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The Reversed Neighborhood Effects in Mental Arithmetic of Spoken Mandarin Number Words

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In the present study, under the spoken Mandarin number words format, we employed verification tasks to investigate the neighborhood effects in single-digit multiplication. The results revealed that, in the Arabic digits format condition, the neighborhood effects like as the former studies discovered is natural, however, the unexpected reversed neighborhood effects were found in the spoken Mandarin number words format. Specifically, RTs of higher neighborhood effects multiplication problems were longer than lower neighborhood effects.

Keywords: Single-Digit Multiplication; Neighborhood Effects; Reversed; The Spoken Mandarin Number Words Format

Introduction

How are mental arithmetic problems solving? Direct retrieval is an important way by which to come to a solution, and many theories have been proposed to describe the underlying mechanism of arithmetical fact retrieval (e.g., Groen, 1972; Siegler, 1988). How, then, are multiplication solutions stored and retrieved? An influential viewpoint is that problems are stored in an associative network (e.g., Campbell, 1995). However, there is no consensus on internal organization of this network. It is worth notice that interacting neighbors (IN) model provided a new meritorious feature (Frank et al., 2007; Verguts & Fias, 2005a, 2005b).

What IN model propose is that answers to multiplication problems are retrieved by the dual processes of cooperation and competition. If a particular problem is presented, a number of neighboring nodes in a semantic associative network are activated, each corresponding to a particular problem. For example, upon presentation of 4 × 8, the representation of the problems 4 × 9, 4 × 7, 5 × 8, and 3 × 8 will also be activated to some degree. Furthermore, if the different candidate solutions converge on the same unit or decade part of the answer, cooperation will occur between these answers, and retrieval will be comparatively easy. For instance, the answer "36" points in the correct direction for the decade part of the problem 4 × 8, but "28" does not. On the other hand, if many candidates point in a different direction (as "28" does for both decades and units), competition will ensue, and the retrieval process will be slowed down.

Tom Verguts and Wim Fias (2005b) subsequently proposed neighborhood effects in mental arithmetic. Specifically, neighborhood effect is the sum of tens and units' err form level. The tens' err form refers to the ten-digit of direct neighborhood-answer in the problem presented (e.g., 6 × 4) aggregate the number of ten-digit of correct answers and minus the number of ten-digit of the answers far from the correct answers. The units' err form is similar. The neighborhood effect level is the digits for tens add the digits for units. In the present study, both direct and arisen neighbor problems were employed.

On the other hand, the crucial assumption of the IN model is that not all problems is represented, rather, for each commutative pair of problems (e.g., 9 × 4 and 4 × 9), there is only one representational unit. The assumption that problems are stored in max × min order is not critical, as long as only one order is stored systematically (i.e., max × min or min × max).

In summary, IN model provided a novel perspective to reveal the mechanism of mental arithmetic semantic processing. Domahs et al. (2006; 2007) provided direct behavioral and neuroscientific evidence for the presence of neighborhood-consistency effects. They found that neighborhood consistency effects in simple multiplication stem at least partly from central (lexico-semantic') stages of processing. Domahs et al. (2007) expanded the task dimensions of the IN model, however, this model still needs to be improved or verified in many aspects since it is a new model. Verguts and Fias (2005b), IN model's founders, suggested that it is necessary to expand this model in the following three aspects: 1) The expression of mathematical formula in the "semantic field" in this model is simple and clear, but it is also too static and single, since it is not consistent to the main points of widely recognized encoding complex model. Because the individual's mathematical knowledge is a complex system, which contains many components and levels, and it constantly and dynamically changes along with the individual experience. 2) Previous findings were based on the study of Arabic numerals form, but the number has multiple surface forms, such as Arabic numbers, Roman numbers, spoken Mandarin numbers, and dot-matrix digits, etc., and many studies have found that numerical surface form not only affects the encoding stage, but also affect the retrieval phase and the production stage (e.g., Campbell & Metcalfe, 2008; Kadosh, 2008; Kadosh, Henik, & Rubinsten, 2008; Metcalfe & Campbell, 2008), that is, after stimulate the coding, problem in different numerical surface form remain its specificity and process in different paths, therefore, it is particularly important to expand the interacting neighbors model across numerical surface form. 3) Most studies suggest that most simple knowledge of the multiplication was stocked and retrieved from the interconnected network of memory (e.g., Rickard, 2005). Part of the activation on the problem still remained in the network when the problem was solved (e.g., Galfano, Rusconi, & Umiltà, 2003). Therefore, it is necessary to use priming paradigms to expand the IN model (neighborhood effects).

Based on this, the purpose of this study is: to expand on the cross numerical surface form of interacting neighbors model, in other words, to investigate whether the neighborhood-consistency effects are harmonious in form of spoken Mandarin number words or Arabic digits. The logic of this study is: If the response of high-consistency problem is shorter than low-consistency one, which indicates neighborhood-consistency effect is significant, so as to provide evidences to IN model's cross numerical surface form universals, otherwise, it couldn't provide evidences.

Experiment One Neighborhood Effects in Arabic Digits

Participants

Fifty healthy non-psychology-major college students (23 males, 27 females) participated in the current study. The age range was 19 - 23, and five participants were left-handed. All were Mandarin speakers with normal hearing who had not previously participated in our lab's experiments. Each subject was paid a small fee for participating.

Design

The present study adopted a 4 × 2 × 2 within-subject design. The three independent variables were SOA (0 ms, 200 ms, 500 ms, 800 ms), neighborhood effects (Low: –6, –4; High: 0, 2), and operand-order effects (smaller-operand-first entries, larger-operand-first entries). The dependent variable was reaction time for solutions.

Materials

Materials consisted of single-digit multiplication problems with a × b = c form. Solutions to each problem were classed as correct or incorrect. We used a total of 30 multiplication problems.

Stimulus materials were presented using Arabic digits forms which appeared on a computer monitor as white characters approximately 6 mm high × 4 mm wide against a black background.

Procedure

The experiment used a group-testing format. The formal experiment was preceded by twenty practice trials. Participants were asked to remain relaxed and natural during the whole experiment. The procedure was programmed by E-Prime software.

At the beginning of the trial, a white "+"was presented at the center of a computer screen for 800 ms. Then, the first stimulus "Op1" (multiplicand) appeared on the screen for 500 ms. After a blank period of 500 ms, the second stimulus "Op2" (multiplicator) appeared for another 500 ms. The third stimulus "Sol" (product) was presented either 0 ms or 800 ms after onset of the second stimulus 1 cm below the position of the Op2. Data from trials where the reaction time exceeded 1500 ms were not used. The subjects were asked to judge whether Sol was true or false.

To balance the frequency of occurrence of a specific number as a correct probe or error lure, each multiplication problem was presented twice (once per SOA). Altogether, each participant's data set consisted of 120 items error lures and 120 correct probes. The problems were presented in pseudo-randomized order such that the same problem could only be repeated after at least four distinct intervening problems. No more than four correct probes or lures was presented consecutively.

Using pseudo-randomized order, 240 trials were presented in 8 blocks, each containing 30 trials. During one block, the "yes" response had to be given with the left hand, and the "no" response with the right hand. During the other block, the response-hand assignment was reversed. The order of response-hand assignments was counterbalanced across participants and blocks. A short break was provided every 30 trials. Ten blocks together lasted approximately 25 minutes.

Results

Data from trials with incorrect responses and correct responses with RTs more than three standard deviations from the mean (3.9%) were eliminated.

RTs of neighborhood effects in different SOA conditions are listed in **Table 1** and **Figure 1**.

Table 1.
Reaction time (M ± SD) of neighborhood effects in different SOA conditions in Arabic digits format.

Neighborhood Effects	SOA			
	0 ms	200 ms	500 ms	800 ms
Low (–4, –6)	742.22 ± 3.88	529.64 ± 3.88	444.72 ± 3.90	423.98 ± 4.02
High (0, 2)	717.93 ± 3.26	513.68 ± 3.15	434.95 ± 3.20	420.03 ± 3.16

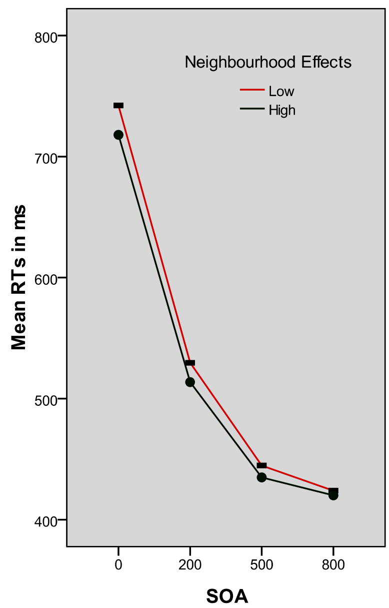

Figure 1.
RTs of neighborhood effects in different SOA conditions in Arabic digits format.

A 4 × 2 × 2 repeated-measures ANOVA was conducted with SOA, neighborhood effects, and operand-order effects independent variables and RTs as the dependent variable. Statistical results revealed significant main effects of SOA (F (3, 147) = 3106.00, p < .001), neighborhood effects (F (1, 49) = 28.52, p < .001), and operand-order effect (F (1, 49) = 60.45, p < .001). That is, RTs at the smaller SOA level was significantly longer than that at the bigger SOA level (M = 730 ms, SD = 2.53; M = 522 ms, SD = 2.50; M = 440 ms, SD = 2.52; M = 422 ms, SD = 2.56. SOA = 0 ms, 200 ms, 500 ms, 800 ms, respectively). We response to the multiplication faster in the condition of small number firstly presented (M = 519 ms, SD = 1.78) than the large number firstly presented (M = 538 ms, SD = 1.79; p < .001). RTs at high-consistency problem (M = 522 ms, SD = 1.60) is shorter than low-consistency one (M = 535 ms, SD = 1.96; p < .001). Some interactions were significant ($F_{\text{SOA × operand-order}}$ (3, 147) = 18.37, p < .001; $F_{\text{SOA × neighborhood effects}}$ (3, 147) = 2.94, p < .05).

Experiment Two Neighborhood Effects in Spoken Mandarin Number Words

Materials

The same as experiment one in "Participants", "Design", and "Procedur". Stimulus materials were presented using spoken Mandarin number words which were read aloud by a female voice. DJ-301MV outdoor-type ear headphones were used to present auditory stimuli at a moderate volume. Auditory stimulus was recorded by WaveCN1.70 sound-editing software. Each stimulus was recorded into a separate file in PCM audio form. The average data rate was 44,100 kb/s, the sampling rate was 22.50 kHz, and the audio sampling size was 16 bits with a single voice channel.

Results

The data from trials with incorrect responses and correct responses with RTs more than three standard deviations from the mean (4.3%) were eliminated.

RTs of neighborhood effects in different SOA conditions are listed in **Table 2** and **Figure 2**.

A 4 × 2 × 2 repeated-measures ANOVA was conducted with SOA, neighborhood effects, and operand-order effects as independent variables and RTs as the dependent variable. Statistical results revealed significant main effects of SOA (F (3, 147) = 1209.43, p < .001), neighborhood effects (F (1, 49) = 22.85, p < .001), and operand-order effect (F (1, 49) = 422.64, p < .001). That is, RTs at the smaller SOA level was significantly longer than that at the bigger SOA level (M = 907 ms, SD = 4.50; M = 695 ms, SD = 4.45; M = 589 ms, SD = 4.35; M = 566 ms, SD = 4.36. SOA = 0 ms, 200 ms, 500 ms, 800 ms, respectively). We response to the multiplication faster in the condition of small number firstly presented (M = 644 ms, SD = 3.07) than the large number firstly presented (M = 735 ms, SD = 3.18; p < .001). The neighborhood effect was also significant, but it was modified by an interesting inversion phenomenon. RTs at a high-consistency problem (M = 700 ms, SD = 2.82) is significantly longer than low-consistency one (M = 679 ms, SD = 3.41; p < .001). Some interactions were significant ($F_{\text{SOA × operand-order}}$ (3, 147) = 24.85, p < .001; $F_{\text{operand-order × neighborhood effects}}$ (1, 49) = 6.78, p < .01; $F_{\text{SOA × operand-order × neighborhood effects}}$ (3, 147) = 7.22, p < .001).

General Discussion

Under the condition of spoken Mandarin number words, neighborhood-consistency effects has a "reversal phenomenon", which is a high-consistency problem's reaction time is longer than the low-consistency problem's, and this phenomenon has been observed in all levels of SOA, these indicated that the task difficulty didn't impact the "reversal phenomenon", which is the opposite to the previous results in using Arabic numeral surface forms. Of course, whether there will be "reverse phenomenon" in neighborhood-consistency effects under other digital forms (such as Roman numeral form, dot matrix digital form, etc.) needs to be further investigated. Researchers have reported a similar inversion phenomenon for several numerical-processing effects, such as the SNARC effect (Zebian, 2005) and the distance effect (Turconi, Campbell, & Seron, 2006).

The differences of neighborhood-consistency effects in Arabic numeral surface form and in spoken Mandarin number words might be explained by the specificity of audio-visual sensory channel, because the presence of digital information resides longer in the visual channel than the auditory channel, therefore, digital information can easily be totally and instantaneously accepted without the impact of overlapping stimuli. While in auditory channels, the numerical information present is relatively short, and the digital information is only partial and non-instantaneously presented with the impact of overlapping (Anderson & Holcomb, 1995). This "reversal phenomenon" questioned the recent proposed IN model, indicated that the model does have a lot of aspects to be verified and to be corrected.

Differences of neighborhood-consistency effects in the Arabic numeral form and spoken Mandarin number words provide

Table 2.
Reaction time (M ± SD) of neighborhood effects in different SOA conditions in spoken mandarin number words format.

Neighborhood Effects	SOA			
	0 ms	200 ms	500 ms	800 ms
Low (–4, –6)	885.59 ± 6.85	688.93 ± 6.88	581.28 ± 6.72	559.12 ± 6.85
High (0, 2)	927.62 ± 5.93	702.05 ± 5.65	596.04 ± 5.52	573.78 ± 5.40

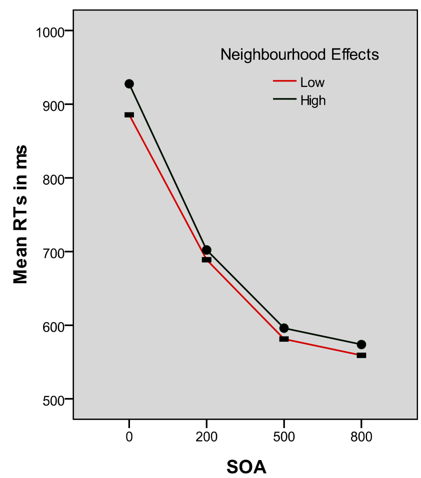

Figure 2.
RTs of neighborhood effects in different SOA conditions in spoken mandarin number words format.

evidence to support the hypothesis that the numerical surface form affects the specific pathways of cognitive processing. The specific pathway hypothesis assumes that the numerical surface form affects not only the encoding phase, but also the retrieval phase and the production stage. In other words, after stimulate the coding, problems in discrete numerical surface form remain its specificity and process in different paths (e.g., Campbell & Clark, 1988). A substantial body of research supports the separate-pathway hypothesis (e.g., Campbell, 1994; Campbell, 1999; Campbell & Clark, 1992; Campbell & Fugelsang, 2001; Campbell, Parker, & Doetzel, 2004; Metcalfe & Campbell, 2008).

The core hypothesis of interacting neighbors model is that "7 × 4" and "4 × 7" have only one representational unit, Butterworth et al. (2001) proposed the core assumptions of the COMP model took a similar view, However, Robert and Campbell's (2008) study found, "7 × 4" and "4 × 7" problems didn't have significant difference in reaction time in addition and multiplication tasks, thus demonstrated that "7 × 4" and "4 × 7" problems didn't have inherent comparison and have not been converted into a common internal representational unit, which also indicated that the "7 × 4" and "4 × 7" may have a different kind of problem representation. This discovery questioned the core assumptions of the IN model and the COMP model. The nature of the query is actually the controversy of the nature of the operand order effects. When we calculate a simple multiplication problem, the Chinese and Occidental showed the opposite effect of the operand order. The Chinese response to the multiplication faster with lower error rates in the condition of small number firstly presented (e.g., 3 × 8 = 24) than the large number firstly presented (8 × 3 = 24) when they calculate a simple multiplication problem. While the Occidental response in an opposing way. In the present study, we found that, the operand order effect is significant in the form of spoken Mandarin number words, which correspond to the COMP model and IN model, that is, supports the standpoint of "7 × 4" and "4 × 7" has only one representational unit.

Robert and Campbell (2008) found that people reaction were not significantly different in "7 × 4" and "4 × 7" problems in addition and multiplication tasks. But this "not significantly different" does not guarantee the internal mechanism of identity, and coupled with the study subjects were Canadians who learned the full multiplication table (containing both "7 × 4" and "4 × 7" problem). Maybe for the reason of their learning experiences, the perceptual transformation toward the "7 × 4" and "4 × 7" problems seem be automatic for them. Refer to the reaction, there may have slight differences, and this difference can't be detected at a statistically significant level.

Conclusion

In the present study, the similar neighborhood effects were found in the Arabic digit format like as the former studies discovered, however, the unexpected reversed neighborhood effects were found in the spoken Mandarin number word format.

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