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Abstract

A 2003 study by Green and Bavelier showed that action video-game playing modified the visual selective attention of habitual players. Here we tested whether processing of Chinese characters became more phonologically or orthographically oriented depending on whether participants were experienced typing with the phonology-based (*zhuyin*) or the orthography-based (*cangje*) word-entry method. In Exp. 1, 38 *cangje* and 40 *zhuyin* users typed a short text on a computer using the word-entry method they had experienced. Every keystroke was recorded and typing errors were categorized. In Exp. 2, 25 *cangje* and 25 *zhuyin* users had to circle all characters which contained a predesignated radical when they read a short passage. In Exp. 3, 25 *cangje* and 20 *zhuyin* users heard pairs of syllables and had to decide whether the two syllables in a pair shared the same onset consonant in one block of trials or the same rhyme in another block of trials. Analysis showed participants with extensive experience using phonology-based typing displayed more phonologically related typing errors, better sensitivity to the onset and rhyme of a syllable, but poorer sensitivity to the radical of a character. Participants with extensive experience using orthography-based typing displayed opposite results. Although the general cognitive system might be similar in the two groups of participants, the specific configuration of the system can vary to meet the demand of a particular design of the artifactual environment.

Keywords: human artifacts, cognition, Chinese characters, computer word entry.

Introduction

One striking difference between human and nonhuman species is that humans typically live in an artifactual environment they create. This means that when survival requires adaptation to the environment, humans adapt to a very different environment than nonhumans. How the artifacts we create affect our cognition is an important issue which has not been significantly addressed. Norman (1991, pp. 17-18) once remarked, “Despite the enormous impact of artifacts upon human cognition, most of our scientific understanding is of the unaided mind: of memory, attention, perception, action, and thought, unaided by external devices. There is little understanding of the information processing roles played by artifacts and how they interact with the information processing activities of their users”.

This picture has begun to change in recent years with the advocacy of the ‘extended mind’ hypothesis (Clark and Chalmers, 1998). Appreciating the active role of the environment in driving cognitive processes, the authors proposed that the human mind and the environment form a coupled system with continuous two-way interactions between the two.

The report of the Flynn effect also helped to change the picture. Flynn (1984) observed that the absolute scores on widely used tests of abstract reasoning have increased in North America and Europe since World War II. This effect is essentially worldwide with average scores on intelligence tests rising for the better part of a century (Flynn, 1987). The rate of gain amounts to three IQ points per decade, and it is even higher on certain specialized measures. The basis for these large gains remains unknown. Possibilities include a genuine increase in intelligence, greater sophistication about tests, better nutrition, more schooling, altered child-rearing practices, and most importantly here, the technology-driven changes of culture. With respect to the last possibility, Neisser (1997) suggested that the highly visual environment (e.g., television, video games, computers, picture puzzles, and mazes) may play a fundamental role in the increase in IQ scores. If intelligence is viewed as a set of cognitive skills (Hunt, 1995), technology-driven changes of our modern culture have probably induced changes in some aspects of human cognition.

Neisser’s hypothesis has been tested recently. A behavioral study by Green and Bavelier (2003) showed that action video-game playing enhanced the capacity of visual attention and its spatial distribution in the habitual players, as well as enhanced their task-switching abilities and decreased attentional blinks (failure to notice an event when it appears in a very rapid sequence of other events). Other behavioral studies have also reported similar effects in visual search (Castel, Pratt, & Drummond, 2005) and eye-hand motor coordination (Griffith, Voloschin, Gibb, & Bailey, 1983). The genetic studies by Lahn and colleagues (Evans, Gilbert, Mekel-Bobrov, Vallender, Anderson, Vaez-Azizi, Tishkoff, Hudson, & Lahn, 2005; Mekel-Bobrov, Gilbert, Evans, Vallender, Anderson, Hudson, Tishkoff, & Lahn, 2005) showed that the genes regulating and determining the brain size in humans (microcephalin and ASPM) have continued to evolve since they were first noticed. These genes have spread across the human population and increased in frequency at a rate that cannot be explained by a neutral drift. These researchers noted that 'the age of [these genes] and their geographic distribution across Eurasia roughly coincide with two important events in the cultural evolution of Eurasia—namely, the emergence and spread of domestication from the Middle East ~10,000 years ago and the rapid increase in population associated with the development of cities and written language 5000 to 6000 years ago around the Middle East' (Mekel-Bobrov, et al., 2005, p. 1722). Lahn suspected that 'these alleles may have provided an adaptive advantage in some brain related function' (reported in Balter, 2005, p. 1662). Together, these studies suggest that the artifactual environments which form the core of human cultures may select for structural and functional changes in cognition.

The present study assessed Neisser's hypothesis by testing whether using different computer word-entry methods in Chinese might change the users' sensitivity to different aspects of the language. In typing Chinese, two types of word entry methods are common. The *zhuyin* method is phonology based. The users key in the phonological contents of a character, which consist of the initial consonant, the medial vowel if there is one, the rhyme, and the tone. For the character 'zhuo' (桌), these include four keystrokes: /zh/, /u/, /o/, and 1 for the first tone. The users must possess the right phonological knowledge of a character to enter it on the computer. The *cangje* method is orthographically based. With this method, the requirements are very different. Each character is decomposed into a few radicals. To type a character requires keying in the radicals in a specified sequence (卜, 日, 木 for桌). The users must possess a fluent memory of the component radicals of each Chinese character to type with this method. As the methods show, one requires the users to maintain a correct memory representation of the sounds of a character and retrieve them when typing, while the other requires the representation and processing of the character's orthography. The question is whether the differential demands of the two methods result in differential sensitivity for the habitual users to the phonological and orthographic aspects of the characters. A reasonable prediction is that the *zhuyin* users tend to be more sensitive to the phonological aspect of the character, while the *cangje* users the orthographic aspect. This prediction was tested in three different experiments.

In Exp. 1, participants typed a short text on a computer using the word-entry method with which they were experienced. Every keystroke was recorded, and typing errors were categorized. It was hypothesized that the typing errors of the *zhuyin* users would be primarily phonological (i.e., errors that were homophonous to the targets), whereas those of the *cangje* users would be mainly orthographic (i.e., errors that resembled the targets in visual form). In Exp. 2, participants had to circle all characters which contained a predesignated radical when they read a short passage. It was hypothesized that the *zhuyin* users tended to miss more targets than the *cangje* users. In Exp. 3, participants heard pairs of syllables and had to decide whether the two syllables of a pair shared the same onset consonant on one block of trials or the same rhyme on another block of trials. It was hypothesized that the *cangje* users tended to respond slower than the *zhuyin* users.

Experiment 1

In this experiment, we gave the *cangje* and the *zhuyin* users a typing test and recorded the errors they made. Because the *cangje* users processed the characters in the orthographic mode, whereas the *zhuyin* users processed the characters in the phonological mode, we predicted that the *cangje* users should make more orthographically related errors while the *zhuyin* users should make more phonologically related errors.

Method

Participants

Participants were undergraduate and graduate students recruited from National Chung Cheng University and National Cheng Kung University. Their ages ranged from 18 to 24 years. Informed consent was obtained from each participant, who was paid 100 Taiwan dollars for their participation in an experiment that lasted about half an hour. There were 38 *cangje* dominant users and 40 *zhuyin* dominant users. The two groups of participants were matched for their typing speeds, which were on the average 60 characters per minute and were classified at between the advanced and the professional level according to the criterion of the Techficiency Quotient Certification of the Computer Skills Foundation, Taiwan.

Procedure

The experiment was conducted on an IBM-compatible personal computer with a Pentium 4 2.4G microprocessor and a 17-in. LCD monitor. The participants were asked to type a short text (492 characters long) using the word-entry method with which they were most fluent. Every keystroke was recorded by HyperCam, a computer program that captures the action from the Windows screen and saves it to AVI (Audio-Video Interleaved) movie file[1].

Results and Discussion

The errors the participants made were categorized into seven categories. Table 1 presents the mean number of errors in each category made by the *cangjie* and the *zhuyin* users. The results of the nonparametric median tests revealed a significant difference between groups for each category except 'other'. Of special interest to the purpose of the study, the *zhuyin* users made significantly more phonologically related errors while the *cangje* users made significantly more orthographically related errors (see row 1 and 2 of Table 1). The *zhuyin* users also made significantly more phonologically and orthographically related errors than the *cangje* users (row 3). Also of interest is the finding

[1] http://www.hyperionics.com/hc/

that the *cangje* users tended to miss a character, while the *zhuyin* users tended to add or substitute for a character. Overall, the *cangje* users made a greater number of typing errors than the *zhuyin* users, but the difference was not significant.

The results of this experiment indicate clearly that the kind of errors made in typing is constrained by the mode of processing in typing. The *cangje* users typed in the orthographic mode; therefore, their errors were primarily of the orthographic type. The *zhuyin* users typed in the phonological mode; therefore, their errors were primarily of the phonological type. The different modes of processing, once having become habitual, likely lead to additional processing consequences, which were tested further in Experiments 2 and 3.

Table 1: Mean number of errors in each category made by the *cangjie* and the *zhuyin* users, and the results of the nonparametric median tests between groups.

Error Category	*cangjie*	*zhuyin*	p <
phonologically related	0.05	2.3	.0001
orthographically related	1.39	0.03	.0001
phonologically and orthographically related	0.32	0.6	.0094
omission	5.29	1.28	.0001
addition	0.03	0.53	.0025
substitution	0.26	0.93	.0005
other	0.08	0	.1442
overall	7.42	5.65	.2813

Experiment 2

In this experiment, we asked the *cangje* and the *zhuyin* users to search for a predesignated radical in characters while they read a passage. Because the *cangje* users habitually paid attention to the orthographic detail of a character, they would be more likely to find the radical than the *zhuyin* users who habitually ignored the orthographic detail.

Method

Participants

Participants came from the same pool as that of Experiment 1. There were 25 *changjie* users and 25 *zhuyin* users, matched on their typing speed. Some of the *changjie* users also participated in Experiment 1.

Procedure

The participants were asked to circle all characters which contained a predesignated radical (日) when they read a passage (1236 characters long). The passage was printed horizontally from left to right on A4-size paper. There were 50 target characters in total, with each line containing at most one. The participants went through the passage only once, without looking back at the early portion of the story. They were asked five questions at the end of the task which assessed their comprehension of the passage. Except for four participants who answered one question wrong, all participants answered all the questions correctly, indicating comprehension was perfect.

Results and Discussion

The *zhuyin* users missed significantly more targets than the *cangje* users (48% vs 42%, $\underline{t}_{48} = 1.69$, $\underline{p} < .05$, one-tailed), a processing consequence that naturally followed from their habitual mode of processing.

Experiment 3

Experiment 3 examined the processing consequence that might be in favor of the *zhuyin* users. An onset and rhyme matching task was adopted, in which the participants heard two words and had to decide if they shared the same onset consonant, the same rhyme or neither. Because this task demanded the processing of phonological detail and the *zhuyin* users habitually paid attention to such detail, they would be faster in making the decision than the *cangjie* users.

Method

Participants

There were 25 *changjie* users and 20 *zhuyin* users, matched on their typing speed. Some of the *changjie* users also participated in Experiments 1 and 2.

Procedure

The participants listened to pairs of Chinese syllables, and were asked to judge for each pair if the syllables shared the same onset consonant or the same rhyme. The syllables were spoken by one of the authors, recorded, digitized, and played back via a pair of loudspeakers connected to the computer. There were a total of 160 pairs for consonant comparisons and 160 pairs for rhyme comparisons. Half of the pairs were positive (e.g., bao1 and bi2; the numbers indicate the tones), and the other half were negative (e.g., dao1 and bi2). The participants performed onset comparisons and rhyme comparisons in separate blocks, and the order of the two subtasks was counterbalanced across the participants. The experiment was programmed in DMDX (Forster and Forster, 2003). Response times were measured in milliseconds from the presentation of the second character of a pair to the participants' keypress.

Results and Discussion

The *cangje* users responded significantly more slowly than the *zhuyin* users [onset: 770 ms vs 680 ms, $\underline{t}_{43} = 2.5$, $\underline{p} < .02$ and rhyme: 758 ms vs 646 ms, $\underline{t}_{43} = 2.7$, $\underline{p} < .02$]. Error rates were comparable for the two types of users: 8.5% vs 9.1% for the *cangje* and the *zhuyin* users on the onset task, and 3.4% vs. 3.8% on the rhyme task ($\underline{p}$s > .05). Again, the result reflected a processing consequence that followed from the specific task demand and the habitual modes of processing of the two groups of participants.

General Discussion

Results from the three experiments indicated that different computer word-entry methods seem to modify the way a Chinese character was processed by the fluent typists. The phonology based typing resulted in more phonologically related typing errors, better sensitivity to the onset and rhyme of a syllable, but a poorer sensitivity to the radical of a character. The orthography-based typing led to the opposite consequences. The results suggest that long-term experience with a particular type of artifact can lead to cognitive changes.

One objection that may be raised against our interpretation is that our results demonstrated only correlation but not causation since we did not manipulate word-entry method. It is possible that our ***cangjie*** typists were more orthographically oriented, to begin with, while our ***zhuyin*** typists were more phonologically oriented. The different orientations led them to adopt different word-entry methods. This possibility is hard to assess and cannot be ruled out. We can only note that there are far more ***zhuyin*** users than ***cangjie*** users in Taiwan, simply because every child has learned the *zhuyinfuhao* (a pinyin-equivalent pronunciation system) in grade schools, which makes ***zhuyin*** typing fairly easy. In contrast, ***cangjie*** is a totally different 'spelling' system that requires separate learning outside of classrooms and much additional memorization effort. None of our ***zhuyin*** typists can type the ***cangjie*** way. But all of our ***cangjie*** typists can type with the ***zhuyin*** method, though very slowly.

Although our results can be interpreted as merely demonstrating an effect of learning or transfer from the conventional view, the interpretation may be limited in scope and perspective. Learning, by this view, is often accompanied by an intentionally designed target with an intended effect. It is explicit in nature. For example, people may learn arithmetic so that they can do addition, subtraction, multiplication, and division. Yet, much of the learning which occurs is incidental and unplanned (implicit in nature). Some may even be undesired. In other words, much of learning is related to the artifacts that surround us. Understanding and appreciating the effect of such learning requires a different view of learning than the conventional one. Although the conventional view does include the possibility that the brain and one's cognitive thinking that support learning can change, it misses a good part of learning and the massive effect of such learning on human brain and cognition. The artifactual view, which emphasizes incidental and unplanned learning, offers a more useful account of the results obtained in the present study. It also captures probably the most important aspect of learning.

The effects of computers (as human artifacts) on human cognition cannot be overstated as technological innovations increase. With the changing reliance on computer word processing, it is foreseeable that handwriting might become secondary in the future. When penless Chinese becomes reality, the way Chinese users represent and access Chinese characters and words mentally is likely also to change. This, in turn, will have a dramatic effect on learning and reading Chinese scripts. In fact, Xu[2] is currently experimenting on a computer-assisted program of teaching American students to learn Chinese characters without having them write the characters. The Penless Chinese Program is an ideal testing ground for examining whether and how Chinese characters might be represented and accessed differently by the students of the program.

Artifacts are diverse, but they fall in two broad categories of material and symbolic (Tomasello, 1999). Pen and paper, video games, and computer word entry involve material artifacts. Language and writing systems are symbolic artifacts; so are mathematics and logic. For Norman (1991), all of these are regarded as cognitive artifacts. According to Norman, 'a cognitive artifact is an artificial device designed to maintain, display, or operate upon information in order to serve a representational function' (p. 17).

Researchers from different but related fields such as philosophy, linguistics, and cognitive psychology have in fact been asking the questions of whether and how cognition might be modified or "reconfigured" through long-time interactions with the artifacts. The much debated Sapir-Whorf hypothesis (i.e., the language one speaks affects the way one conceptualizes the world) is a prime example of such an endeavor. The discussion of how literacy might change cognition and the brain organization is another (Eskritt, Lee, & Donald, 2001; Ostrosky-Solís, García, & Pérez, 2004). Even the argument for language-dependent processing (i.e., the architecture and processing mechanism of the presumed innate and universal language faculty vary according to the design characteristics of the particular language a speaker acquires), espoused by many psycholinguists (cf. Cutler, 1997; Chen, Chen, & Dell, 2002; Chen & Dell, 2006), may be regarded as addressing the same general issue. Finally, the recent advance of the concept of 'extended mind' (Clark & Chalmers, 1998) or 'situated cognition' (Clancey, 1997) is precisely speaking the same issue too. However, the focus of many of these endeavors is on the symbolic artifacts. Whether and how the material artifacts might affect cognition is an issue in need of serious and systematic investigation with greater effort from cognitive scientists.

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