# Self-Referential Processing Enhances Near Space Distance: Evidence from Behavior and ERPs

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## Abstract

This study employed a study-recognition paradigm to investigate how spatial distance influences self-referential processing. Event-related potential (ERP) technology was first used to explore how different spatial distances affect the process of self-referential processing, combined with a recognition test to verify the stability of this influence. The results demonstrated: (1) During the study phase, near spatial distance exerted a significant enhancing effect on self-referential processing during the late-stage cognitive processing phase, which was subsequently verified in the recognition test; (2) The study also revealed an enhancing effect of near spatial distance on other-referential processing during the study phase, but this effect was not verified in the recognition test. This study confirms that near spatial distance can facilitate more elaborate self-referential processing, thereby expanding our understanding of self-referential processing and the self.

## Full Text

### Enhancement Effect of Near Spatial Distance on Self-Referential Processing: Evidence from Behavioral and ERP Studies

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## Abstract

This study employed a learning-recognition paradigm to investigate how spatial distance influences self-referential processing. Using event-related potential (ERP) technology, we first explored how different spatial distances affect the process of self-referential processing, and then verified the stability of this effect through a subsequent recognition test. The results revealed: (1) During the learning phase, near spatial distance exerted a significant enhancement effect on self-referential processing at late cognitive processing stages, which was further validated in the recognition test; (2) The study also found an enhancement effect of near spatial distance on other-referential processing during the learning phase, though this effect was not confirmed in the recognition test. These findings demonstrate that near spatial distance can facilitate more elaborate processing of self-referential information, expanding our understanding of self-referential processing and the nature of self.


**Keywords:** self-referential processing; spatial distance; enhancement effect

## 1. Introduction

Spatial distance refers to the linear distance between stimuli or between a stimulus and the self (Trope & Liberman, 2010), while self-referential processing involves associating stimuli with one’ s self-concept (Kim, 2012). The more closely a stimulus is associated with the self, the faster it is processed and the better it is remembered (Rogers, Kuiper, & Kirker, 1977). Previous research has shown that spatial distance can influence individuals’ cognitive processing of external stimuli (Kasai, Morotomi, Katayama, & Kumada, 2003; ValdésConroy, Román, Hinojosa, & Shorkey, 2012). This raises the question: Can different spatial distances affect this specific form of processing known as self-referential processing? In other words, does the degree of association between a stimulus and self-concept during self-referential processing vary as a function of spatial distance?

To address this question, we first reviewed existing research on self-referential processing. Scholars have extensively explored self-referential processing at both behavioral and neurophysiological levels. In behavioral studies, memory performance for adjectives (Kalenzaga & Jouhaud, 2018) or narrative stories (Grilli, Woolverton, Crawford, & Glisky, 2018) has been found to be better under self-referential conditions compared to other-referential conditions. Neuroimaging studies have revealed that individuals’own names and names of significant others elicit greater activation in the medial prefrontal cortex (MPFC) than celebrity names (Tacikowski, Brechmann, & Nowicka, 2013). Additionally, the dorsolateral prefrontal cortex (dLPFC) shows greater activation for self-referential processing (Taylor et al., 2009). ERP studies have demonstrated that self-referential processing elicits larger LPC amplitudes than mother-referential and celebrity-referential processing (Kong, Chen, Zhang, & Kou, 2012). Using an oddball paradigm, Fan et al. (2013) found that highly self-relevant names (participants’ own names) produced larger P3 amplitudes than moderately self-relevant names (e.g., father' s name), which in turn elicited larger P3 amplitudes than non-self-relevant names (e.g., Obama). Similarly, the "individual self" level has been shown to produce larger P3 amplitudes than the "family" level, which in turn produces larger amplitudes than the "national" level (Wang et al., 2017; Chen et al., 2011).

In summary, previous research has primarily examined self-referential processing from the perspective of social distance (e.g., self-friend-stranger), with the general conclusion that self-referential processing shows a clear advantage over non-self-referential processing. Moreover, as the social distance of the reference becomes closer to the core self, the degree of frontal activation and the amplitude of P3 or LPC components increase. Since P3 and LPC components reflect the degree of elaborate information processing (Yuan, Yang, Meng, Yu, & Li, 2008; Fields & Kuperberg, 2016), these findings suggest that closer social distances attract more attentional resources and facilitate more elaborate processing of stimuli. While research from the social distance perspective has been extensive, one important aspect has been overlooked: the "self" exists in space, and the formation of close social distance relationships typically involves contact at near spatial distances (Kolb, 2015). For instance, the development of close relationships from strangers to romantic partners or best friends inevitably involves prolonged contact at near spatial distances. However, previous studies have implicitly embedded the influence of spatial distance on self-referential processing within social distance research, lacking direct investigation into how spatial distance affects self-referential processing. This is precisely the question we posed at the outset. Therefore, exploring this issue will help further expand our understanding of self-referential processing and the nature of self.

What kind of influence can different spatial distances have on self-referential processing? Does near spatial distance, like social distance, promote more elaborate information processing? Previous studies have found that as others' spatial distance to an individual decreases, cooperation levels increase (Zheng, Cai, Li, & Shao, 2017) and individuals exhibit more friendly behavior (Wang & Yao, 2016). In a visual spatial attention task, participants detected objects in near space faster and more accurately than those in far space (ValdésConroy et al., 2012). Stimuli at near spatial distances have also been found to elicit larger P1 or N1 amplitudes than those at far distances (Kasai et al., 2003; Valdés-Conroy, Sebastián, Hinojosa, Román, & Santaniello, 2014; Griffin, Miniussi, & Nobre, 2002). These results strongly support attention theories related to spatial distance (Abrams, Davoli, Du, Iii, & Paull, 2008; Reed, Grubb, & Steele, 2006), which posit that stimuli presented at near spatial distances can capture more attentional resources and facilitate more elaborate subsequent cognitive processing.

In summary, both self-referential processing and near spatial distance can prioritize attentional capture and obtain more attentional resources, leading to more elaborate processing of stimulus information. This suggests that these two factors have synergistic effects on cognitive processing, with self-referential processing at near spatial distances capturing the most attentional resources. Based on this, we hypothesized that near spatial distance would enhance self-referential processing compared to far spatial distance. Furthermore, this study used ERP technology to explore at which cognitive processing stage this enhancement occurs. Previous research indicates that early cognitive processing components P1 and N1, which reflect visual attention, are primarily influenced by stimulus physical properties and involve less deep cognitive processing (Li, Liang, Zhang, & Gao, 2016; Liu, Forte, Sewell, & Carter, 2018). Related studies have also found no significant differences in P1 and N1 amplitudes and latencies between self-referential and non-self-referential processing (Dainerbest, Trujillo, Schnyer, & Beevers, 2017; Fan et al., 2016). Therefore, we hypothesized that although spatial distance affects cognitive processing, its influence on self-referential processing does not occur at early stages. Specifically, P1 and N1 components, which reflect early cognitive processing, would show significant differences between near and far spatial distances but would not be affected by reference type.

Handy, Grafton, Shroff, Ketay, and Gazzaniga (2003) noted that stimuli closer to an individual not only increase the attractiveness of stimulus information but also facilitate subsequent cognitive and behavioral processes. ValdésConroy et al. (2014) found that object discrimination at near spatial distances elicited significantly larger LPC amplitudes than at far distances, suggesting that individuals' top-down attentional control mechanisms are modulated by spatial distance during late processing stages, with near spatial distance enhancing this process. Based on this, we hypothesized that the enhancement effect of near spatial distance on self-referential processing occurs at late stages. Specifically, self-referential processing at near spatial distances would elicit larger LPC amplitudes than at far distances.

This study utilized visual linear perspective principles to construct different spatial distance conditions on a plane that more closely approximates reality. We employed a learning-recognition paradigm combined with ERP technology, which has high temporal resolution, to test these hypotheses. First, we used ERP technology to examine how spatial distance affects self-referential processing during the learning phase. By analyzing differences in early P1 and N1 components and late LPC components, as well as hemispheric activation levels, between near and far spatial distance conditions, we aimed to reveal the cognitive neural basis of the enhancement effect of near spatial distance on self-referential processing and identify the stage at which this enhancement occurs. Then, we measured participants' correct recognition rates during the recognition phase to reflect processing outcomes. By comparing memory performance for self-referential information between near and far spatial distance conditions, we sought to provide more direct and explicit evidence for the enhancement effect of near spatial distance on self-referential processing. Overall, this study broadens our understanding of self-referential processing from the perspective of spatial distance, exploring whether an enhancement effect of near spatial distance on self-referential processing exists and investigating its stage and neural basis from both behavioral and ERP levels to reveal the mechanism of spatial distance in self-referential processing.

Twenty-eight university students (8 males) with a mean age of 24.90 years participated in the study. All participants were right-handed, healthy, with no history of brain injury or neurological disorders, and had normal or corrected-to-normal vision. Before the experiment, participants completed a basic information form and signed an informed consent form, and received compensation after completing the experiment. This study was approved by the Academic Ethics and Moral Committee of the corresponding author' s institution.

## 2. Method

### 2.1 Participants

The same 28 participants described above.

### 2.2 Experimental Design

The experiment employed a 2 (distance: near, far) × 2 (reference: self, other) within-subjects design, resulting in four experimental conditions: near-self, far-self, near-other, and far-other. We used a learning-recognition paradigm. During the learning phase, participants classified word pairs without knowing that a recognition test would follow. After a simple calculation interference task, participants completed a recognition test with randomly presented old words (previously shown) and new words (not previously shown) in equal numbers. We recorded behavioral responses and EEG data during the learning phase, as well as reaction times and correct recognition numbers during the recognition phase. Additionally, a stranger reference condition (using an unfamiliar person' s name) was included as an alert group.

**Spatial distance manipulation:** We adopted the corridor background used in Markman and Brendl' s (2005) study to manipulate spatial distance, creating a more realistic sense of spatial distance (see Figure 1 [Figure 1: see original paper]) (Wang & Yao, 2016). Using Block 1 in Figure 1 as an example, near spatial distance was defined as the distance between the middle grid and the upper grid on the screen, while far spatial distance was defined as the distance between the middle grid and the lower grid. The far spatial distance on screen was twice the near spatial distance. To balance visual field effects, we ensured that the middle word grid could appear at both near and far distances from both upper and lower grids by using Block 1 and Block 2. This created four combinations: in Block 1, the middle word grid was near the upper grid and far from the lower grid; in Block 2, it was far from the upper grid and near the lower grid.

**Self and other reference manipulation:** Previous research has demonstrated that using names instead of the physical self as reference successfully manipulates spatial distance without being influenced by bodily self (Markman & Brendl, 2005; Oakes & Onyper, 2017). Therefore, we used participants' own names for self-reference and their best friend' s names (provided before the experiment) for other-reference to control for familiarity effects.

### 2.3 Materials

**2.3.1 Stimuli** We selected 218 neutral two-character noun phrases (e.g., newspaper, apple) from the *Modern Chinese Corpus Word Frequency Table*. The stimulus distribution was as follows: 24 phrases for each of the four experimental conditions (totaling 96 old words), 12 for practice, 14 for the stranger condition, and 96 new words. The assignment procedure was: (1) 26 phrases were selected for practice and stranger conditions. Since these conditions were not included in subsequent statistical analyses and the phrases presented in each condition were consistent, they did not affect experimental validity, so no rating was conducted for these phrases. (2) The remaining 192 phrases were compiled into a familiarity rating questionnaire using a 5-point scale (1-5, with higher scores indicating greater familiarity) and administered to 96 university students (34 males, mean age 24.82 years). Word frequency was extracted from the *Modern Chinese Corpus Word Frequency Table*. (3) Based on familiarity ratings, the phrases were divided into two groups with similar familiarity levels, with one group selected as old words. (4) This selected group was further divided into four groups based on familiarity ratings, with minor adjustments made according to word frequency to ensure no significant differences in familiarity or frequency among the four groups. ANOVA confirmed no significant differences in familiarity, $F(4, 380) = 0.37$, $p = 0.628$, or frequency, $F(4, 187) = 0.76$, $p = 0.551$, among the four old-word groups and the new-word group. (5) We also assessed valence and arousal ratings from 92 participants (16 males, mean age 22.25 years) and 94 participants (18 males, mean age 22.68 years), respectively. Results showed no significant differences in valence, $F(4, 364) = 1.79$, $p = 0.143$, or arousal, $F(4, 372) = 1.25$, $p = 0.293$, among the word groups.

**Table 1** presents the descriptive statistics for the groups.

**2.3.2 Procedure** **Learning phase:** Participants wore electrode caps and sat comfortably in a dimly lit, soundproof room approximately 80 cm from the computer screen. Stimuli were presented using E-prime 2.0 with a white background. The experimental procedure is illustrated in Figure 2 [Figure 2: see original paper].

First, a fixation cross "+" appeared in the middle grid for 800-1200 ms. Then, a word phrase was randomly presented in the middle grid while a name appeared randomly in either the upper or lower grid. The visual angle was 1.8° for near spatial distance and 3.6° for far spatial distance. Participants were instructed to press the up arrow "↑" when their own or friend' s name appeared in the upper grid, and the down arrow "↓" when it appeared in the lower grid. When a stranger' s name appeared in either grid, they pressed the "f" key. They were asked to mentally associate the word phrases with the names. The stimulus disappeared upon response or after a maximum of 2000 ms. Participants were instructed to respond as quickly and accurately as possible, minimize blinking, and avoid unnecessary body or head movements.

Before the formal experiment, each participant completed practice trials for both Block 1 and Block 2 (12 trials each). The presentation order of Block 1 and Block 2 was counterbalanced across participants. Participants proceeded to the formal experiment only after achieving 95% accuracy. During the formal experiment, each block contained 62 word phrases (48 for self and friend references, 14 for stranger references), with presentation order counterbalanced across participants. Following previous self-referential processing research (Symons & Johnson, 1997), each phrase was presented three times, resulting in 372 trials total.

After the learning phase, participants were informed they would complete a simple calculation interference task (20 problems, e.g., 9-2×3=?), judging whether the results were odd or even. Following this interference task and a 1-minute break, participants were given a surprise recognition test for the previously learned word phrases (192 old and new words total). They pressed "D" for words they believed had been presented during the learning phase and "K" for new words, with response keys counterbalanced across participants. Words were presented for 3000 ms or until a response was made.

As shown in the procedure, the stranger reference condition served two purposes: (1) Since self and other references required the same response keys (up arrow for upper grid, down arrow for lower grid), participants could complete the task without distinguishing between their own and friend' s names. The stranger condition, requiring an "f" key press, forced participants to discriminate among names, ensuring they actually referenced self or friend during the task. (2) The stranger name appeared less frequently (23%) than self and friend names (77%), making errors more likely and thus increasing participant vigilance.

### 2.4 EEG Recording and Analysis

EEG data were recorded using a Neuroscan 4.4 system with a 64-channel electrode cap, referenced to the left mastoid, with ground at the midpoint between Fz and Cz. Horizontal and vertical electrooculograms were recorded from electrodes placed 1.5 cm lateral to the outer canthi of both eyes and 1 cm above and below the left orbit, respectively. The sampling rate was 1000 Hz/channel, with a bandpass filter of 0.01-100 Hz. Electrode impedance was kept below 5 kΩ.

Offline analysis was conducted using Scan 4.4 software. Raw EEG data were re-referenced to bilateral mastoids, with eye movement and muscle artifacts removed. Data were filtered using low-pass, zero-phase shift digital filtering with a 24 dB/oct attenuation. Trials with amplitudes exceeding ±80  V were automatically rejected as artifacts. The epoch was 1000 ms, with a 200 ms pre-stimulus baseline and 800 ms post-stimulus analysis window. After artifact rejection, trials from the four experimental conditions were averaged separately. Based on grand average waveforms and previous research, early visual attention components P1 and N1 related to spatial distance were primarily located in occipital regions, while self-related cognitive processing components appeared mainly in medial prefrontal cortex (Kalenzaga et al., 2015; Leshikar & Duarte, 2014). Therefore, we selected early components P1 (105-135 ms; PO5, PO3, PO4, PO6), N1 (150-180 ms; PO5, PO3, PO4, PO6) (Sambo & Forster, 2009; ValdésConroy et al., 2014), and late positive component LPC (350-550 ms; F5, F3, F1, F2, F4, F6) (Peng et al., 2017) for statistical analysis using SPSS 19.0. Greenhouse-Geisser correction was applied to $p$-values for main effects and interactions that violated sphericity assumptions.

One female participant' s data were incomplete and excluded, leaving 27 participants (8 males, mean age 25.20 years) for final behavioral and ERP analyses.

## 3. Results

### 3.1 Behavioral Data Analysis

Accuracy rates for all four conditions during the learning phase exceeded 98%, so no difference analysis was conducted. Reaction time data beyond three standard deviations were excluded, accounting for 2.10% of total data.

A 2 (distance: near, far) × 2 (reference: self, other) repeated measures ANOVA on learning phase reaction times revealed significant main effects of distance, $F(1, 26) = 15.66$, $p = 0.001$, $^2$p = 0.38, and reference, $F(1, 26) = 46.28$, $p < 0.001$, $^2$p = 0.64. Reaction times were significantly faster in near spatial distance conditions (726.30 ms) than far spatial distance conditions (747.54 ms), and significantly faster in self-referential conditions (716.46 ms) than other-referential conditions (757.37 ms). The distance × reference interaction was not significant, $F(1, 26) = 0.88$, $p = 0.360$.

A 2 (distance: near, far) × 2 (reference: self, other) repeated measures ANOVA on correct recognition reaction times showed no significant main effects or interactions (all $F$s $< 0.05$, all $p$s $> 0.84$).

A 2 (distance: near, far) × 2 (reference: self, other) repeated measures ANOVA on correct recognition scores revealed a non-significant main effect of distance, $F(1, 26) = 0.15$, $p = 0.704$, but a significant main effect of reference, $F(1, 26) = 7.44$, $p = 0.011$, $^2$p = 0.22, with more words correctly recognized in self-referential conditions (15.43) than other-referential conditions (14.08). Crucially, the distance × reference interaction was significant, $F(1, 26) = 10.13$, $p = 0.004$, $^2$p = 0.28. Simple effects analysis showed that memory performance was significantly better for self-referential words at near spatial distance (16.22) than far spatial distance (14.63), $F(1, 26) = 5.81$, $p = 0.023$, $^2$p = 0.18. No significant difference was found between near and far spatial distances for other-referential words, $F(1, 26) = 2.77$, $p = 0.108$.

**Table 2** presents descriptive statistics for the learning and recognition phases ($N = 27$).

### 3.2 ERP Data Analysis

**3.2.1 P1 (105-135 ms)** A 2 (distance: near, far) × 2 (reference: self, other) × 2 (hemisphere: left, right) repeated measures ANOVA on P1 latency revealed no significant main effects or interactions (all $F$s < 1.54, all $p$s > 0.22). For P1 amplitude, the main effect of distance was marginally significant, $F(1, 26) = 3.89$, $p = 0.059$, $^2$p = 0.13, with larger P1 amplitudes in near spatial distance conditions (1.33 V) than far spatial distance conditions (0.83 V) (see Figures 3A & 3B [Figure 3: see original paper]). No significant main effects or interactions were found for reference or hemisphere (all $F$s < 1.94, all $p$s > 0.17).

**3.2.2 N1 (150-180 ms)** A 2 (distance: near, far) × 2 (reference: self, other) × 2 (hemisphere: left, right) repeated measures ANOVA on N1 latency revealed a significant main effect of distance, $F(1, 26) = 10.44$, $p = 0.003$, $^2$p = 0.29, with shorter N1 latencies in far spatial distance conditions (166.62 ms) than near spatial distance conditions (169.54 ms). No significant main effects or interactions were found for reference or hemisphere (all $F$s < 1.23, all $p$s > 0.27). For N1 amplitude, the main effect of distance was marginally significant, $F(1, 26) = 4.11$, $p = 0.053$, $^2$p = 0.14, with larger N1 amplitudes in far spatial distance conditions (-5.00 V) than near spatial distance conditions (-4.39 V) (see Figures 3A & 3B [Figure 3: see original paper]). No significant main effects or interactions were found for reference or hemisphere (all $F$s < 1.95, all $p$s > 0.17).

**3.2.3 LPC (350-550 ms)** A 2 (distance: near, far) × 2 (reference: self, other) × 2 (hemisphere: left, right) repeated measures ANOVA on LPC amplitude revealed significant main effects of distance, $F(1, 26) = 8.32$, $p = 0.008$, $^2$p = 0.24, with larger LPC amplitudes in near spatial distance conditions (2.75 V) than far spatial distance conditions (1.85 V) (see Figures 3C & 3D [Figure 3: see original paper]), and reference, $F(1, 26) = 19.14$, $p < 0.001$, $^2$p = 0.42, with larger LPC amplitudes in self-referential conditions (2.75 V) than other-referential conditions (1.85 V) (see Figures 3C & 3D [Figure 3: see original paper]). The distance × reference interaction was not significant, $F(1, 26) = 1.34$, $p = 0.258$. As shown in the data, both self-referential and other-referential processing at near spatial distances elicited larger LPC amplitudes than at far distances (near-self: 3.36 V > far-self: 2.14 V; near-other: 2.14 V > far-other: 1.56 V) (see Figures 3C & 3D [Figure 3: see original paper]).

A significant main effect of hemisphere was also found, $F(1, 26) = 14.31$, $p = 0.001$, $^2$p = 0.36, with larger LPC amplitudes in the right frontal region (2.73 V) than the left frontal region (1.87 V) (see Figures 3C & 3D [Figure 3: see original paper], Figure 4 [Figure 4: see original paper]). No significant interactions were found between distance and hemisphere, reference and hemisphere, or distance, reference, and hemisphere (all $F$s $< 1.35$, all $p$s $> 0.25$). Overall, both self-referential and other-referential processing at near spatial distances showed more pronounced right frontal activation than at far distances (near-self: 3.87 V > far-self: 2.55 V; near-other: 2.53 V > far-other: 1.98 V) (see Figures 3D [Figure 3: see original paper] and Figure 4 [Figure 4: see original paper]).

**Figure 3 [Figure 3: see original paper]** shows grand-averaged ERP waveforms for the four experimental conditions (P1: 105-135 ms; N1: 150-180 ms; LPC: 350-550 ms). **Figure 4 [Figure 4: see original paper]** shows topographic maps for the four experimental conditions.

## 4. Discussion

### 4.1 Influence of Spatial Distance on Early Cognitive Processing

This study investigated the characteristics of self-referential processing from the perspective of spatial distance using a learning-recognition paradigm combined with ERP technology. The results showed no significant main effects of reference on P1 and N1 component amplitudes or latencies during early processing stages. According to previous research, early visual attentional processing involves less deep cognitive processing and is primarily influenced by stimulus physical properties (Li et al., 2016; Liu et al., 2018). In this study, the physical properties of different reference type names were essentially identical, resulting in no significant differences in P1 and N1 amplitudes and latencies. In contrast, the physical properties of distance levels differed between near and far conditions, and we found significant main effects of distance on P1 and N1 amplitudes and N1 latency. For P1 amplitude, near spatial distance conditions elicited significantly larger amplitudes than far spatial distance conditions. This result supports attention theories regarding near spatial distance stimuli (Abrams et al., 2008) and the "priority entry" effect (Spence & Parise, 2010), demonstrating that stimuli at near spatial distances can capture attention more preferentially and extensively.

For N1 amplitude, far spatial distance conditions elicited significantly larger amplitudes than near spatial distance conditions, opposite to the P1 result. This finding further confirms that although P1 and N1 components are both closely related to early attention, they represent two distinct components (Slagter, Prinssen, Reteig, & Mazaheri, 2016). Previous research indicates that more difficult tasks require greater attentional resources (Li, Jiang, Li, Liu, & Liu, 2015), and the N1 component is closely related to attentional control (Klimesch, Sauseng, & Hanslmayr, 2007) and orientation (Natale, Marzi, Girelli, Pavone, & Pollmann, 2006). In this study, establishing associations between word phrases and names was relatively more difficult in far spatial distance conditions, requiring participants to actively recruit more attentional resources to complete the processing. Consequently, far spatial distance conditions elicited larger N1 amplitudes with shorter latencies.

In summary, the absence of significant reference main effects on P1 and N1 components indicates that spatial distance' s influence on different reference types does not occur at early cognitive processing stages. At the initial stage of early visual processing, near spatial distance elicited larger P1 (105-135 ms) amplitudes, suggesting that near spatial distance captures more attentional resources than far spatial distance. During the subsequent preparation stage for establishing word-name associations, far spatial distance required recruitment and expenditure of more attentional resources, resulting in larger N1 (150-180 ms) amplitudes and shorter latencies. Overall, near spatial distance captured more attentional resources than far spatial distance during early processing stages.

### 4.2 Influence of Spatial Distance on Referential Processing

**Learning phase:** The results showed that self-referential processing produced faster responses, larger LPC amplitudes, and greater right frontal activation compared to other-referential processing. These findings confirm the elaborate processing theory of self (Klein, 2012)—since the self is a unique cognitive structure, memory content related to the self holds special personal significance, and materials processed under self-referential conditions receive faster and more elaborate processing, demonstrating the self-referential processing advantage. These results also further 证实 the lateralization effect of self-referential processing, showing that the right hemisphere predominantly controls self-cognitive processing (Keenan, Nelson, O' Connor, & Pascual-Leone, 2001; Morita et al., 2018). Additionally, near spatial distance produced faster responses than far spatial distance (consistent with ValdésConroy et al., 2014, 2012) and elicited larger LPC amplitudes. The distance × reference interaction was not significant for either reaction time or LPC amplitude. These behavioral and ERP results showed significant main effects of distance and reference but no significant interaction, indicating that the effects of distance and reference did not influence each other (Zhang & Xu, 2015). In other words, near spatial distance produced faster responses and larger LPC amplitudes than far spatial distance under both self-referential and other-referential conditions. Topographic maps also showed more pronounced right frontal activation for both self-referential and other-referential processing at near versus far spatial distances. Fields and Kuperberg (2016) noted that larger LPC amplitudes reflect greater cognitive resource investment and deeper information storage during processing. Based on previous research and our findings, although processing time was shorter for near spatial distance, the P1, N1, and LPC data indicate that more attentional resources and deeper processing were invested in near spatial distance stimuli under both reference conditions. This resulted in an enhancement effect of near spatial distance on both self-referential and other-referential processing during late encoding stages compared to far spatial distance. These results strongly support spatial distance attention theories (Abrams et al., 2008; Reed et al., 2006): physical spatial distance can influence psychological cognitive processing, with nearer distances capturing more attentional resources and facilitating subsequent cognitive processing.

**Recognition phase:** Self-referential processing showed better memory performance than other-referential processing, consistent with the encoding phase and previous research (Gregg, Mahadevan, & Sedikides, 2017). The memory advantage observed during recognition retrieval further demonstrates that encoding under self-referential conditions involves deeper processing and constructs better retrieval cues (Argembeau, Comblain, & Linden, 2005). The main effect of distance was not significant, but the reference × distance interaction was significant. Simple effects analysis revealed that memory performance for self-referential words was significantly better at near spatial distance than far spatial distance. This finding extends Oakes and Onyper' s (2017) research, which showed that when object distance from participants remained constant, virtually pulling objects toward the self produced better memory than pushing them away (see also Truong, Chapman, Chisholm, Enns, & Handy, 2016). Fujita, Henderson, Eng, Trope, and Liberman (2006) and Henderson, Fujita, Trope, and Liberman (2006) explained this phenomenon by demonstrating that participants described near-distance stimuli more concretely and far-distance stimuli more abstractly, with concrete cues facilitating memory retrieval. Combined with the more elaborate and deeper processing of near-distance stimuli during the learning phase, these factors contributed to the persistence of near spatial distance enhancement effects on self-referential processing during recognition retrieval.

These findings demonstrate that self-referential processing can preferentially capture attention, leading to elaborate stimulus processing. Self-referential processing at near spatial distances further enhances this effect, resulting in even more elaborate processing. These results not only support spatial distance attention theory but also enrich the theoretical framework of self-referential processing by showing that spatial distance is an important factor influencing self-referential processing. Moreover, the self-referential processing advantage arises from associations with self-concept (Kim, 2012; Ma & Han, 2010). Our findings indicate that when external stimuli are physically closer to an individual, they more readily associate with self-concept and enter the self-domain.

However, unlike the learning phase, no significant difference was found between near and far spatial distances for other-referential processing during the recognition phase, indicating that the enhancement effect of near spatial distance on other-referential processing disappeared. Combined with LPC amplitude data (Figures 3C & 3D [Figure 3: see original paper]), this suggests that other-referential processing recruited relatively fewer attentional resources and involved shallower processing during the learning phase. Additionally, since other-referential processing lacks close connection to the self, the constructed memory retrieval cues were poorer (Argembeau et al., 2005). Consequently, due to weaker memory traces and the intervening interference task, words processed under other-reference were more susceptible to forgetting according to classic memory decay and interference theories. Therefore, although near spatial distance enhanced processing during the encoding phase, this enhancement was offset by these factors and failed to manifest during the recognition phase.

In summary, the results from both learning and recognition phases indicate that compared to far spatial distance, near spatial distance produces a clear enhancement effect on self-referential processing that occurs during late encoding stages (larger LPC amplitudes and right frontal activation) and remains stable during recognition retrieval (better memory performance). For other-referential processing, near spatial distance enhancement appeared only during the encoding phase and disappeared during recognition retrieval, suggesting that self-referential processing at near spatial distances is more stable and deeper than other-referential processing.

### 4.3 Summary and Outlook

This study employed a learning-recognition paradigm and ERP technology to explore self-referential processing from the perspective of spatial distance during both encoding and retrieval phases. The findings demonstrate that near spatial distance enhances self-referential processing compared to far spatial distance. Beyond verifying spatial distance attention theory and enriching the theoretical framework of self-referential processing, this study offers valuable insights: previous research has shown that people or objects with closer social distance to the core self can activate deeper self-concepts and produce more pronounced processing advantages (Allan, Morson, Dixon, Martin, & Cunningham, 2017). Our findings reveal that closer spatial distance can also activate deeper self-concepts. These results suggest that both social distance and spatial distance play important roles in self-concept formation, with closer distances exerting greater influence. While we typically emphasize the importance of close others (e.g., parents) for developing a healthy self-concept, our findings imply that if spatial distance is great (e.g., left-behind children and their parents), their influence on children’ s self-concept formation will be substantially diminished. Therefore, promoting physical proximity and companionship may be essential for cultivating healthy personality development.

This study has several limitations: First, we used 2D simulation to manipulate spatial distance. Future research could employ 3D or real-world settings to enhance ecological validity. Second, we focused primarily on spatial distance effects on self-name referential processing; future studies could explore effects on other self-related information processing. Finally, future research could further investigate the retrieval phase of other-referential processing to explore the stability of spatial distance effects across different reference types.

In conclusion: (1) No significant differences were found in early P1 and N1 component amplitudes and latencies across different reference types at near and far spatial distances. However, near spatial distance elicited larger LPC amplitudes and greater right frontal activation than far spatial distance during self-referential processing, with better recognition memory performance. These results demonstrate a clear enhancement effect of near spatial distance on self-referential processing that occurs primarily at late cognitive processing stages. (2) Near spatial distance elicited larger LPC amplitudes and greater right frontal activation than far spatial distance during other-referential processing, but no significant difference was found in recognition memory performance between the two distance conditions. This indicates that self-referential processing at near spatial distances is more stable and deeper than other-referential processing.

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*Note: Figure translations are in progress. See original paper for figures.*