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Feature of Cross-Culture in the Interacting Neighbors Model: Neighborhood-Consistency Effects

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The verification task is employed to investigate whether there is a neighborhood-consistency effect in the single-digit multiplication. It goes further in the expansion of cross-culture on the interacting neighbors model which was put forward recently, and examine whether this model possesses cross-culture or not. The results showed that both the operand-order effect and the neighborhood-consistency effects were significant. That the operand-order effect is significant shows that the special experience of learning the typical Chinese multiplication table affects participants in Chinese Mainland. That is, Mainland Chinese participants have specificity in single-digit multiplication. That the neighborhood-consistency effect is found in participants of Mainland Chinese shows the feature of cross-culture in the interacting neighbors' model.

Key words: interacting neighbors' model, neighborhood-consistency effects, operand-order effect, cross-cultural feature

Introduction

Operand-Order Effect

Unlike those used in the West, a typical Chinese multiplication table includes only smaller-operand-first entries (e.g., 4×9 = 36, but not 9×4 = 36. see Figure 1). Based on this unique feature, the simple multiplication for Mainland Chinese subjects has been found to show a robust operand-order effect. That is, participants in Mainland China took a shorter time to respond to smaller-operand-first problems (e.g., 4×9) than to larger-operand-first problems (e.g., 9×4). Zhou et al. (2007) ERP study revealed that, different from participants of Hong Kong and Macao who learn the whole multiplication table which include both larger-operand-first problems and smaller-operand-first problems simultaneously, when confronted with the larger-operand-first problems, subjects from Mainland China elicited greater negative potentials across representative electrodes of the entire scalp, emerging at about 120 ms after the onset of the second operand and lasting until around 750 ms; namely the operand-order effect was rather prominent.

Zhou and Dong (2003) presumed that participants in Mainland China store equations of the smaller-operand-first entries only and so when larger-operand-first problems were encountered, they needed to reverse the order of the problems, while this was unnecessary in coping with the problems of smaller-operand-first. LeFevre and Liu (1997) found that the latency which reversed the order of the two operands to form a familiar order was about 44 millisecond. Furthermore, the operand-order effect was discovered in the spoken Mandarin number words format, which showed characteristics of cross-number-form (Zhang, 2008). Zhou et al. (2007) suggested that the operand-order effect has been attributed to the early learning of the Chinese multiplication table. This operand-order sensitivity appears to stay with Chinese people for a lifetime.

1×1=1

1×2=2 2×2=4

1×3=3 2×3=6 3×3=9

1×4=4 2×4=8 3×4=12 4×4=16

1×5=5 2×5=10 3×5=15 4×5=20 5×5=25

1×6=6 2×6=12 3×6=18 4×6=24 5×6=30 6×6=36

1×7=7 2×7=14 3×7=21 4×7=28 5×7=35 6×7=42 7×7=49

1×8=8 2×8=16 3×8=24 4×8=32 5×8=40 6×8=48 7×8=56 8×8=64

1×9=9 2×9=18 3×9=27 4×9=36 5×9=45 6×9=54 7×9=63 8×9=72 9×9=81

Figure 1: *the Typical Chinese Multiplication Table in Arabic Form*

The operand-order effect reveals that participants in Mainland China have their uniqueness in the simple multiplication, providing an excellent medium for cross-culture research.

Interacting Neighbors Model

Many models attempted to reveal the essence of semantic processing for simple multiplication facts. They assumed that multiplication facts are represented in a network structure wherein problem operands constitute semantic categories, and that the products are category exemplars that are activated when problem operands are presented. The correct product can be retrieved from the network because it is semantically related to both operands and has a familiar association with a specific operand pair.

For simple multiplication facts, it is worthwhile to notice that the interacting neighbors (IN) model proposed by Verguts and Fias (2005a) in which learning and performance are governed by the consistency of a problem's correct product with neighboring products, provided a new meritorious feature. Their model introduced a new assumption: whether or not a product shares a common decade or unit value with neighboring products in the times table has a major impact on learning and performance.

IN model deems that double processing of promoting cooperation and competition are contained in the retrieval of products to multiplication problems. If the candidate product to be chosen is among the same unit or the same decade as the correct product, the cooperation will be promoted; the retrieval will be much easier. For example, “21” is in the same decade of the answer to the problem “7 × 4”, however, “35” is not. In other words, if the candidate product goes against the unit and decade of the correct answer, the competition will play a role and the retrieval will become slower.

The core component of the IN model is a semantic field representing the multiplication tables, and two crucial assumptions pertaining to this semantic field are put forward. The first is that the network is internally organized based on the size of the operands, which implies that problems with similar operands (e.g., 4 × 5 and 5 × 5) are stored closely together, an assumption that is shared by the table search models. The second assumption is that not all problems can be represented, specifically, that there is only one representational unit for each commutative pair of problems (e.g., 4 × 5 and 5 × 4), that is, only larger-operand-first problems (i.e., 5 × 4) are represented.

According to the schedule progress of problem solving, the entire model can be divided into four fields: ⑴ Input field. Two operands of the simple multiplication problems are embodied in two separate input field, the larger operand activates the corresponding node of max input field, in the same way, the smaller operand activates the corresponding node of min input field. For instance, with respect to 6 × 4, 6 activates the node of the maximum input field while 4 activates the node of the minimum input field. ⑵ Semantic field. The triangular bi-dimensional semantic field is where the diverse solutions are represented. Each multiplication problem can activate this field extensively, for instance, 6 × 4 will activate mainly the fourth rank in the sixth row in the semantic field, however, the adjacent rows and ranks can be activated to different degrees (for instance, the fifth rank in the sixth row). ⑶ Decomposition fields. In the decade field and the unit field, two parts can be available in the decomposition fields. For instance, the appearance of the problem 6×4 will activate its own node and the adjacent node in the semantic field. Furthermore, the activation can be spread to 20 in the decade field and 4 in the unit in decomposition fields. ⑷ Response field. The information in the decomposition fields must be converted into one single output. This is the fourth, yet last, field. This field contains the integer that is smaller than 100, but 0 is not available. If the response units reach the activated confidence interval, they will be executed.

Later on, Tom Verguts and Wim Fias (2005b) put forward neighborhood effects in mental arithmetic. Most relevant research provided evidence for the effect. For instance, in word naming, words that have at least one neighbor with a different pronunciation (e.g., GAVE, neighbor HAVE) yield longer response times than words without such a neighbor (e.g., WORD) (Glushko, 1979). Galfano, Rusconi, & Umiltà (2003) found that the presentation of two digits(e.g., 8 and 6) not only automatically activate the correct multiplication problem and the corresponding answers (Thibodeau, Lefevre, & Bisanz (1996) also identified this), but also activate the direct adjacent of the problems of such multiplication on problems (e.g., 40 (= 8 × 5), 56 (= 8 × 7)). In addition, Niedeggen and Rösler (1999) confirmed this assumption from an ERP study. The presentation of two digits was present in the separate unit and decade (Nuerk, Weger, & Willmes, 2001; Nuerk & Willmes, 2005). Consequently, neighborhood effects of mental arithmetic can be measured through the degree of separation in the unit and decade. The problem 8 × 6 is exemplified here. The correct product, 48, and the adjacent product 40 (40 = 8 × 5) share the common digit 4 in the decade, however, another adjacent product to problem 56 (56 = 8 × 7) possesses 5 which differs from the correct answer in the decade. Furthermore, the neighborhood effect provides a novel explanation for the tie effect, which possesses fewer immediate adjacent problems for the tie effect (e.g., 7 × 7) compared with the non-tie problems (for instance，6 × 7).

In conclusion, the relevant research of operand-order effect reveals that the extraordinary learning experience of obtaining multiplication knowledge affects the representation of multiplication knowledge in the brain, namely the simple multiplication for participants in Mainland China took on its own uniqueness. Yet the IN model put forward recently is based on the foundation of Western participants who are accustomed to the larger-operand first problems. Based on this, our explicit assumption is as follows: If the operand-order effect is prominent, the uniqueness of simple multiplication mental arithmetic for participants in Mainland China can be embodied. If the neighborhood effect is prominent, it is said to be that the IN model is applicable for simple multiplication mental arithmetic for participants in Mainland China. Namely, the model is equipped with the feature of cross-culture.

Method

Participants

Fifty healthy, non-psychology-major college students (male: 24, female: 26), whose ages ranged from 18 to 22, and of which six volunteers were left-handed. They had not attended a psychological experiment previously in our lab. Each subject was paid a small fee for participating.

Stimulus Materials and Experimental Approaches

Materials consisted of single-digit multiplication problems in the a × b = c form. The product of each problem was classed as correct or incorrect. Specifically, the incorrect product was expressed in a way (a - 1) × b + 2 which had no connection with both operands, for example, products for the problem of 8 × 6 were 48 and 44 (i.e., (8 - 1) × 6 + 2). Generally, 2 was added to the incorrect product, however, more importantly it required an answer that did not include either of the operands, and also conformed to the odd-even multiplication rule (that is odd × odd = odd, odd × even or even × even = even). Some operands (e.g., 0, 1, 5) and repeated operand problems (e.g., 6 × 6) were not used so as to avoid problem solving based on rule-based processes. Lastly, a total of 30 multiplication problems were employed.

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.

To balance the frequency of the occurrence of a specific number as a correct probe or error lure, each multiplication problem was presented twice, namely a total of 60 trials presented in 2 blocks could be available. Correct and incorrect products made up 50% of the problems respectively. Using pseudo-randomized order, half of the trials were correct products, and the other half were incorrect products. The order of response-hand assignments was counterbalanced across participants. Neighborhood-consistency effect adopted the method of calculation put forward by Verguts and Fias (2005b).

Procedure

The experiment used a group-testing format. The formal experiment was preceded by 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 0 ms after onset of the second stimulus. Data from trials where the reaction time exceeded 1,500 ms were not used. The subjects were asked to judge whether Sol was true or false. Time for rest and adjustment may last 10 minutes as long as possible between blocks. The concrete time for rest and adjustment could be determined by the participants according to their practical needs. They could continue to the next block by pressing any key. Experimental procedures are illustrated in Figure 2.

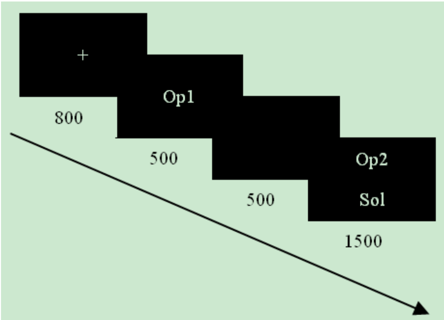

Figure 2: *the Experimental Procedures*

Results

The data from trials with incorrect responses and correct responses with RTs more than three standard deviations from the mean were eliminated. A 2 × 2 repeated-measures ANOVA was conducted with neighborhood effects and operand-order effect as independent variables and RTs or errors rate as the dependent variable. Statistical results revealed the following.

Analysis of Latencies

The main effect of neighborhood effects was significant, $F(1, 49) = 17.49$, $p < .001$. Specifically, RT at the lower neighborhood ($M = 742$ ms) was significantly longer than that at the higher neighborhood ($M = 718$ ms). The main effect of the operand-order effect was significant, $F(1, 49) = 63.41$, $p < .001$. That is, RT at larger-operand-first ($M = 753$ ms) was significantly longer than that at smaller-operand-first ($M = 707$ ms). The interaction was not significant, $F(1, 49) = 0.02$, $p = .90$. RTs of neighborhood effects in different operand-order effect conditions are illustrated in Figure 3.

Analysis of Errors

With respect to the main effects of neighborhood and operand-order, we found comparable features. The main effect of neighborhood effects was significant, $F(1, 49) = 2.88$, $p < .05$. Specifically, more errors were at the lower neighborhood (9.68%) than at the higher neighborhood (7.35%). The main effect of the operand-order effect was significant, $F(1, 49) = 2.45$, $p < .05$. That is, more errors were under larger-operand-first (9.59%) than under the smaller-operand-first condition (7.44%). The interaction was not significant, $F(1, 49) = 0.11$, $p = .74$. Error rate of neighborhood effects in different operand-order effect conditions is illustrated in Figure 4.

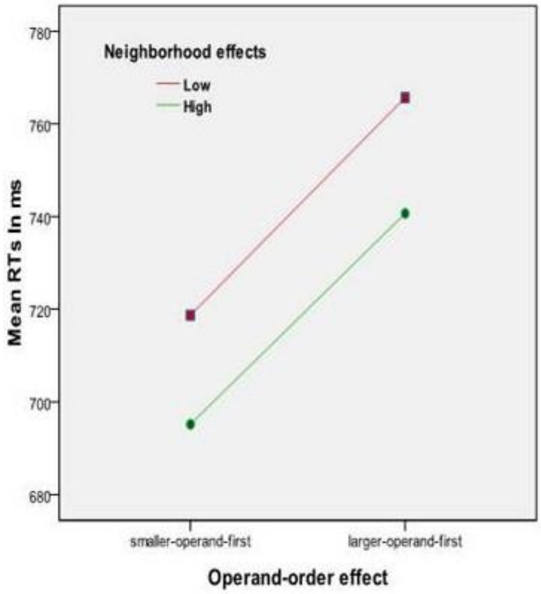

Figure 3: *RTs of Neighborhood Effects in Different Operand-order Effect Conditions*

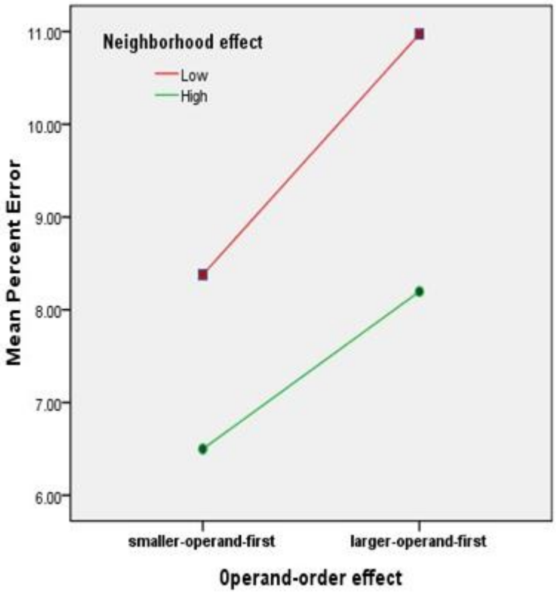

Figure 4: *Errors Rate of Neighborhood Effects in Different Operand-order Effect Conditions*

Discussion

The Uniqueness of Simple Multiplication for Participants

Our results substantiated the previous research that participants in Mainland China have access to uniqueness in simple multiplication mental arithmetic. We found that reaction time for the smaller-operand first problems is shorter than the problems of larger-order first, namely, the operand-order effect is rather prominent. The uniqueness of this finding for Mainland Chinese was accorded with an encoding complex hypothesis, which stressed that the individual learning experience has the function of modification for formation of mathematical cognition. Furthermore, the mathematical cognitive system witnessed dynamic changes as the individual experience changed continuously (J. I. D. Campbell, 1994). The existence of operand-order effect catered for us in researching cross-culture as an exceptional medium.

Feature of Cross-Culture in the IN model

In the present study, we found that the reaction time for problems with higher consistency is shorter than problems with lower consistency, namely the neighborhood-consistency effect was prominent, which provided the evidence for the core assumption of the IN model that the retrieval of answers to multiplication problems contained dual processing (promoting cooperation and depressing competition). We also discovered that the subjects in Mainland China demonstrated totally different operand-order effect from Western participants, which showed that participants in Mainland China possessed uniqueness in solving problems of simple multiplication mental arithmetic. Evidently, this implied the cross-culture feature of the neighborhood-consistency effect and the IN model.

Nonetheless, as to what Tom Verguts and Wim Fias pointed out, the IN model needed to be perfected in numerous aspects. (1) Although the IN model provides a simple and elegant explanation for diverse phenomena of multiplication memory, it is overly static and unitary, which does not accord with the mainstream hypothesis of an encoding complex model. (2) The conclusions of previous research are based on the form of Arabic numerals, however, the same quantity can be represented using multiple surface forms (e.g., Arabic digits, written or spoken number words, Roman numerals, etc.). Moreover, a large body of research suggests that the numerical surface form affects the encoding, retrieval, and generation phases of number processing. That is, numeric stimuli maintains their surface properties as specific codes throughout processing by various separate pathways (Campbell & Metcalfe, 2008; Kadosh, 2008; Kadosh, Henik, & Rubinsten, 2008; Metcalfe &

Campbell, 2008; Zhang, M., Si, J., Zhu, X & Xu, X., 2010). Consequently, the expansion on the surface form for the IN model appears quite important. (3) Plentiful research suggested that the simple multiplication knowledge is stored and retrieved from the interrelated memory network. Partial activation still remains on the network after one problem is practiced (Galfano et al., 2003). Therefore, priming paradigms needed to be employed for the IN model (neighborhood-consistency effects).

Domahs, Delazer and Nuerk (2006) concluded that operand-related errors were more likely to involve decade-consistent answers than decade-inconsistent answers, apparently supporting the IN model. Subsequently, in an ERP study, Frank et al. (2007) suggested that neighborhood-consistency effects stem at least partly from the central (‘lexico-semantic’) stages of processing. Their results were compatible with current models on the representation of simple multiplication facts – in particular with the IN model – and with the notion of decomposed representations of two-digit numbers in general. In the verified tasks, neighborhood-consistency effects were initially discovered, which expanded in the cross-task for the IN model. More recently, Zhang., Si, and Zhu (2012) employed verification tasks to investigate the neighborhood effects in single-digit multiplication. Their results revealed that, in the Arabic digits format condition, the neighborhood effects, as former studies discovered, is natural. Surprisingly, the unexpected reversed neighborhood effects were found in the spoken Mandarin number words format. Newly, Campbell, Dowd, Frick, McCallum and Metcalfe (2011) reported an experiment in which neighborhood-consistency effect was directly manipulated to test a variety of predictions related to the IN model. A robust neighborhood-consistency effect was presented in their results, which afforded unequivocal evidence for the IN model.

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