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The holistic processing of price comparison: Behavioral and electrophysiological evidences

Bihua Cao[a,b], Fuhong Li[a,b], Li Zhang[a,b], Yifeng Wang[a,b], Hong Li[a,b,*]

[a] School of Psychology, Southwest University, Chongqing 400715, China
[b] Key Laboratory of Cognition and Personality (SWU), Ministry of Education, China

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ABSTRACT

Although considerable studies have investigated the cognitive mechanism and the neural basis of number processing, it is unclear how numbers are represented in the practical context such as price comparison. In the present study, participants were asked to judge whether the target prices with different units (*yuan*, *jiao*, *fen*) were "higher or lower than 5 *jiao*" while event-related potentials were recorded. The behavioral results did not reveal a main effect of distance when distance was defined in terms of the digits of prices. However, a significant effect of distance was found when distance was defined in terms of the whole magnitude of prices. The electrophysiological results revealed similar distance effects (DE) during the 350–450 ms interval after stimulus onset, with an enhanced positivity for far distance than for close distance. These findings suggest that the digits and the units of prices are processed holistically rather than separately during a price comparison task.

1. Introduction

Number plays an important role in our everyday lives. It can be used to express amounts, compare prices, describe weight, and discuss journal impact factors, etc. (Cohen Kadosh and Walsh, 2009; Monroe and Lee, 1999). Several studies have investigated the neural mechanism of number processing and reported a typical distance effect (DE) on mental representations of numbers (Dehaene and Akhavein, 1995; Dehaene, 1996; Moyer and Landauer, 1967; Pinel et al., 2001; Temple and Posner, 1998; Zhou et al., 2007, 2008). However, it is unclear how numbers are represented in the practical context of everyday judgments, such as price cognition.

Price cognition refers to the cognitive processes that underlie consumers' judgments concerning the magnitude of a price or the difference between two prices (Adaval and Monroe, 2002; Janiszewski and Lichtenstein, 1999; Neidrich et al., 2001; Thomas and Morwitz, 2009). Price comparison is similar to multi-digit numerical comparison, which can explained by either a holistic model or a compositional (digital) model (Dehaene, 1997; Dehaene et al., 1990; Hinrichs et al., 1981). The holistic model claims that people often compute the whole magnitude of the multi-digit numbers or prices before comparison (Brysbaert, 1995; Dehaene et al., 1990; Reynvoet and Brysbaert, 1999; Thomas and Morwitz, 2005a; Viswanathan and Narayan, 1994). Alternatively, the compositional model posits that multi-digit numbers are represented digit-by-digit and processed separately (Nuerk et al., 2001; Poltrock and Schwartz, 1984).

However, previous studies on price comparison have mostly used the same unit (e.g. $). In reality, prices have many different monetary units. For example, "dollar" and "cent" are both used in America. When describing the price of a product, people often use a number together with a unit to denote it (e.g., "five dollars" or "eight cents"). In China, each price consists of a number and a Chinese monetary character (e.g., 1元 , 5角 or 6分). The basic unit of Chinese currency (Renminbi, RMB) is *yuan* (元) and the fractional units are *jiao* (角) and *fen* (分). 1 *yuan* equals 10 *jiao*, and 1 *jiao* equals 10 *fen*. So the relationship among the three Chinese units is '*yuan* > *jiao* > *fen*'.

The purpose of this study was to test whether price comparison is based on the holistic or the compositional model by using different monetary units. Twelve prices were designed as the target stimuli, which consisted of four digits (1, 4, 6 and 9) combined with three Chinese monetary units. Participants were instructed to judge whether the target prices were lower or higher than the standard price (5 *jiao*).

According to the holistic model (Brysbaert, 1995; Dehaene et al., 1990; Reynvoet and Brysbaert, 1999), subjects compute the whole magnitude of the prices before comparing them to the standard price. We expected that, if that were true, we would find a significant effect of distance, which is generally defined in terms of the

* Corresponding author at: School of Psychology, Southwest University, Chongqing 400715, China. Tel.: +86 23 68367960; fax: +86 23 68367960.
E-mail addresses: fuhongli@swu.edu.cn (F. Li), lihongwrm@vip.sina.com, lihong1@swu.edu.cn (H. Li).

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whole magnitude of price. For example, 6 *yuan* and 9 *yuan* are further while 1 *yuan* and 4 *yuan* are closer to 5 *jiao*. Specifically, we expected that the reaction times (RTs) would be shorter and the accuracies would be higher for prices with far distance (6, 9 *yuan*) than for prices with close distance (1, 4 *yuan*).

In contrast, the compositional model (Hinrichs et al., 1981; Nuerk et al., 2001; Poltrock and Schwartz, 1984; Thomas and Morwitz, 2005b, 2009) predicts that subjects process the digits and the units separately. They would first process the units which semantically functioned as the same as the decades digits of the two-digit numbers. When the unit of the target price is *yuan* or *fen*, which is different from that of the standard price, subjects can compare prices merely by processing the units of prices without considering their digits. If that were the case, there would be no distance effect among the prices with *yuan* or *fen* as units. Specifically, there would be no difference in reaction times (RTs) or accuracies between the prices with the same units (e.g., 1 *yuan* would be regarded as the same as 9 *yuan* when compared to 5 *jiao*). Nevertheless, when the unit of target price is the same as that of the standard price, subjects should continue to process the digits after identifying the unit. As a result, the RTs of target prices with *jiao* as units would be expected to be longer than of those with the other two kinds of units, as more time would be needed to process the digits. In addition, the typical distance effect (Dehaene and Akhavein, 1995; Pinel et al., 2001) would be found among the following prices: 1 *jiao*, 4 *jiao*, 6 *jiao* and 9 *jiao*. In other words, the prices with close distance to the standard price (4 *jiao* and 6 *jiao*) would have longer reaction times and more errors than those with far distance (1 *jiao* and 9 *jiao*).

Furthermore, we conducted high-density event-related potentials (ERPs) recording and analyzed the ERP complexes related to distance effects to investigate whether price comparison was processed separately or holistically. Previous studies have found that semantic processing of numbers activated the parietal cortex, and that the distance effect occurred at the parieto–occipito–temporal electrode sites during the N1-P2p and P2p time windows (Dehaene, 1996; Dehaene and Cohen, 1995; Pinel et al., 2001; Temple and Posner, 1998). The price stimuli used here included numbers and units, so the price comparison task was more difficult than number comparison task, and the timing courses of the semantic representation of price could be later relative to the P2p time windows.

2. Methods

2.1. Participants

Fifteen undergraduates (seven males and eight females, ranging from 18 to 24 years old; *mean* = 21.7 years; *SD* = 1.84) took part in this experiment. All participants were healthy, right-handed, had normal or corrected to normal eyesight, and signed an informed consent form for the experiment. After the experiment, each participant was paid RMB 20 *yuan* (about US $3.0).

2.2. Task

Participants were informed that prices of some goods in a shop would be presented on the computer screen. They were instructed to decide whether the prices were higher or lower than the standard price (5 *jiao*) as quickly and accurately as possible, by pressing the "F" or the "J" key using the left or right index finger. The assignment of higher or lower than 5 *jiao* to "F" or "J" keys was randomized among participants.

2.3. Stimuli

Twelve numeral price stimuli consisted of four numerical values (1, 4, 6 and 9) combined with three units (*yuan*, *jiao* and *fen*): 1 *yuan*, 4 *yuan*, 6 *yuan*, 9 *yuan*, 1 *jiao*, 4 *jiao*, 6 *jiao*, 9 *jiao*, 1 *fen*, 4 *fen*, 6 *fen* and 9 *fen*. Stimuli were presented in yellow on a blue background and subtended a visual angle of 2.8° when seen on a 17-inch computer screen from a distance of about 70 cm. Number in each price was presented in Times New Roman 50-point font and the unit was presented in SongTi 30-point font of Chinese monetary unit.

Table 1
Two types of definition of distance and the corresponding stimuli.

Units		Digit distance	Holistic distance
yuan	Close	4 *yuan*, 6 *yuan*	1 *yuan*, 4 *yuan*
	Far	1 *yuan*, 9 *yuan*	6 *yuan*, 9 *yuan*
jiao	Close	4 *jiao*, 6 *jiao*	4 *jiao*, 6 *jiao*
	Far	1 *jiao*, 9 *jiao*	1 *jiao*, 9 *jiao*
fen	Close	4 *fen*, 6 *fen*	6 *fen*, 9 *fen*
	Far	1 *fen*, 9 *fen*	1 *fen*, 4 *fen*

2.4. Procedure

A fixation cross appeared at the center of the screen for 500 ms. Then the target price was presented for 100 ms, followed by a blank screen until a response was recorded (see Fig. 1). The inter-stimulus interval (ISI) was varied randomly between 1000 and 1200 ms.

Participants were required to complete 20 practice trials. They were permitted to enter into the formal experimental sessions only when the accumulated accuracy reached 90%. Experimental trials were delivered in six blocks of 108 trials (for a total of 648 trials, with 216 trials in each unit). In addition, each condition was presented pseudo-randomly across prices. As a result, there was no repetition of price on consecutive trials. The entire experiment lasted approximately 40 min.

2.5. Electrophysiological recording

Electroencephalography (EEG) was recorded from 64-channel scalp sites using tin electrodes mounted in an elastic cap (Brain Products, German), with the linked reference on the left and right mastoids, and a ground electrode was placed on the medial frontal aspect. The horizontal electrooculogram (EOG) was recorded as the voltage between electrodes placed 1 cm to the left and right of the external canthi to measure eye movements, and the vertical EOG was recorded supra- and infra-orbitally at the left eye. The EEG and EOG were amplified using a 0.05–100 Hz bandpass. All interelectrode impedance was maintained below 5 kΩ. The averaging of ERPs was computed off-line with computer algorithms to reject those trials with eye movements, blinks, motion, or other artifacts at any of the channels. Trials with EOG artifacts (mean EOG voltage exceeding ±80 μV) and those contaminated with artifacts were excluded from averaging; as a result, about 6.4% of total trials were excluded (6.0% for the *yuan* units, 5.3% for the *jiao* units and 7.9% for the *fen* units). The resulting averages were baseline-corrected on the 100 ms prior to stimulus onset and low-pass filtered at 40 Hz.

3. Results

3.1. Behavioral results

Incorrect responses or the reaction times (RTs) fell beyond two standard deviations were rejected (2.3%). Then, accuracy rates and RTs were analyzed by the two below ways in order to test the hypothesis described in Section 1. First, accuracy rates and RTs were submitted to a repeated ANOVA with 3 (unit: *yuan* vs. *jiao* vs. *fen*) × 2 (distance: close vs. far) as within-subjects factors. Like previous studies (Dehaene, 1996; Temple and Posner, 1998; Pinel et al., 2001), the close or far distance was defined in terms of the value of digits. That is, the digits 1 and 9 have far distances from the digit 5, while the digits 4 and 6 have close distances (Table 1).

The accuracies of *yuan*, *jiao* and *fen* were 98.2%, 94.0% and 97.3%, respectively. The results of ANOVA indicated that there were main effects of unit and distance on the accuracies [$F_{unit}(2, 28) = 14.90$, $p_{unit} < 0.001$; $F_{distance}(1, 14) = 9.96$, $p_{distance} = 0.007$]. In addition, a significant interaction of distance by unit was found, $F(2, 28) = 21.56$, $p < 0.005$. Further analysis indicated that there was only distance effect for *jiao* unit, $F(1, 14) = 6.93$, $p = 0.020$. In contrast, no distance effect was found for *yuan* and *fen* (Fig. 2).

With respect to RTs, the results of ANOVA indicated that a main effect of unit was found, $F(2, 28) = 58.68$, $p < 0.001$. Paired comparison (LSD) showed that there were significant differences among three units ($p < 0.001$ for all comparisons). The RTs of *yuan*, *jiao* and *fen* were 528 ms, 598 ms and 557 ms, respectively. There was a significant effect of distance, $F(1, 14) = 27.88$, $p < 0.001$, with 10 ms faster for the far distance than close distance. There was a

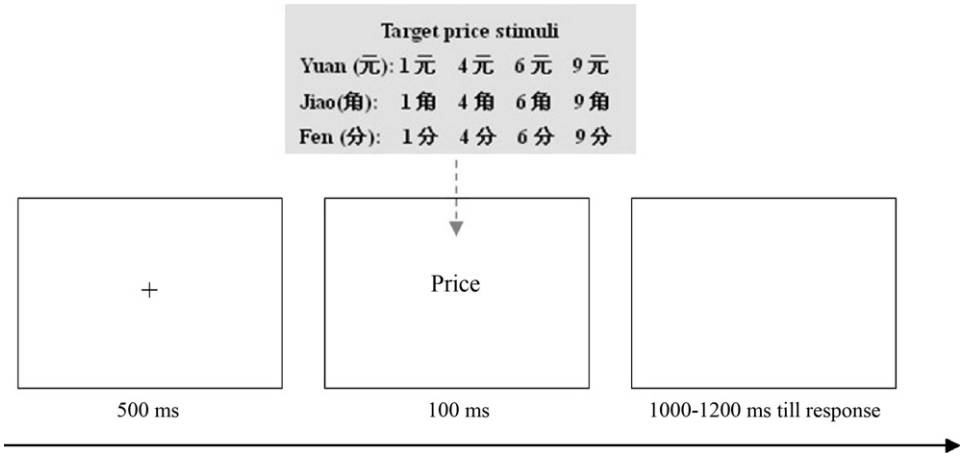

Fig. 1. Experimental procedure used in the present study. Participants were presented with twelve price stimuli, which consisted of four digits (1, 4, 6 and 9) combined with three units (*yuan*, *jiao* and *fen*), and had to indicate whether the stimulus presented was higher or lower than "5 *jiao*".

significant interaction of distance by unit, $F(2, 28) = 30.70$, $p < 0.001$. Further analysis indicated that there was only distance effect for *jiao* units, $F(1, 14) = 58.57$, $p < 0.001$, while no distance effect was found for *yuan* or *fen* (Table 2 and Fig. 2).

The above results indicated that the distance effect was found only for *jiao* unit, and the performance of *jiao* was lower than that of *yuan* and *fen*, reflecting a significant effect of unit on the processing of price. In order to preclude the effect of units and precisely investigate the semantic representation of price, the following analysis was performed within each kind of unit. In addition, the distance was defined in terms of the whole magnitude of price based on the holistic model. Specifically, for the *jiao* units, the differentiation of far and close was the same as the above analysis. However, for the *yuan* units, the two prices with close distance to the standard price were 1 *yuan* and 4 *yuan*, while the two prices with far distance included 6 *yuan* and 9 *yuan*. For the *fen* units, the two prices with close distance to the standard price were 6 *fen* and 9 *fen*, while the two prices with far distance included 1 *fen* and 4 *fen*. The accuracy rates and RTs were submitted to a one-way ANOVA, with distance (close vs. far) as within-subjects factors for each unit, respectively (Table 1). The results of ANOVA were shown below.

For *yuan* units, there was a significant distance effect on accuracy, $F(1, 14) = 5.61$, $p = 0.033$. The accuracy of far distance (98.8%) was higher than close distance (97.6%). Main effect of distance was found for RTs, $F(1, 14) = 68.39$, $p < 0.001$, with 20 ms faster for far distance than close distance (Fig. 2).

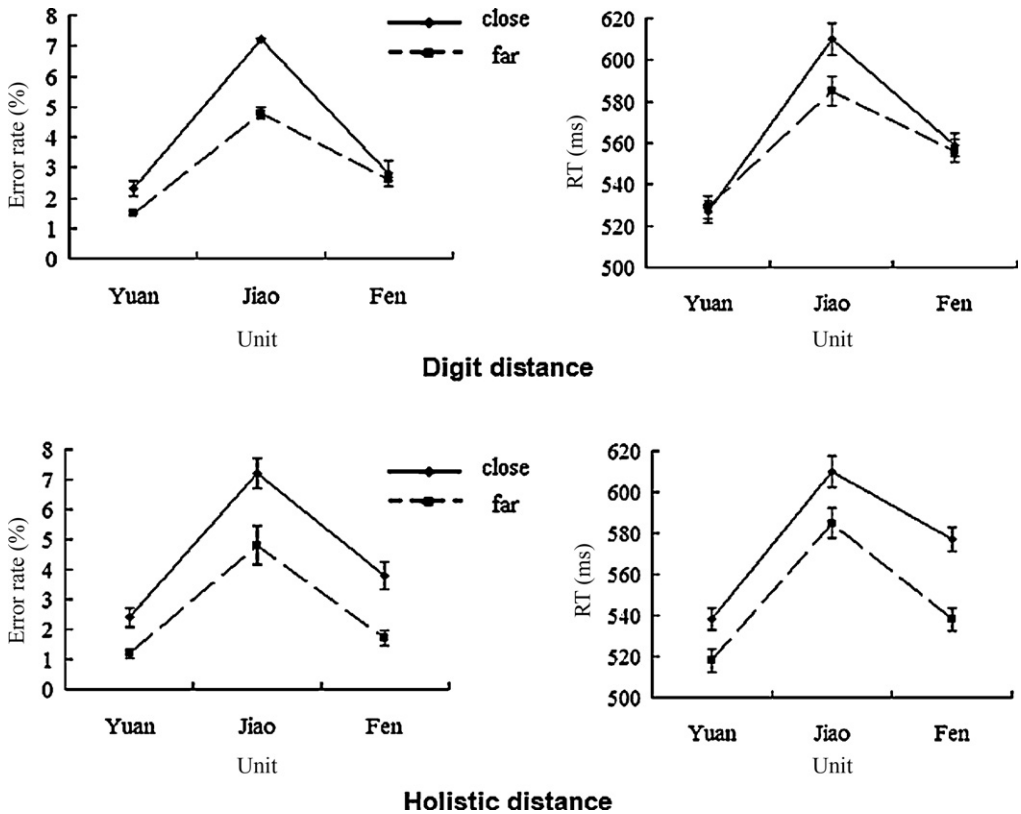

Fig. 2. The accuracy rates (left) and averaged RTs (right) for different distances. Top: The distance was defined in terms of the digits of prices. The distance effect was found only for *jiao* units, but not for *yuan* or *fen* units. Bottom: The distance was defined in terms of the whole magnitude of prices. Distance effects were found for each unit.

Table 2
Summary of behavioral results of ANOVAs on the distance defined in terms of digit distance and holistic distance.

Unit	Behavioral measures	Digit distance		Holistic distance	
		F	*p*	*F*	*p*
yuan	Accuracy	1.99	0.180	5.61	0.033*
	RT	1.00	0.335	68.39	<0.001**
jiao	Accuracy	6.93	0.020*	6.93	0.020*
	RT	58.57	<0.001**	58.57	<0.001**
fen	Accuracy	0.18	0.676	17.28	0.001**
	RT	1.22	0.287	69.06	<0.001**

* $p < 0.05$.
** $p < 0.01$.

Table 3
Summary of ERP results of ANOVAs on the distance defined in terms of digit distance and holistic distance.

Unit	ERP measures	Digit distance		Holistic distance	
		F	*p*	*F*	*p*
yuan	P2	0.96	0.345	6.76	0.021*
	350–400 ms	1.08	0.316	11.17	0.005**
	400–450 ms	0.003	0.958	5.01	0.042*
jiao	350–400 ms	5.86	0.030*	5.86	0.030*
	400–450 ms	7.24	0.018*	7.24	0.018*
fen	P1	13.18	0.003**	1.02	0.994
	P2	0.23	0.638	4.55	0.008**
	300–350 ms	6.45	0.024*	1.50	0.241
	350–400 ms	2.57	0.131	23.08	<0.001**
	400–450 ms	0.02	0.894	18.74	<0.001**

* $p < 0.05$.
** $p < 0.01$.

For *fen* units, a significant distance effect was found on accuracy, $F(1, 14) = 17.28$, $p = 0.001$, with 2.1% higher for far distance than close distance. Main effect of distance was found on RTs, $F(1, 14) = 69.06$, $p < 0.001$, with 39 ms faster for far distance than close distance (Fig. 2).

3.2. Electrophysiological results

Based on previous studies (Dehaene, 1996; Temple and Posner, 1998; Pinel et al., 2001; Cao et al., 2010) and the visual investigation of the current ERP waveforms, the following eight sites located symmetrically in the laterality were selected to be analyzed: P3/P4 and P5/P6 (parietal scalp sites), P7/P8 and PO7/PO8 (parieto–occipito–temporal sites). The peak latencies were measured relative to stimulus onset. The P1 component was measured in the 80–120 ms, N1 was detected in the 120–180 ms, P2 was assessed in the 180–250 ms and N2 was measured in the 250–300 ms time windows. There was no clear peak from 300 ms to 450 ms, so the mean amplitudes of these time windows were measured every 50-ms intervals to identify the time windows of distance effect as precisely as possible.

In order to directly investigate the semantic representation of price, the ERP averages were submitted to a 2 (distance: close vs. far) × 2 (laterality: left, right) × 4 (electrodes) repeated ANOVA for each unit separately. For all analyses, *p*-values were corrected for deviation from sphericity according to the Greenhouse–Geisser method. As analyzed in the behavioral data, the four prices with *jiao* units (i.e., 1 *jiao*, 4 *jiao*, 6 *jiao* and 9 *jiao*) have the same unit as the standard price, 5 *jiao*, so the two kinds of definition of distance (i.e. in terms of the digits or the whole magnitude of prices) did not change the results. For *jiao* units, the result of ANOVA showed that the main effect and the interaction of distance by laterality were not found on the latencies and amplitudes of P1, N1 and N2. There were main effects of laterality on the P2 latency and amplitude [$F_{\text{latency}}(1, 14) = 6.49$, $p_{\text{latency}} = 0.023$, with 10 ms earlier at the right than the left electrode sites; $F_{\text{amplitude}}(1, 14) = 9.56$, $p_{\text{amplitude}} = 0.008$, with 2.70 μV higher at the right than at the left electrode sites]. During 300–350 ms, there were no main effect and interaction of distance by laterality. During 350–400 ms, a significant effect of distance was observed [$F(1, 14) = 5.86$, $p = 0.030$, with an enhanced positivity for far distance (5.22 μV) than for close distance (4.27 μV)]. During 400–450 ms, there was a significant effect of distance [$F(1, 14) = 7.24$, $p = 0.018$, with a greater positivity for far distance (5.63 μV) than for close distance (4.76 μV)] (Fig. 4b).

For the prices with *yuan* and *fen* units however, the distance of could be defined in two different ways, and caused different results of analysis. When the distances of the prices were defined in terms of the digit values, the results of ANOVA indicated that there was no distance effect for the prices with *yuan* units. For *fen* units, distance effect was only observed on the P1 amplitude [$F(1, 14) = 13.18$, $p = 0.003$] and the mean amplitudes in 300–350 ms time window [$F(1, 14) = 6.45$, $p = 0.024$], with a greater positivity for far distance than for close distance (Table 3 and Fig. 3).

When the distances of the prices were defined in terms of the whole magnitude of price, the results of ANOVA revealed a significant effect of distance for both units. For *yuan* units, no main effects or interactions were found on the latencies and amplitudes of P1 and N1 components. There was also no main effect or interaction on the P2 latency. However, main effect of laterality was found on P2 amplitude [$F(1, 14) = 7.04$, $p = 0.019$, with the higher amplitude at the right (5.03 μV) than at the left electrode sites (2.98 μV)]. A significant effect of distance was found on the P2 amplitude [$F(1, 14) = 6.76$, $p = 0.021$, with a greater positivity for far distance than for close distance]. On the N2 amplitude, There were a main effect of laterality [$F(1, 14) = 7.38$, $p = 0.017$, with a higher amplitude at the right than at the left electrode sites], and main effect of distance [$F(1, 14) = 4.60$, $p = 0.050$, with a greater positivity for far distance than for close distance]. However, effects of laterality and distance both disappeared when the N2 peak amplitude was subtracted from the P2 peak. It suggested that the difference of N2 amplitude might be mostly attributed to the P2 difference. During 300–350 ms, there were no main effect and interaction. A significant effect of distance was found on the mean amplitude during 350–400 ms [$F(1, 14) = 11.17$, $p = 0.005$, with a greater positivity for far distance (5.92 μV) than for close distance (5.03 μV)]. The significant distance effect was also found on the mean amplitude during 400–450 ms [$F(1, 14) = 5.01$, $p = 0.042$, with a greater positivity for far distance than for close distance] (Fig. 4a).

For *fen* units, no main effect or interaction were found on the latencies and amplitudes of P1 and N1 components. Main effect of laterality was found on the P2 latency [$F(1, 14) = 4.08$, $p = 0.046$, with 8 ms earlier at the right than at the left electrode sites]. There was an interaction of distance by electrode sites on the P2 amplitude, $F(3, 42) = 4.55$, $p = 0.008$. Further analyses revealed a main effect of distance at the P3 and P7 sites. The peak amplitude at P3 site was larger for the close distance (3.74 μV) than for the far distance (2.84 μV), $F(1, 14) = 12.90$, $p = 0.003$. At P7 site, the peak amplitude was larger for the close distance (3.28 μV) than for the far distance (2.50 μV), $F(1, 14) = 10.57$, $p = 0.006$. There was no main effect or interaction from N2 to 350 ms. During 350–400 ms, a significant effect of distance was found [$F(1, 14) = 23.08$, $p < 0.001$, with a greater positivity for far distance (5.12 μV) than for close distance (3.73 μV)]. There was a significant distance effect during 400–450 ms [$F(1, 14) = 18.74$, $p = 0.001$, with a greater positivity for far distance (5.96 μV) than for close distance (4.55 μV)] (see Fig. 4c). The distribution of distance effects found for *fen* units was similar to *yuan* and *jiao* units (Fig. 5).

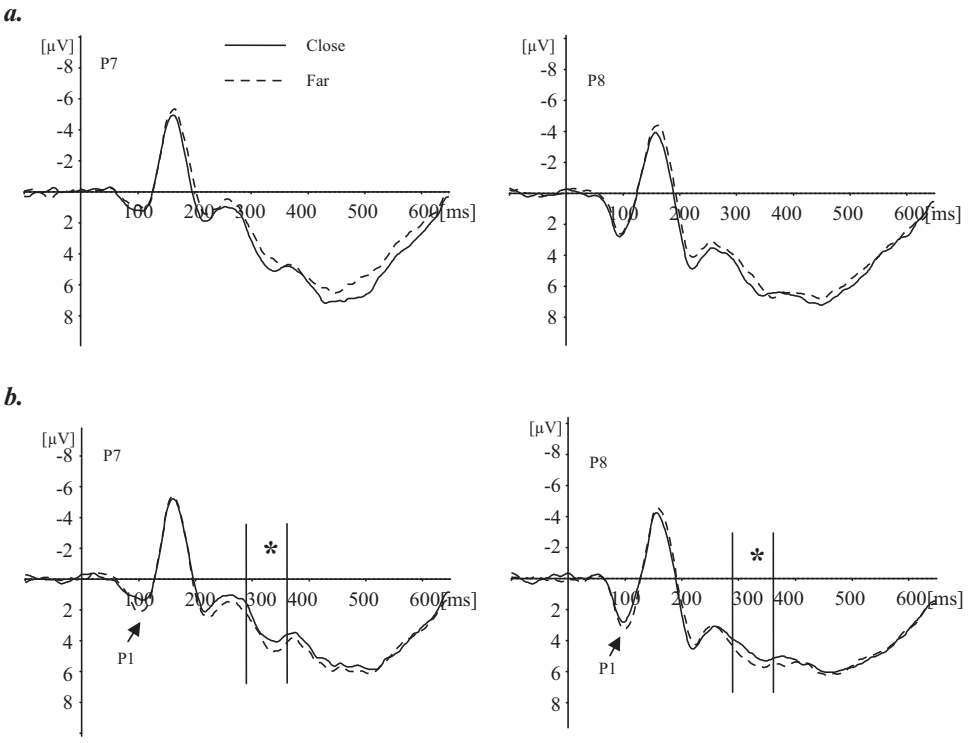

Fig. 3. Grand-averaged ERP waveforms of *yuan* and *fen* unit for different distances defined in terms of the digits of prices (Digit distance). (a) The ERPs elicited by the *yuan* unit. (b) The ERPs elicited by the *fen* unit. Arrows and asterisks indicate a statistically significant result with $p < 0.05$. The distance effect was only found with the *fen* units during the P1 and 300–350 ms time windows, but there was not distance effect with the *yuan* units.

4. Discussion

In the present study, participants were asked to judge whether the target price was higher or lower than the standard price, 5 *jiao*. The target prices had either the same or different units as the standard price. When the target price had the same unit as the standard price, participants had to process the digits of the price. The behavioral results replicated the typical distance effect, which suggests that participants were semantically processing the digits of prices with *jiao* as units.

When the target price had different units compared to the standard price (i.e., the target price was 1 *yuan*, 4 *yuan*, 6 *yuan*, 9 *yuan*, 1 *fen*, 4 *fen*, 6 *fen*, or 9 *fen*), participants were expected to process the prices in different ways as explained by different models. Based on the compositional model, participants were expected to process the digits and units of prices separately, with priority on the processing of units (Hinrichs et al., 1981; Nuerk et al., 2001). After identifying the different units, participants could complete the price comparison merely based on the relationship between the units without considering the digits of prices. Our behavioral results appear to support this prediction. The reaction times for the eight prices with different units to the standard price were shorter than those for prices with *jiao* units, and the typical distance effect was not found for the *yuan* and *fen* units, suggesting that participants did not process the digits of prices. Nevertheless, when distance was defined in terms of the whole magnitude of prices, the results revealed a significant difference between close distance (1 *yuan* and 4 *yuan*) and far distance (6 *yuan* and 9 *yuan*). A similar effect was also found for *fen* units. These results strongly suggested that, contrary to the prediction of the compositional model, participants did not process the digits and the units of prices separately. In fact, these results matched well with the holistic model (Brysbaert, 1995; Dehaene et al., 1990; Reynvoet and Brysbaert, 1999), which predicts that subjects process digits and units of prices holistically.

ERP results indicated that there was a distance effect for *jiao* units during 350–450 ms, with a greater positivity for far distance (1 *jiao* and 9 *jiao*) than for close distance (4 *jiao* and 6 *jiao*). However, ERP results did not reveal any distance effect for the *yuan* units from P1 to 450 ms if the distance was defined in terms of the digit values (i.e., digits 4 and 6 were close to 5, while digits 1 and 9 were far from 5). For *fen* units, distance effects were found only on the P1 amplitude and mean amplitudes of 300–350 ms, with an enhanced positivity for far distance (1 *fen* and 9 *fen*) than for close distance (4 *fen* and 6 *fen*). The P1 component has been reported to be related to early visual processing rather than semantic representation (Dehaene, 1996; Temple and Posner, 1998). The minor distance effect observed at 300–350 ms might be due to some other factors such as the difference between specific digits or prices (Cao et al., 2010), as well as semantic representations of the magnitude of digits. Overall, the absence of significant distance effect in the ERPs elicited by the prices with *yuan* and *fen* as units suggested that participants did not merely process the digits of prices (Verguts and Moor, 2005; Zhou et al., 2008). These results provided little support for the compositional model.

However, if the distance was defined in terms of the whole magnitude of prices, a significant distance effect was found for all units. Just as the distance effect found for the *jiao* units, significant distance effects were also found for the *yuan* and *fen* units during the 350–450 ms period after the onset of stimulus and the effects showed the same polarity (i.e., the prices with far distance from the standard price elicited a greater positivity than those with close distance). Together with the behavioral results, the distance effect found for the *yuan* and *fen* units at the 350–450 ms time window strongly argue against the compositional model and support the

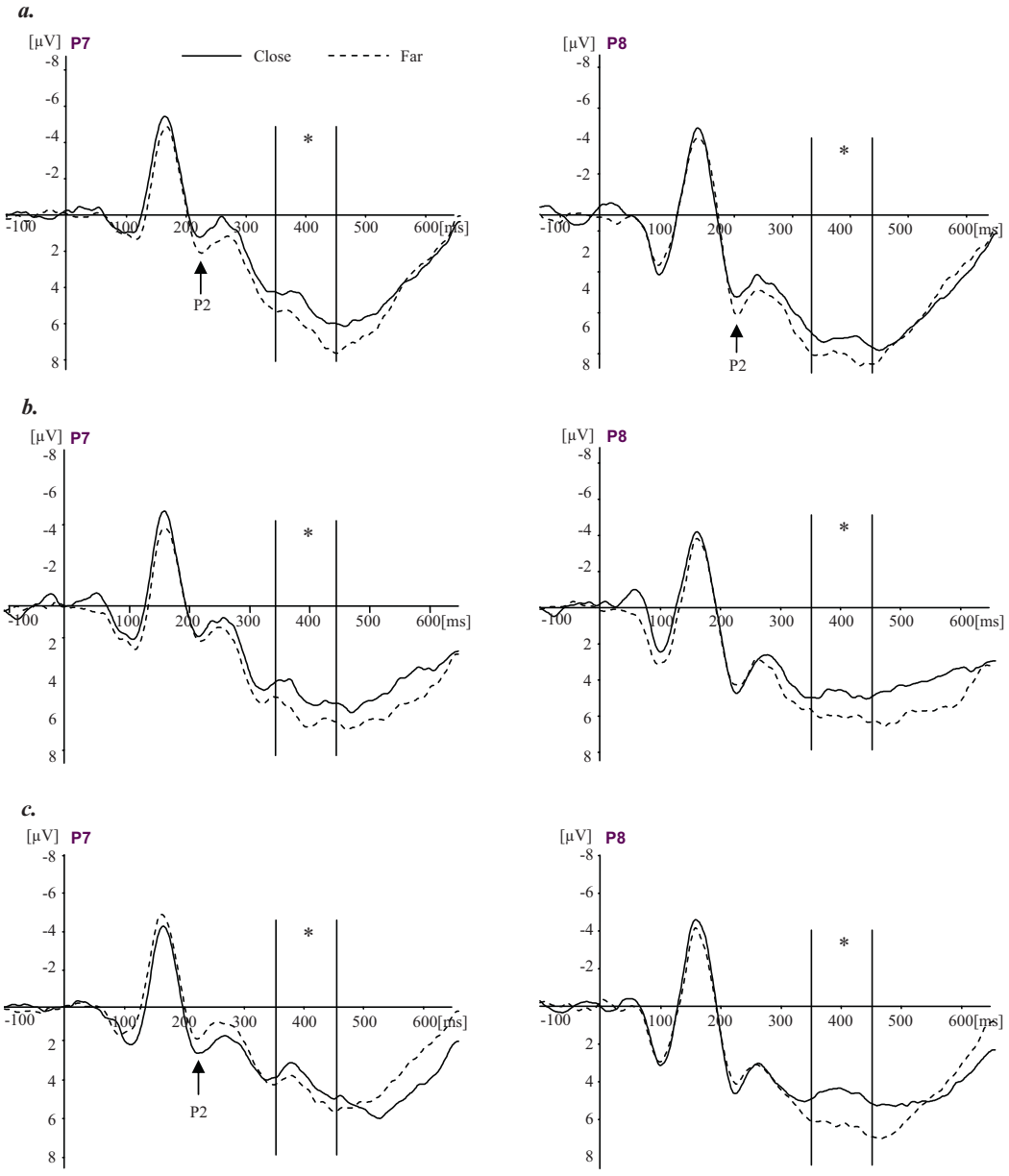

Fig. 4. Grand-averaged ERP waveforms of each unit for different distances defined in terms of the whole magnitude of prices (Holistic distance). (a) The ERPs elicited by the *yuan* unit. (b) The ERPs elicited by prices with the *jiao* unit. (c) The ERPs elicited by the *fen* unit. Arrows and asterisks indicate a statistically significant result with $p < 0.05$. The distance effects were found during the 350–450 ms time windows for each unit, with an enhanced positivity for far distance than for close distance.

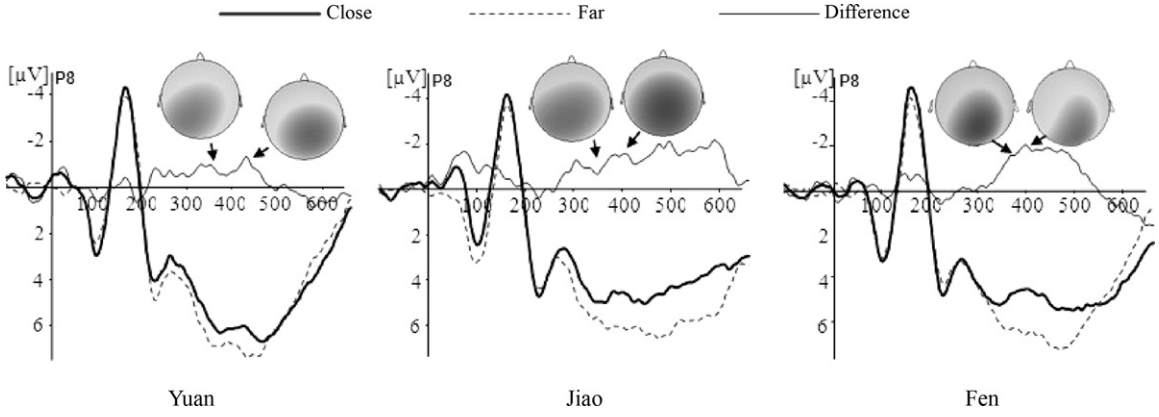

Fig. 5. Topographic maps of the distance effect for each unit.

holistic model of price comparison. These effects were consistent with interpretations of the N400-family effects occurring in this time range, which were identified as semantic processes (Kutas and Federmeier, 2000). These effects were also consistent with the results of Paulsen and Neville (2008) and Paulsen et al. (2010) for non-symbolic magnitude comparison, who also found N400-like effects of distance during similar time windows, with a greater negative-going waveform for closer distance than far numerical distance.

It is noteworthy that the distance effect was also found at the P2 component for the *yuan* and *fen* units. Previous ERP studies on numbers found a distance effect on the P2 component (abbreviated as P2p; Dehaene, 1996; Temple and Posner, 1998; Pinel et al., 2001; Turconi et al., 2004; Cao et al., 2010). However, the distance effect at the P2 component in the current study might not be related to semantic representations of price because of opposite polarity for *yuan* and *fen* units. For *yuan* units, far distance elicited a greater positivity than close distance; on the contrary, close elicited a greater positivity than far distance for *fen* units. The opposite polarity of the P2 components might be explained in terms of the magnitudes of digits of the prices. As stated above, 6 *yuan* and 9 *yuan* are farther from the standard price than 1 *yuan* and 4 *yuan*, while 6 *fen* and 9 *fen* are closer to the standard price than 1 *fen* and 4 *fen*. The magnitudes of digits 6 and 9 are obviously larger than of digits 1 and 4. It has previously been shown that adults spontaneously process small and large numbers differently (Hyde and Spelke, 2009; Liu et al., 2011). Therefore, it is plausible that the distance effect found at the P2 component in this study might be related to the magnitudes of digits (Hyde and Spelke, 2009).

Unlike previous studies on price comparison and two-digit comparison, the present study used three distinct monetary units: *yuan*, *jiao* and *fen*. Our behavioral results clearly revealed a significant difference between units. In comparison with the other two units, the *jiao* units elicited the lowest accuracy and the longest RTs, while the *yuan* units elicited the highest accuracy and the shortest RTs. This effect may be due to the overall distance of the target prices to the standard price. In fact, the magnitude of the four prices with *jiao* units was closer to the standard price than of the other eight prices with *yuan* or *fen* as units. Interestingly, it has been suggested that the internal representations of two close prices would be more similar or would overlap more than prices that are farther apart prices (Thomas and Morwitz, 2009).

Previous ERP studies on numeral cognition found the distance effect during N1-P2p transition and P2p time windows (Dehaene, 1996; Temple and Posner, 1998; Pinel et al., 2001; Turconi et al., 2004; Cao et al., 2010). However, the present study did not find a convincing distance effect at the P2p time window. Instead, a significant distance effect was found at a late time window, 350–450 ms. There are two possible explanations for this difference. First, because the price included numbers and Chinese monetary units, the visual identification stages of prices were longer than that of numbers alone (Cao et al., 2010). Secondly, the price comparison task was more difficult than the number comparison task. Participants process only the digit numbers in a number comparison task. However, in our price comparison tasks, participants had to semantically process both the digits and units of prices and access the whole magnitude of prices before comparing each price with the standard price. This may be why the semantic representation of price occurred later in our study than in number comparison tasks reported previously.

5. Conclusions

When participants were asked to judge whether the target prices with different units were higher or lower than the standard price, prices with different distances (defined in terms of the whole magnitude of prices) from the standard price were processed differently. In comparison with those with close distance, the prices with far distance had shorter RTs and higher accuracies as well as increased positivity during the 350–450 ms time window. Taken together, these behavioral and electrophysiological results indicate that the processing of price is holistic.

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