alternative sequential keyboards.

Furthermore, chord keyboards create the opportunity of utilizing graphic compatibility between the graphic features of the characters and the spatial layouts of the chord combinations of keys. Compatibility, suggested by Fitts and Seeger (1953), is an important concept in the design of human–machine systems. It has been shown that: compatibility affects the information processing of the stimulus, the time of learning the mapping rule between stimulus and response, the error rate and the reaction time in response to the stimulus (Fitts and Seeger, 1953; Gopher, 1979; Liu and Zhang, 1997). Several successful designs utilizing the compatibility between characters and keys has been reported (Gopher, 1979;

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Liu and Zhang, 1997). For example, utilizing the Graphic compatibility between Hebrew characters and chord combinations of keys, Gopher (1979) developed a four-key chord typewriter for Hebrew characters. The experiment showed that a letter-shaped chord was acquired with little training and was highly resistant to forgetting.

The QWERTY keyboard, which was originally designed for typing English, has also been the primary device for inputting Chinese characters into computers. Because written Chinese is graphic language rather than an alphabetic language, more complicated steps are necessary to input Chinese characters than English letters. First, a Chinese character is divided into several elements based on the graphic information (graphic code) or the phonetic information (Kanji code); then each element is mapped onto a key of QWERTY keyboard. In this way, Chinese characters can be typed into computers in a fashion similar to English words (Cheng, 1994).

This approach has several shortcomings: (1) Although there is a natural relationship between Kanji (Chinese characters) and English letters, the QWERTY keyboard is not well suited for inputting English letters (Conrad, 1965; Kroemer, 1992; McMulkin, 1994; Beddoes, 1994; Gopher, 1988), let alone for inputting Chinese characters. (2) As far as graphic codes are concerned, there are no natural relationships between ECC and their corresponding keys on the QWERTY keyboard, so mastering the mapping rules requires rote memorization. Therefore, in order to input ECC into computers efficiently, a new kind of keyboard other than the QWERTY keyboard is needed.

We expect that when inputting elements of Chinese characters (ECC), pressing chords on a chord keyboard will be shown to be a superior alternative to pressing single keys on QWERTY keyboard for the following reason: Like Hebrew, written Chinese is one of the graphic languages, rich in graphic information. Therefore, ECC can be naturally mapped into chord combination of keys (CCK) according to the compatibility between the graphic features of ECC and the spatial displays of CCK.

In the following pages, we first propose a chord code that capitalizes on the graphic compatibility of ECC and CCK. We then describe an experiment designed to test the proposed chord code, and report the results of this experiment.

2. Compatible chord code

2.1. CCK Set

A single-handed keyboard with five keys was designed as presented in Fig. 1. We prefer single-handed keyboard to two-handed ones because the code of single-handed keyboard can be easily translated to two-handed keyboard, while the reverse translation would be problematic. Keys 2–4 were designed to be operated by the three middle fingers of one hand. For right-handed person, key 1 was operated by the thumb and key 5 was operated by the little finger; for left-handed person, key 1 was operated by little finger and key 5 was operated by the thumb.

Sixteen CCK were chosen from the all 32 (2^5) CCK in the five-key keyboard to match the ECC set proposed in the following description.

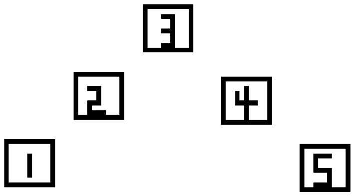


Fig. 1. General scheme of the Chinese chord keyboard.

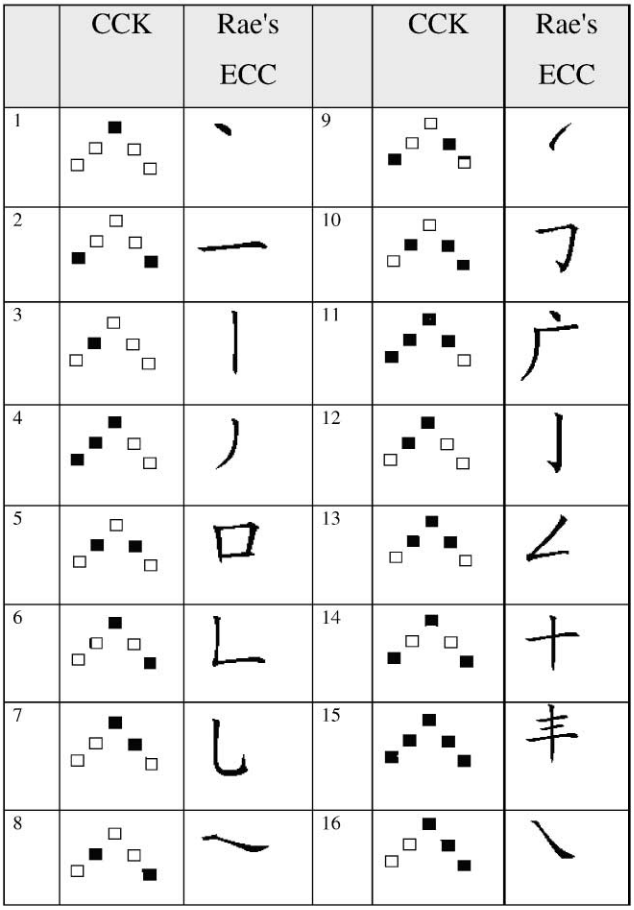


Fig. 2. Mapping rule of the compatible chord code (CCK filled in black).

2.2. ECC set

The ECC set of Rae's code (see Fig. 2), which can be used for inputting all Chinese characters, was used as the

ECC for our code (Cheng, 1994). There are thousands of codes that decompose all Chinese characters into elements (Cheng, 1994). We chose Rae's code for the following reasons: (1) it decomposes all Chinese characters into graphic elements. (2) To our knowledge, the Rae's code is one of codes with the fewest elements (only 16 elements). The fewer elements it has, the less of a burden it places on memory .

2.3. Mapping rule

We assigned each element of ECC Set to an element of CCK Set according to the graphic compatibility between them. The proposed mapping rule was illustrated in Fig. 2.

3. Experiment

In order to test whether the proposed chord code was well designed, we compared the proposed compatible chord code with two other comparable codes in terms of the time needed for mastering the mapping rules and the speeds for input elements of Chinese characters. Both of comparable codes used the same ECC set and the same CCK set as the proposed code. One differed from the compatible code in that it mapped ECC onto CCK randomly (random code). If the compatible code was better than the random code with respect to learning time and inputting speed, we could confidently claim that the compatible code was designed well. The other comparable code used the same mapping rule as the compatible code but differed in that it had a visual cue that explicitly indicated the graphic compatibility between ECC and the corresponding CCK (compatible + cue code). If it was not better than the compatible code with respect to learning time and inputting speed, we could confidently claim that the proposed compatible code was excellently designed because visual cues did not enhance this mastering.

3.1. Method

3.1.1. Subjects

Sixty subjects, 17–24 years old, were randomly assigned to three groups of 20. Each group was assigned one of the three codes to learn. All subjects were required to use their dominant hands throughout the experiment.

3.1.2. Materials

The differences among the three codes are illustrated in Fig. 3. In the compatible code, the ECC were mapped onto the CCK based on the graphic compatibility between the graphic features of ECC and the spatial layout of the CCK. The compatible + cue code is similar as the compatible code except that visual cues were put on the CCK to explicitly indicate the graphic compatible between the ECC and the CCK. In the random code, the ECC were mapped onto the CCK randomly.

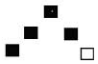
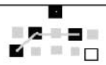
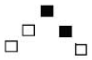
ECC	CCK		
	Compatible	Compatible + cue	Random
			

Fig. 3. Example of the mapping rules of the three codes (Black boxes corresponds to pressed keys).

3.1.3. Procedures

Participants were randomly assigned to one of the three groups with the constraint that each group contains an equal number of males and females.

3.1.3.1. Learning CCK. All of the participants practiced in pressing CCK on the single-handed Chinese chord keyboard according to the patterns displayed on a computer monitor. First, five white boxes were displayed with the same configuration as the Chinese chord keyboard. Then some of the boxes were filled in black. The subjects were instructed to press the corresponding keys on the Chinese chord keyboard. Then the pattern of another CCK was displayed. In this way, the 16 CCK were displayed in a random order in a session. The practice did not end until the subject could accurately press all CCK in two consecutive sessions. The elapsed time and numbers of sessions needed to produce two entirely accurate session were recorded for each subject.

3.1.3.2. Learning ECC and mapping rule. First, each participant studied one of the mapping rules printed on a piece of paper for 2 min. Then the 16 ECC were displayed one at a turn in a random order on a computer monitor, for three seconds each. The subjects were instructed to press the appropriate CCK according to the learned mapping rule as quickly as possible. If they pressed incorrectly, the correct CCK was displayed for participants to learn it again. The response error was recorded. After each of the 16 ECC had been probed, another training session followed. There were total 16 training sessions. The participant could have a rest between any two sessions. We used 16 training sessions because, in a preliminary study three subjects mastered the random mapping rules after 16 training session.

3.1.3.3. Testing phase. Participants were given 128 trials, 8 trials at each of 16 ECC. The trial order was randomized. The ECC in each trial was displayed on a computer monitor for 3 s. Participants were required to press the appropriate CCK as soon as possible. No feedback was given. The response time and the response error were recorded.

3.1.4. Results

3.1.4.1. Learning CCK. Subjects mastered the CCK with relatively little practice. The amount of practice required to master the CCK ranged from 8 min (four practicing sessions) to 76 min (38 practicing sessions), and was less than 26 min for half of the participants (13 practicing sessions).

3.1.4.2. Learning ECC and mapping rule. The number of correct response is plotted as a function of learning session and mapping rule in Fig. 4. The major results are these: it was much easier to master the compatible mapping rule than to master the random mapping rule. Second, the visual cue explicitly indicating the graphic compatibility between the CCK and the ECC did not contribute to mastering the compatible mapping rule.

These conclusions were supported by statistical analyses.

The number of the correct responses was analyzed using a repeated measures ANOVA with terms for learning session, and mapping rule. Learning session was with-participant, and mapping rule was between-participants.

The effect of learning session was significant, $F(15, 945) = 155.62$, $\text{MSe} = 2.54$, $p < 0.001$. The interaction between mapping rule and learning session was significant, $F(30, 945) = 13.63$, $p < 0.001$. The learning curves for the compatible group and for the compatible + cue group were identical. There was no significant difference in the patterns of the learning curves between the compatible + cue group and the compatible group, $F(15, 945) = 1.03$, $p > 0.1$. There was significant difference in the patterns of the learning curves between the random group and the other two groups, $F(15, 945) = 26.24$, $p < 0.001$. The effect of mapping rule was significant, $F(2, 63) = 47.57$, $\text{MSe} = 41.302$, $p < 0.001$. There was no significant difference between the compatible + cue group and the compatible group (the difference was 0.829), Boniferroni $t(3, 63) = -1.71$, $p > 0.1$. The average number of correct responses across the 16 sessions in the compatible group was significantly higher than that in the random group (the difference was 3.61), Boniferroni $t(3, 63) = 7.46$, $p < 0.001$.

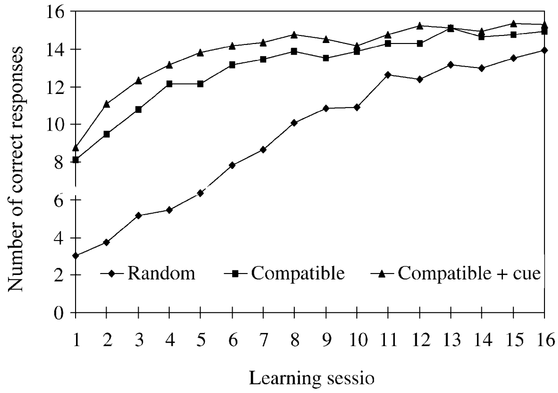


Fig. 4. The number of the correct response as a function of learning session and mapping rule.

Table 1
The response time and the number of correct responses as a function of mapping rule (total number of correct responses is 128)

	Random	Compatible	Compatible + cue
Response time (ms)	1055	875	854
No. of Correct responses	112	117.6	116.6

3.1.4.3. Testing phase. Two major results appear in Table 1. First, the participants who leaned the compatible mapping rule input ECC much more quickly than those who learned the random mapping rule. Second, it is not evident that the participants who leaned the compatible + cue mapping rule input ECC more quickly than those who learned the compatible mapping rule.

These conclusions were supported by statistical analyses.

The response time and the number of the correct responses were analyzed, respectively, using a repeated measures ANOVA with terms for mapping rule. The response time was measured as the latencies from the point when the ECC was displayed to that when the participant input the CCK. The effect of mapping rule in terms of the number of the correct responses was not significant, $F(2, 63) = 2.24$, $\text{MSe} = 88.79$, $p > 0.1$. This indicates that participants mastered the random mapping rule to the same level that they mastered the other two mapping rules during the learning phase. However, the effect of mapping rule in terms of response time was significant, $F(2, 63) = 30.42$, $\text{MSe} = 8890.55$, $p < 0.001$. The participants who learned compatible mapping rule responded quicker than those who learned random mapping rule (the difference was 180ms), Boniferroni $t(3, 63) = 6.35$, $p < 0.001$. There was, however, no significant difference of response time between the compatible group and the compatible + cue group (the difference was 21 ms), Boniferroni $t(3, 63) = 0.74$, $p > 0.1$.

4. Discussion

In using QWERTY keyboards, people need many translations of their fingers, each fingers at least among three keys. However, in using the single-handed chord keyboards, people reduce their motor translations to a minimum level, each finger fixed on one key. Therefore, it was very easy to acquire the skill of pressing the CCK on the proposed chord keyboard. Half of the subjects acquired the skill of pressing the chord without visually monitoring the pressing, in less than half of hour.

The result that participants who learned the compatible mapping rule much more easily than participants who learned the random mapping rule indicates that the graphic compatibility between the ECC and the CCK facilitated the learning of the mapping rule. In other words, the compatible chord code was designed well. The result that participants were easier mastering the compatible + cue mapping rule than the compatible mapping rule indicates that the compatible mapping rule was excellently designed. The explicit indication of the graphic compatibility, which was implicitly applied in designing the compatible mapping rule, had no significant effect on learning the mapping rule. It appears that the code capitalizes on a graphic compatibility that is innate, rendering the visual cue redundant.

Although the participants mastered the random mapping rule with extended practice, they input ECC more slowly than those who learned the compatible mapping rule. Participants who learned the compatible mapping rule performed as well as those who learned the compatible + cue mapping rule. These results again support that the compatible chord code was excellently designed.

In the present study, we conducted an experiment in inputting ECC rather than inputting Chinese characters. Generally speaking, we can generalize that a chord keyboard well designed for inputting ECC is also well designed for inputting Chinese characters. However, we should take into account the digram and trigram sequences in Chinese characters. It may be necessary to assign pairs of ECC that occur frequently together to fingers so as to avoid repetition of finger strokes as far as possible. There is no evidence that the proposed compatible chord code, which was fine for random sequences of ECC, will slow the input of whole words but we should test the proposed compatible chord code in Chinese characters before concluding finally that it is well designed for inputting Chinese characters.

In conclusion, using the graphic compatibility between ECC and CCK, we can design some promising codes for inputting Chinese characters, especially when limited space and number of keys are available.

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