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Joint Influence of Metaphor Familiarity and Mental Imagery Ability on Action Metaphor Comprehension: An Event-Related Potential Study*

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The present study investigates whether an individual's mental imagery ability, in addition to metaphor familiarity, affects the degree of sensory-motor involvement during action metaphor comprehension. We assessed participants' mental imagery ability using the Vividness of Mental Imagery Questionnaire-2 (VVIQ-2) and recorded the participants' event-related potentials (ERPs) while they read (1) Literal, (2) Familiar Metaphor, (3) Unfamiliar Metaphor, and (4) Abstract sentences. The ERP mental imagery effect (200–750 ms) in the Literal relative to the Abstract condition was reliably correlated with participants' VVIQ scores. A median split based on the VVIQ scores showed that high-VVIQ participants elicited ERP frontal imagery effects that were more prolonged in the Unfamiliar Metaphor condition (350–550 ms) than in the Familiar Metaphor condition (350–450 ms), suggesting that people with high imagery ability tend to routinely recruit sensory-motor experiences to facilitate metaphor comprehension, and to a greater extent for unfamiliar metaphors than for familiar ones. On the other hand, low-VVIQ participants with less effective mental imagery abilities showed no imagery effects in either metaphor conditions, but an early posterior N400 mismatch effect (200–350 ms) in the Unfamiliar Metaphor condition. The results suggest that low-VVIQ participants tend to rely on more general semantic access mechanisms during metaphor comprehension that detect the semantic mismatch between the unintended literal meanings of the metaphors and the context. Both processing styles are affected by metaphor familiarity and lead to successful metaphor comprehension in the current study. However, whether these processing styles lead to comprehension differences for metaphors appearing in discourses or conversations will require further research.

Key words: ERP imagery effect, metaphor processing, familiar metaphor, unfamiliar metaphor, mental imagery

1. Introduction

The present study investigates how metaphor familiarity and mental imagery ability jointly affect metaphor comprehension. Metaphors are pervasive in our daily life; they not only structure our conceptual systems, but also shape the way we perceive the world. In particular, metaphors are

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a critical cognitive construct that facilitates abstract thinking. For example, metaphors influence the way people reason about complex issues, make problem-solving decisions (Thibodeau & Boroditsky 2011), and learn new concepts by extensions from older ones (Carroll & Thomas 1982). Indeed, 'metaphor is the main mechanism through which we comprehend abstract concepts and perform abstract reasoning' (Lakoff 1992).

One possible explanation for the processing advantages for metaphors, according to embodied cognition theories, is the linkage between the sensory-motor information of the literal meanings and the intended figurative interpretations (Gibbs et al. 2006; Wilson & Gibbs 2007). However, studies investigating whether sensory-motor systems are indeed involved in metaphor comprehension when no real physical actions are implied have yielded mixed findings.

On the one hand, there is evidence showing that figurative, as well as literal, action sentences induce brain activation in sensory- or action-related brain regions, including motor cortex (Boulenger et al. 2009, e.g. {*John grasped the idea/object.*}; Cardillo et al. 2012, e.g. {*The insults hopped on her tongue.*}), motion-sensitive visual areas (Chen et al. 2008, e.g. {*The man fell under her spell.*}; Saygin et al. 2010, e.g. {*The hiking trail crossed the barren field.*}; Wallentin et al. 2005b, e.g. {*The man goes through the sorrow.*}), and textual-selective somatosensory cortex (Lacey et al. 2012, e.g. {*She had a rough day.*}). In addition, Cacciari and colleagues (2011), with the transcranial magnetic simulation (TMS) technique, demonstrated that Italian fictive sentences (transliterated examples provided by Cacciari et al. in their paper: {*The road walks parallel to the river.*}) and metaphorical (but not idiomatic) sentences (e.g. {*Marta walks over the decay road regrettably.*}) both elicited large motor-evoked potentials (MEPs), as did literal sentences, indicating the involvement of the motor system in comprehending figurative expressions.

On the other hand, some studies provided evidence of the involvement of sensory-motor information for comprehending literal sentences only, but not figurative sentences. For example, Bergen et al. (2007) found that literal sentences such as {*The mule climbed.*} interfered with visual processing in the corresponding visual field, suggesting that a visual image evoked in the corresponding visual field. However, metaphorical sentences such as {*The cost climbed.*} did not show such an interference effect, suggesting that a visual image is not produced in this case. Similar counter-evidence for sensory-motor involvement during figurative language processing was also reported in the brain imaging literature. For example, Aziz-Zadeh et al. (2006) found somatotopic activation along the motor strip from reading literal action phrases (e.g. *biting the peach*), but not from figurative phrases (e.g. *biting off more than you can chew*). Likewise, Raposo et al. (2009) found activation in motor regions from reading isolated action words (e.g. *grab*) or literal sentences (e.g. {*The fruit cake was the last one so Claire grabbed it.*}), but not from reading figurative sentences (e.g. {*The job offer was a great chance so Claire grabbed it.*}).

One explanation offered to account for such inconsistency in the literature is familiarity of the figurative usage (Cacciari et al. 2011; Desai et al. 2011). It is argued that, with increasing familiarity, which in most cases also increases conventionality, figurative expressions such as metaphors can be appreciated with less reliance on the literal interpretations and weaker links to the sensory-motor associates induced by the literal meanings. Several studies have shown that familiar and unfamiliar metaphors do involve different comprehension processes. For example, Lai et al. (2009) found that, compared to literal sentences, conventional metaphors elicited a transient N400 effect (320–440 ms); however, the N400 effect elicited by novel metaphors were more prolonged and patterned with the anomalous condition (320–560 ms), suggesting that comprehending novel metaphors is more cognitively taxing. The processing differences between familiar and unfamiliar metaphors have been shown to affect sensory-motor involvement during metaphor comprehension. For example, a functional magnetic resonance imaging (fMRI) experiment conducted by Desai et al. (2011) showed that primary motor cortices were engaged only when unfamiliar metaphors were processed; with increasing familiarity of metaphors, sensory-motor simulation became less detailed and involved secondary motor regions instead.

However, familiarity alone does not seem to resolve the inconsistency in the literature completely, as many studies showing supportive evidence for the engagement of sensory-motor associates during figurative language processing used highly familiar figurative expressions (Boulenger et al. 2009; Cacciari et al. 2011; Lacey et al. 2012), as did those studies that provided counter-evidence (Aziz-Zadeh et al. 2006; Bergen et al. 2007; Raposo et al. 2009). In addition, conventional and novel metaphors have been found to elicit no different response patterns under certain circumstances (Blasko & Connine 1993; Pynte et al. 1996).

One other factor that could potentially account for at least some of the controversy but has rarely been considered in the literature is individual differences in mental imagery ability. It has long been noted that 'mental imagery ability is not an undifferentiated general skill' (Kosslyn et al. 1984). When reading perception-related or action-related language expressions, some people tend to 'see in the mind's eye' by forming vivid images, while others do not. In this light, it is possible that some of the inconsistencies as to whether sensory-motor links exist during figurative language comprehension can be accounted for by the heterogeneity in mental imagery ability among the participants.

In view of this, we conducted the following experiment to explore the possibility that, in addition to metaphor familiarity, the ability to generate mental imageries also modulates the involvement of sensory-motor associates during figurative language comprehension. To that end, two independent factors were manipulated, including (1) metaphor familiarity[1] and (2) mental imagery ability. Participants' event-related potentials (ERPs) were recorded while they comprehended these action sentences. To ascertain that all metaphorical sentences were understood metaphorically, an off-line paraphrasing task was conducted after the ERP session. In addition, we assessed each participant's mental imagery ability with the Vividness of Visual Imagery Questionnaire-2 (VVIQ-2) (Marks 1995).

It has been shown in the literature that, compared to reading abstract words, reading concrete words such as object names or action names elicits greater negativity, including an anterior negativity that starts from around 200–300 ms to around 700–900 ms post stimuli-onset, and a central-posterior N400 effect (Holcomb et al. 1999; Huang et al. 2010; Lee & Federmeier 2008). The anterior ERP concreteness effect is similar to the effect observed in mental imagery studies such as Farah et al. (1989) (taking into account differences in reference site), and has been thought to reflect mental imagery generation processes in which the reenactment of sensory-motor

[1] We adopt the terms originally used in prior studies such as 'conventional' and 'novel' metaphors to refer to the manipulations in these studies, but use the terms 'familiar' and 'unfamiliar' metaphors in our study instead, as our metaphorical stimuli were defined in terms of subjective ratings of familiarity but not conventionality. However, the degrees of familiarity for our familiar as well as unfamiliar metaphors are comparable to the conventional and novel metaphors in these studies (De Grauwe et al. 2010; Lai et al. 2009).

experiences occurs. For example, West & Holcomb (2000, 2002) suggested that the frontal ERP concreteness effect 'represent(s) activation in a mental imagery subsystem that is relatively more available to concrete words than to abstract words' and that reflects the access of specific characteristics of the imaged items. This imagery-based linguistic concreteness effect has been found to be more prominent in a mental imagery task (West & Holcomb 2000), but was nevertheless reliable even when there were no explicit instructions for the participants to generate mental images (Huang et al. 2010; Lee & Federmeier 2008; West & Holcomb 2000).

Based on this research series, we thus used this anterior concreteness effect—the ERP imagery effect—as an index for the activation of associated sensory-motor experiences in response to concrete words, which in turn could help us clarify whether associated sensory-motor representations are reenacted during metaphor understanding. To validate that the ERP imagery effect does reflect an individual's mental imagery ability, we would first try to see whether a reliable correlation between participants' ERP mental imagery effects in the Literal condition and their VVIQ-2 scores (Marks 1995) exists. If this correlation is reliable, then of greater interest to this study is whether there are any ERP mental imagery effects in the two metaphor conditions, and whether the mental imagery effects are modulated by metaphor familiarity and an individual's mental imagery ability.

With these manipulations, our study can provide important insights into the heated debate about whether sensory-motor representations are accessed during metaphor comprehension when no actual physical actions are indicated. To our knowledge, we are among the first to investigate how individual differences in mental imagery ability influence the way people process familiar and unfamiliar metaphors. If people with higher or lower mental imagery abilities do indeed show different brain response patterns to familiar and unfamiliar metaphors, then these findings would suggest a need to accommodate these factors in theoretical accounts about how sensory-motor associates are involved in comprehending figurative languages.

2. Methods

2.1 Materials

Eighty-eight action verbs (e.g. *nuó chū lái* 'move out') and 88 abstract verbs (e.g. *bǎo liú zhù* 'keep') were used to construct four different types of sentences, including (1) Literal, (2) Familiar Metaphor, (3) Unfamiliar Metaphor, and (4) Abstract sentences. Metaphors were constructed from conventional conceptual metaphors (not including idiom and proverbs) that vary in the familiarity of linguistic expressions, including 'Familiar Metaphors' (highly familiar linguistic expressions, e.g. {*Tā bǎ sānshínián de gǎnqíng qiē duàn*, 他把三十年的感情切斷, 'He broke a 30-year relationship.'}) and 'Unfamiliar Metaphors' (unfamiliar linguistic manifestations, e.g. {*Tā bǎ guānyú zìjǐ de chuanwén qiē duàn*, 他把關於自己的傳聞切斷, 'He ended a rumor about himself.'}). As shown in Table 1, Literal, Familiar, and Unfamiliar Metaphor sentences ended with the same action verbs, and Abstract sentences ended with abstract verbs. To assess whether participants successfully obtained the metaphorical meanings of the metaphors, each sentence was paired up with probes that were either related or unrelated to the literal meaning of the sentence-final verb (e.g. sentence-final verb: *nuó chū lái* 'move out'; related probe: *yí wèi* 'displace'; unrelated probe: *fàng sheng* 'set free').

Table 1: Examples of experimental sentences and their corresponding probes.

Condition	Sentence	Literal-related probe	Unrelated probe
LIT	tā fèi lì di bǎ chē zi **<u>nuó chū lái</u>** she effortly BA car move come out 'She makes a lot of efforts to move out the car.'	yí wèi displace	fàng shēng set free
FM	tā nǔ lì di bǎ shí jiān **<u>nuó chū lái</u>** she effortly BA time move come out 'She makes a lot of efforts to make the time.'	yí wèi displace	fàng shēng set free
UM	tā nǔ lì di bǎ zì zhì lì **<u>nuó chū lái</u>** she effortly BA willpower move come out 'She makes a lot of effort to strengthen her willpower.'	yí wèi displace	fàng shēng set free
ABS	tā nǔ lì di bǎ shí jiān **<u>bǎo liú zhù</u>** she effortly BA time keep 'She makes a lot of efforts to keep the time.'	guǎn lǐ manage	fàng shēng set free

Sentence-final critical words are bold and underlined. Sentences and probes were arranged into different experimental lists such that each participant saw each action verb and the following probe only once. (LIT: Literal; FM: Familiar Metaphor; UM: Unfamiliar Metaphor; ABS: Abstract)

Experimental sentences were closely matched across conditions, globally and within each individual list, for lexical features, including familiarity, length, concreteness values, and cloze probability of the critical words, and for sentential features, including length, sentence constraint, and comprehensibility of the sentences (Table 2). Probes were also closely matched for their familiarity, concreteness, and semantic relatedness to the meaning of the sentence-final critical words (Table 3).

Table 2: Average rating scores for lexical features of the sentence-final critical words and sentential features of the whole sentence.

Lexical and sentential features	LIT	FM	UM	ABS
Word length	2.0 (0.6)	2.0 (0.6)	2.0 (0.6)	2.2 (0.4)
Word familiarity (1 = very unfamiliar; 7 = very familiar)	5.5 (0.7)	5.5 (0.7)	5.5 (0.7)	5.7 (0.6)
Word concreteness (1 = very abstract; 7 = very concrete)	5.7 (0.6)	5.7 (0.6)	5.7 (0.6)	3.2 (0.4)
Cloze probability (%)	0.0 (0.1)	0.0 (0.1)	0.0 (0.0)	0.0 (0.1)
Sentence length	9.3 (1.6)	9.4 (1.6)	9.4 (1.5)	9.4 (1.6)
Sentence constraint (%)	0.3 (0.1)	0.2 (0.1)	0.2 (0.1)	0.2 (0.1)
Sentence comprehensibility (1 = very incomprehensible; 7 = very comprehensible)	6.7 (0.4)	6.5 (0.5)	5.5 (0.8)	6.6 (0.5)

Lexical and sentential features	LIT	FM	UM	ABS
Sentence familiarity (1 = very unfamiliar; 7 = very familiar)	6.2 (0.8)	5.7 (1.0)	3.5 (0.9)	5.7 (1.1)
Sentence figurativeness (1 = very literal; 7 = very figurative)	1.5 (0.5)	4.4 (0.7)	4.8 (0.8)	2.3 (0.8)

Standard deviations are shown in parentheses. (LIT: Literal; FM: Familiar Metaphor; UM: Unfamiliar Metaphor; ABS: Abstract)

Table 3: Average rating scores for literal-related probes (RP) and unrelated probes (UP).

Lexical and sentential features	Probe	LIT	FM	UM
Word familiarity (1 = very unfamiliar; 7 = very familiar)	**RP**	4.8 (0.8)	4.8 (0.8)	4.8 (0.8)
	UP	5.6 (0.8)	5.6 (0.8)	5.6 (0.8)
Word concreteness (1 = very abstract; 7 = very concrete)	**RP**	5.5 (0.7)	5.5 (0.7)	5.5 (0.7)
	UP	4.9 (1.0)	4.9 (1.0)	4.9 (1.0)
Semantic relatedness to critical word (1 = very unrelated; 7 = very related)	**RP**	4.6 (0.9)	4.6 (0.9)	4.6 (0.9)
	UP	1.4 (0.3)	1.4 (0.3)	1.4 (0.3)
Semantic relatedness to sentence (1 = very unrelated; 7 = very related)	**RP**	5.2 (1.3)	2.7 (1.2)	2.8 (1.1)
	UP	1.0 (0.2)	1.1 (0.3)	1.1 (0.4)

Identical probes were used for the same set of sentences across LIT, FM, and UM conditions, but arranged into different lists such that each participant saw a probe only once. Standard deviations are shown in parentheses. (LIT: Literal; FM: Familiar Metaphor; UM: Unfamiliar Metaphor)

Overall, concrete verbs were rated as more concrete than abstract verbs ($p < 0.01$). In addition, both Familiar and Unfamiliar Metaphors were rated as more figurative than the Literal and Abstract sentences ($p < 0.01$); Unfamiliar Metaphors were rated as less familiar at the sentence level than the other three conditions ($p < 0.01$). Regarding the probes, the literal-related probes were rated as highly related to the message level meaning of the preceding sentences in the Literal condition only.

Each participant read 22 sentences in each of the four conditions, with an additional 22 literal and 44 metaphorical fillers that differed from the critical sentences in syntactic structures, totaling 154 sentences. Four lists were generated to allow the action verbs and probes to be rotated through sentence types (Literal, Familiar Metaphor, and Unfamiliar Metaphor), with each participant reading each action verb and probe only once.

2.2 Participants

Twenty-two college or graduate students from Taipei, Taiwan, participated in this study for cash payment (10 males and 12 females; mean age 23 years, range 20–28). Data from four additional participants were collected but excluded from the subsequent analyses due to excessive artifacts. All participants were right-handed, as assessed by the Edinburgh Inventory (Oldfield 1971); five reported having left-handed family members. All participants were native speakers of Mandarin

Chinese with no consistent exposure to other languages, other than Taiwanese, before the age of five. None of the participants reported any history of neurological or psychiatric disorders or brain damage, and all had normal or corrected-to-normal vision. All participants signed a written informed consent prior to the ERP experiment and all protocols were approved by the Institutional Review Board at the National Taiwan University.

2.3 Procedure

Participants were seated 100 cm in front of a computer monitor in a quiet, shielded room. They were given written instructions and a 15-trial practice to familiarize them with the task and the experimental environment. Each trial began with the display of a fixation cross in the center of the screen for 500 ms. After a Stimulus-onset asynchrony (SOA) of 700 ms, a sentence was presented word by word in the center of the screen. Each word was presented for 300 ms, followed by a blank screen for 200 ms. At the end of the sentence, the screen went blank for 700 ms. A probe was then presented for 300 ms, followed by the question: 'Is this word related to the preceding sentence?' Participants were instructed to judge whether the probe was related to the preceding sentence or not and to answer the question by pressing either a 'yes' or a 'no' button on a computer keyboard. The question disappeared once a button-pressing response was given, or after a lapse of 5 seconds. The next trial then began after 1.5 seconds.

2.4 Off-line behavioral tasks

2.4.1 Metaphor paraphrasing task

To ensure that participants successfully interpreted Familiar as well as Unfamiliar Metaphors, a paraphrasing task was conducted after the ERP session. In this task, metaphors shown in the ERP session were presented one sentence at a time on a computer monitor, and participants were asked to paraphrase the whole sentence orally. Participants' responses were recorded and scored off-line. This task was modified from the paraphrasing task that was first used in Lai et al. (2009), in which participants were told to type in what they thought about the novel metaphors after the ERP session. To prevent participants from generating response strategies by paraphrasing novel metaphors only, both Familiar and Unfamiliar Metaphors were included in the present study.

2.4.2 Mental imagery generation assessment

Following the ERP recording session, participants were also tested for their mental imagery generation ability with the VVIQ-2 (Chou 2007; Marks 1995), a revised version of VVIQ (Marks 1973). VVIQ-2 consists of 32 items; each requires participants to rate the vividness of the mental image related to a specific scene or situation that they formed with their eyes closed. This questionnaire has been validated as a predictor of an individual's imagery ability, including recognition of colored photographs, detection of salient changes in pictures, ability of mental rotation, and early activation in the visual cortex (Cui et al. 2007; Logie et al. 2011; Marks 1973; Rodway et al. 2006). The vividness of imagined scenes or objects was scored on a five-point scale, with higher scores indicating higher vividness of mental imagery (1: 'No image at all, you only "know" that you are thinking of an object'; 5: 'Perfectly clear and as vivid as normal vision').

2.5 ERP recording and data analysis

The electroencephalogram (EEG) was recorded from 32 sintered Ag/AgCl electrodes arranged according to the 10–20 system (QuickCap, Neuromedical Supplies, Sterling, TX, USA). All scalp electrodes were referenced on-line to a common vertex reference located between Cz and CPz, and re-referenced off-line to the average of the right and left mastoids. Vertical eye movements were recorded by a pair of electrodes placed on the supraorbital and infraorbital ridges of the left eye, and horizontal eye movement was recorded by a pair of electrodes placed lateral to the outer canthus of both eyes. Electrode impedance was kept below 5 kΩ for all electrode sites. The continuous EEG was amplified with SYNAMPS2 amplifiers (Neuroscan, Inc., El Paso, TX, USA) through a band-pass filter of 0.05–100 Hz and digitized at a sampling rate of 1,000 Hz.

Epochs of EEG data were taken from 100 ms before stimulus onset to 800 ms after. Trials contaminated by artifacts from amplifier blocking, signal drifting, eye movements, or muscle activity were rejected off-line before averaging. Trial loss averaged 12.33%. Artifact-free ERPs were then averaged by stimuli type after subtraction of the 100-ms pre-stimulus baseline. Prior to statistical analyses, ERPs were digitally filtered with a band-pass of 0.1–30 Hz. Only ERP data for trials that were correctly paraphrased in the off-line paraphrasing task were included in the statistical analysis. To correct for violations for sphericity associated with repeated measures, the Huynh–Feldt adjustment to the degrees of freedom was applied to each analysis of variance (ANOVA). Consequently, for all F tests with more than one degree of freedom in the numerator, the corrected p value is reported. For all analyses, the main effects of electrodes and interactions with electrode sites are not reported unless they are of theoretical significance.

3. Results

3.1 Behavior

3.1.1 Semantic relatedness judgment task

The purpose of this task was to encourage participants to read the sentences carefully for meaning, and also to provide information about whether participants understood the sentences metaphorically. If participants did not manage to obtain the metaphorical meanings of the metaphors and still read the sentences literally, they would inaccurately judge the literal-related probes as related to the preceding sentences. Our results showed that participants were highly accurate in this task, suggesting that they were able to discard the literal meanings of the metaphorical words successfully by the time the probes were presented. Average accuracy for the Literal, Familiar Metaphor, Unfamiliar Metaphor, and Abstract conditions was 89.2%, 95.9%, 93.8%, and 91.8%, respectively.

3.1.2 Paraphrasing task

Forty-four metaphorical sentences were tested in total. Again, participants were highly accurate. The overall accuracy rate was 97.8% (range 90.9%–100%).

3.2 ERPs

3.2.1 Sentence-final critical words

Figure 1 shows the grand average ERP responses at a representative sample of scalp channels for sentence-final critical words. All conditions were characterized by early components typical of visual word presentation, including, over posterior sites, a positivity (P1) peaking around 125 ms, a negativity (N1) peaking around 175 ms, and a positivity (P2) peaking around 250 ms; and over frontal sites, a negativity (N1) peaking around 125 ms and a positivity (P2) peaking around 250 ms. These components were followed by a widespread negative-going wave (N400) and then a late positive component (LPC). Compared to the Abstract condition, the Literal condition showed a larger negativity, starting from around 200 ms up to around 750 ms post stimuli-onset, with the conditional differences bigger at more frontal than more posterior sites. These effect patterns were very similar to the anterior imagery-based concreteness effect reported in previous studies (Huang et al. 2010; Lee & Federmeier 2008; West & Holcomb 2000). Similar differences from the Abstract condition can be seen in the Unfamiliar Metaphor condition, and at a much more restricted set of channels and time range in the Familiar Metaphor condition.

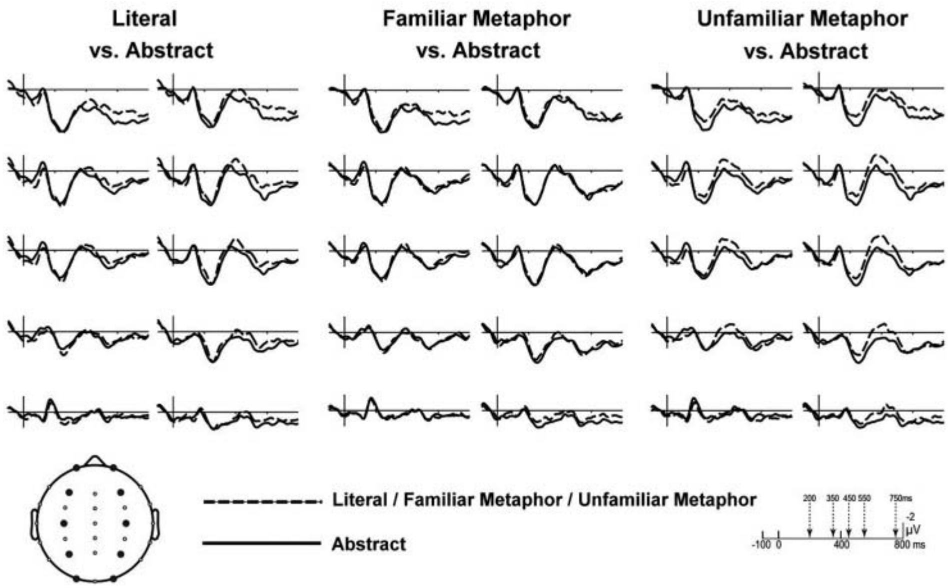

Figure 1: Grand average ERPs from all participants to critical final words in the Abstract (solid line), Literal, Familiar Metaphor, and Unfamiliar Metaphor conditions (dashed line). Data are plotted separately at 10 representative electrode sites (FP1, FP2, F3, F4, C3, C4, P3, P4, O1, O2). For this and all subsequent waveform graphs, negative values are plotted up. Brain responses were more negative in the Literal condition compared to the Abstract condition, starting from around 200 ms to the end of the epoch. This negativity is more robust in the frontal-central scalp sites. Similar negativity was seen in the Unfamiliar Metaphor condition with a larger effect size and broader scalp distribution, but was observable in only a few prefrontal sites in the Familiar Metaphor condition.

Consistent with the findings showing individual differences in mental imagery generation ability (Charlot et al. 1992; Cui et al. 2007; Kosslyn et al. 1984), we observed a great amount of variation across participants in their VVIQ-2 scores and ERP data. To examine whether these variations were correlated, the size of each participant's anterior imagery effect, measured as the mean amplitude difference of the responses to the sentence-final critical words in the Literal condition and the Abstract condition between 200 and 750 ms over the 15 frontal electrodes, was regressed against his/her VVIQ-2 scores. The results showed that the size of the anterior imagery effect elicited by the Literal condition significantly correlated with the VVIQ-2 scores ($r = -.42$, $p = .05$) (Figure 2).

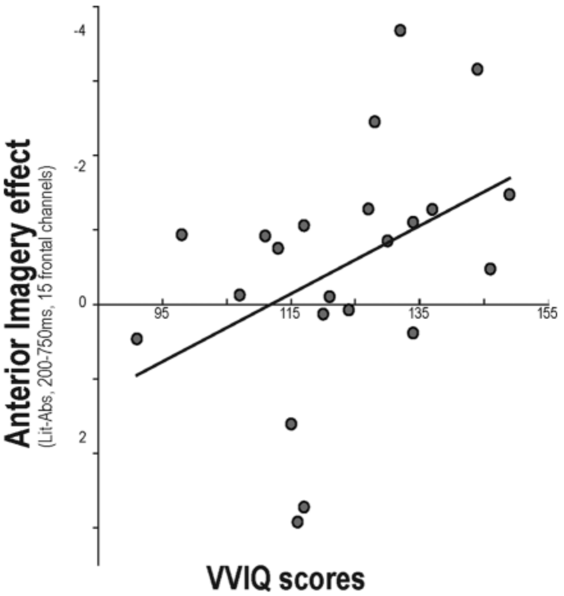

Figure 2: VVIQ-2 scores were plotted on the X axis against the mean amplitude differences between responses to critical words in the Literal and Abstract conditions (Literal–Abstract, 200–750 ms post stimulus-onset over the 15 frontal channels) on the Y axis. To make this figure easily comparable with the ERP figures, negative values are also plotted up. This scatter plot shows that better performance in the mental imagery generation task is associated with larger ERP imagery effect.

Motivated by this finding and our hypothesis that metaphor comprehension may differ depending on whether mental imageries are involved, we divided participants into two groups based on a median split of their VVIQ-2 scores ($N = 11$ in each group). The average VVIQ-2 score was 135 for the high-VVIQ participants (range 124–142) and 111.4 (range 91–121) for the low-VVIQ participants.

Figure 3 shows the averaged ERPs from the high-VVIQ group. Compared to the Abstract condition, there was a large anterior sustained negativity starting from around 200 ms up to around 750 ms in Literal, Familiar Metaphor, and Unfamiliar Metaphor conditions, with the effect in Familiar Metaphor condition seen at a smaller set of electrode sites. This effect was quite widespread and sustained in time in the Literal condition. However, for both metaphor conditions, this negativity was offset by a positive-going component (LPC) after the N400 time window over central-posterior sites.

The low-VVIQ group, on the other hand, showed quite different patterns (Figure 4). There were no clear systematic response differences in the Literal versus Abstract or Familiar Metaphor versus Abstract comparisons. While there was a larger negativity to the Unfamiliar Metaphor condition than to the Abstract condition, the difference was more centrally distributed and restricted to the N400 time window, instead of frontally distributed and sustained. However, similar to the high-VVIQ data, there was also a tendency of positive-going responses following the N400 time window in the two metaphor conditions. (To allow for easier comparisons across the four conditions, Figure 5 overlays the responses from all four conditions for all, high-VVIQ, and low-VVIQ participants.)

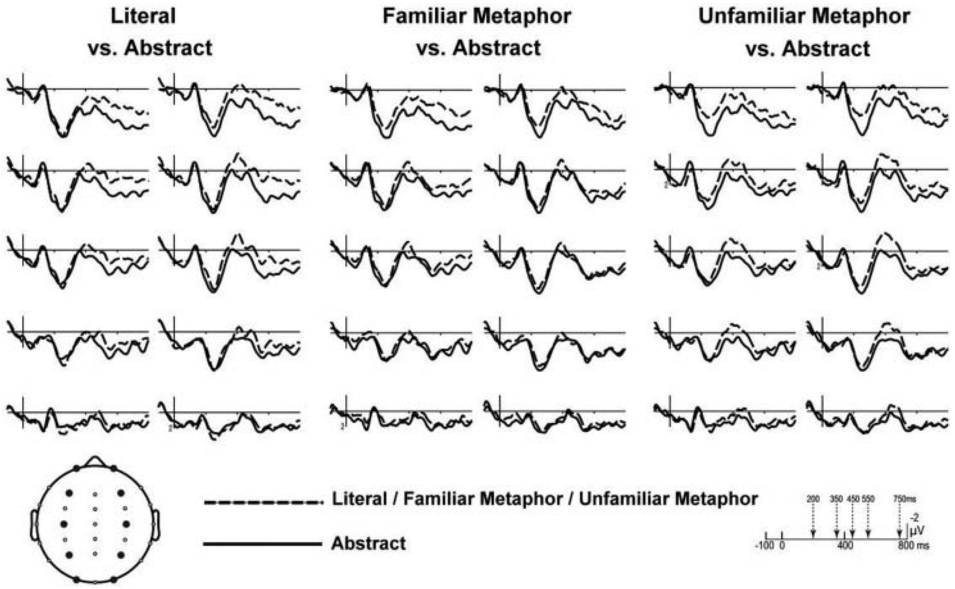

Figure 3: Grand average ERPs from high-VVIQ participants to critical final words in the Abstract (solid line), Literal, Familiar Metaphor, and Unfamiliar Metaphor conditions (dashed line). Brain responses were more negative in the Literal, Familiar Metaphor, and Unfamiliar Metaphor conditions than in the Abstract condition over frontal-central sites. This negative effect was most sustained in the Literal condition (350–750 ms), less prolonged in the Unfamiliar Metaphor condition (350–550 ms), and much more restricted in duration and electrode sites in the Familiar Metaphor condition (350–450 ms).

To characterize these effects, the following statistical tests were conducted. To measure the anterior imagery effects, omnibus ANOVAs with four levels of Condition (Literal versus Familiar Metaphor versus Unfamiliar Metaphor versus Abstract), two levels of Anteriority (frontal versus central-posterior), and 15 levels of Electrodes (frontal sites: FP1, FP2, F3, FZ, F4, F7, F8, FC3, FCZ, FC4, FT7, FT8, C3, CZ, C4; central-posterior sites: CP3, CPZ, CP4, T7, T8, TP7, TP8, P3, PZ, P4, P7, P8, O1, OZ, O2) were conducted on mean amplitudes of each of the four time windows (200–350 ms; 350–450 ms; 450–550 ms; 550–750 ms after stimulus onset). In addition, to measure the LPC effects in the metaphor conditions while accounting for the influence of the preceding overlapping negative responses, we did a peak-to-peak subtraction between the LPC time window (450–750 ms) and the N400 time window (200–450 ms) at the nine central-posterior channels,

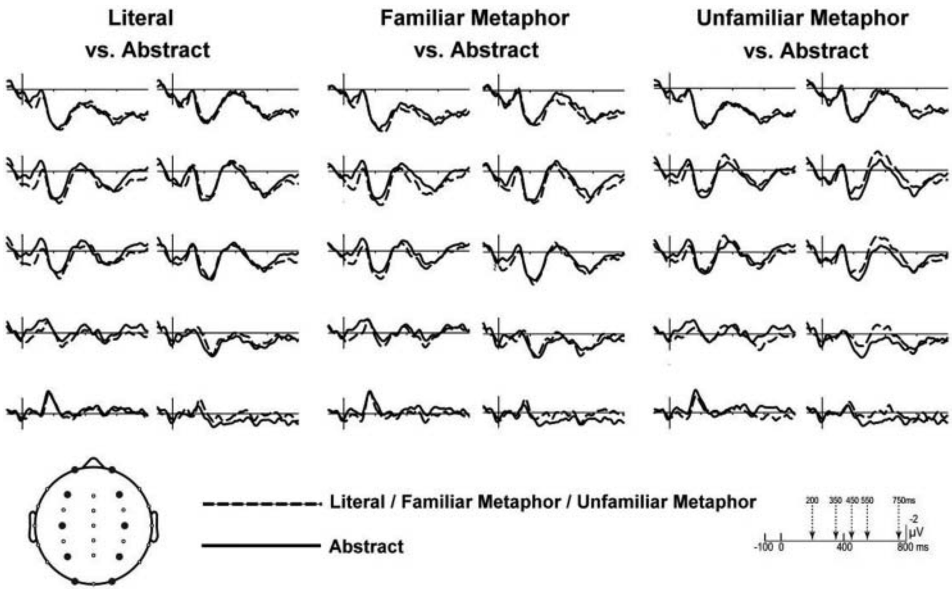

Figure 4: Grand average ERPs from low-VVIQ participants to critical final words in the Abstract condition (solid line), Literal, Familiar Metaphor, and Unfamiliar Metaphor conditions (dashed line). Unlike in the high-VVIQ group, there was no clear frontal negative effect in any of the three comparisons. Instead, the Unfamiliar Metaphor condition elicited greater negative responses than the other three conditions over central-posterior channels.

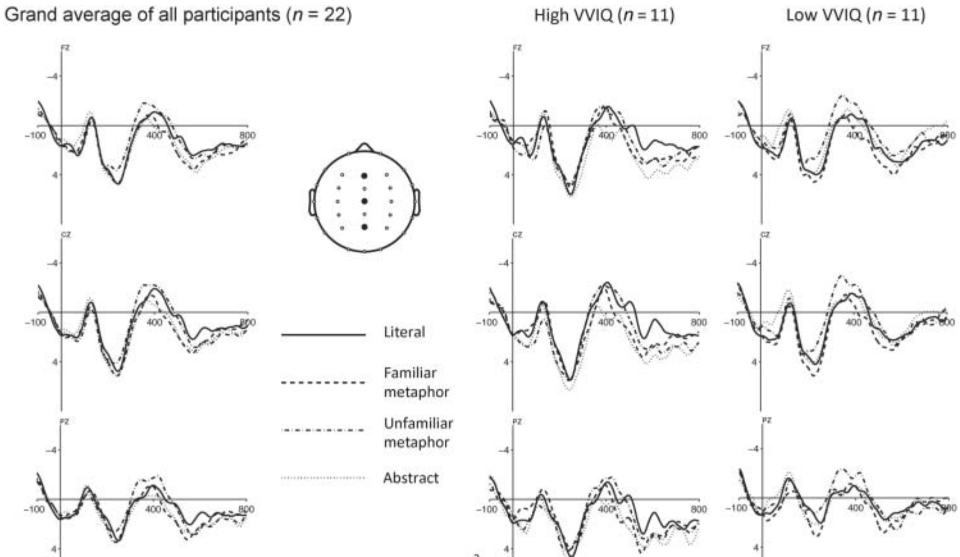

Figure 5: Grand average ERPs to critical final words in the Literal (solid line), Familiar Metaphor (dashed line), Unfamiliar Metaphor (dashed-dotted line), and Abstract (dotted line) conditions were shown at three representative electrode sites (FZ, CZ, PZ) for (from left to right) all participants, the high-VVIQ group, and the low-VVIQ group.

and submitted the results of the subtraction to omnibus ANOVAs with three levels of Condition (Literal versus Familiar Metaphor versus Unfamiliar Metaphor) and nine levels of Electrodes (C3, CZ, C4, CP3, CPZ, CP4, P3, PZ, P4). Results of these tests are reported for high- and low-VVIQ groups separately.

3.2.1.1 High-VVIQ group

[*Anterior imagery effect*]

The results from the **200–350-ms** time window revealed no main effect of Condition [$p > 0.2$] and no significant qualification from Anteriority [$p = .08$]. However, between **350 and 450 ms**, there was a significant main effect of Condition [$F(3, 30) = 4.7$; $p < .01$], with Literal, Familiar Metaphor, and Unfamiliar Metaphor conditions all being significantly more negative than the Abstract condition [Literal versus Abstract: $F(1, 10) = 5.38$; $p < .05$; Familiar Metaphor versus Abstract: $F(1, 10) = 5.15$; $p < .05$; Unfamiliar Metaphor versus Abstract: $F(1, 10) = 12.43$; $p < .01$]. The main effect of Condition continued to be significant into the **450–550-ms** time window [$F(3, 30) = 4.15$; $p < .05$], but this time only Literal and Unfamiliar Metaphor conditions were more negative than the Abstract condition [Literal versus Abstract: $F(1, 10) = 5.14$; $p < .05$; Unfamiliar Metaphor versus Abstract: $F(1, 10) = 12.74$; $p < .01$]. The overall main effect of condition tapered off between **550 and 750 ms**, such that the main effect of Condition was not significant [$p > 0.2$], but there was a Condition by Anteriority interaction [$F(3, 30) = 2.93$; $p = .05$], driven by a marginal effect at the frontal sites [$F(3, 30) = 2.75$; $p = .06$] and a difference between the Literal and Abstract conditions only [$F(1, 10) = 11.34$; $p < .01$].

[*LPC effect*]

The results revealed a significant main effect of Condition [$F(2, 20) = 4.67$; $p < .05$], driven by more positive-going responses in the Unfamiliar Metaphor condition than in the Literal condition [$F(1, 10) = 15.41$; $p < .005$]. The difference between the Familiar Metaphor and Literal conditions, however, was not significant [$p = 0.5$].

3.2.1.2 Low-VVIQ group

[*Anterior imagery effect*]

Unlike the high-VVIQ group, there was a significant main effect of Condition between **200 and 350 ms** [$F(3, 30) = 3.65$; $p < .05$]. Subsequent comparisons showed no reliable differences between the Abstract condition versus any of the other conditions [$p > 0.4$ for Literal versus Abstract and Familiar Metaphor versus Abstract; $p = .08$ for Unfamiliar Metaphor versus Abstract], but the responses were reliably more negative in the Unfamiliar Metaphor condition than in the Literal [$F(1, 10) = 8.48$; $p < .05$] as well as the Familiar Metaphor conditions [$F(1, 10) = 9.11$; $p = .01$]. For the following time windows, there were no significant main effects of Condition or Condition by Anteriority interactions [$p > 0.2$].

[*LPC effect*]

There was only a marginal effect of Condition [$F(2, 20) = 2.83$; $p = .09$], driven by more positive-going responses in the Unfamiliar Metaphor condition than in the Literal condition [$F(1, 10) = 5.42$; $p < .05$].

3.2.1.3 Summary

Motivated by the correlation between the ERP imagery effect in the Literal condition and the behavioral VVIQ-2 scores, we separated our participants into two groups based on their VVIQ-2 scores. This division revealed very different brain response patterns between the high- and low-VVIQ groups. High-VVIQ participants elicited reliable anterior imagery-based negativity to sentence-final action verbs in the Literal and the two Metaphor conditions relative to the abstract endings in the Abstract condition. These imagery effects varied in how sustained they were, though. While the imagery effect in the Literal condition was statistically reliable from 350 to 750 ms, similar to the time range reported in the prior literature (Lee & Federmeier 2008; West & Holcomb 2000), the imagery effect was not as prolonged in the Metaphor conditions, ending at around 550 ms in the Unfamiliar Metaphor condition and reliable only between 350 and 450 ms in the Familiar Metaphor condition. Low-VVIQ participants, on the other hand, elicited no statistically reliable imagery effects. Instead, the Unfamiliar Metaphor condition was significantly more negative than the Literal and Familiar Metaphor conditions between 200 and 350 ms, the early part of the N400 time window. Despite the differences between the high- and low-VVIQ groups, both groups showed more positive-going responses in the Unfamiliar Metaphor condition than in the Literal condition in the LPC measure.

3.2.2 Relatedness effects on the probes

To investigate whether the literal meanings of the sentence-final action verbs in the Familiar Metaphor and Unfamiliar Metaphor conditions were successfully selected out after participants finished reading the sentences, sentences were followed by probes that were either related or unrelated to the literal meanings of the action verbs. Figure 6 plots the results of the related versus unrelated condition from a representative site, PZ, for the three conditions in all and in high-/low-VVIQ participants.

As Figure 6 indicates, for all groups in the Literal condition, the N400 responses were reduced in literal-related probes compared to unrelated probes. There was a hint of N400 relatedness effect in the Familiar Metaphor condition, but no systematic N400 differences between the probes in the Unfamiliar Metaphor condition. To quantify these N400 reduction effects, omnibus ANOVAs with three levels of Condition (Literal versus Familiar Metaphor versus Unfamiliar Metaphor), two levels of Relatedness (related versus unrelated), and 15 levels of Electrodes (posterior electrodes) were conducted on mean amplitudes of data measured between 300 and 500 ms (the N400 time window).

3.2.2.1 High-VVIQ group

The results showed a marginal main effect of Relatedness [$p = .06$] that was significantly modified by Condition [$F(2, 20) = 3.52$; $p < .05$]. The Relatedness by Condition interaction was driven by the Relatedness effect in the Literal condition only [$F(1, 10) = 16.47$; $p < .005$], and not in the two Metaphor conditions [$p > 0.5$].

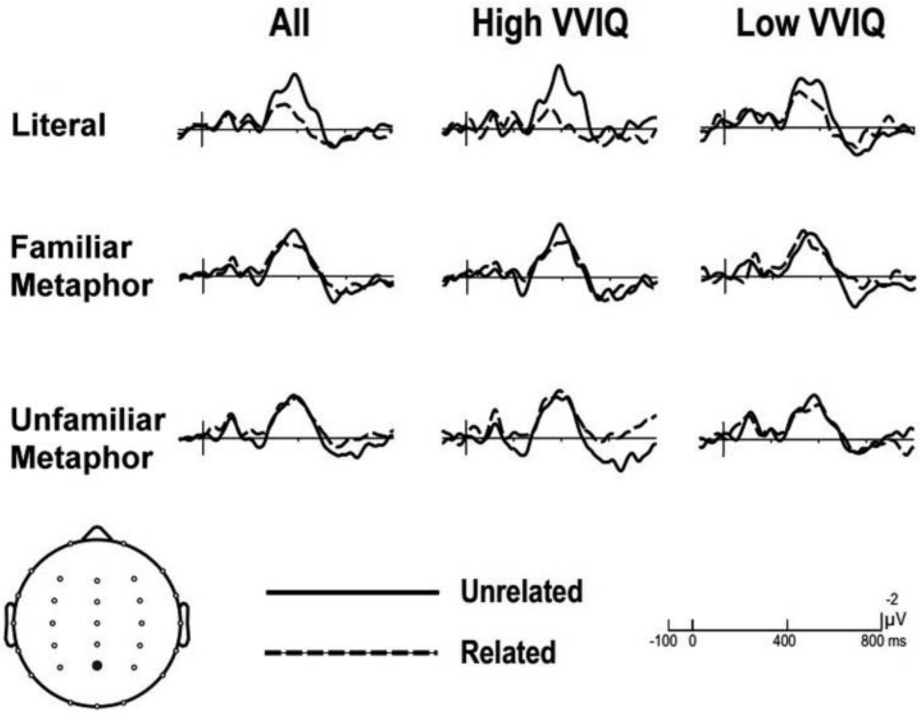

Figure 6: Grand average ERPs from all (left), high-VVIQ (middle), and low-VVIQ (right) participants to literal-related (dashed line) and unrelated probes (solid line) were overlaid at a representative posterior site, PZ, to highlight the N400 semantic relatedness effects (300–500 ms) in the Literal, Familiar Metaphor, and Unfamiliar Metaphor conditions. Data from all three participant groupings showed clear N400 reductions to literal-related probes than to unrelated probes in the Literal condition, but not in the two Metaphor conditions.

3.2.2.2 Low-VVIQ group

For the low-VVIQ group, there were no significant effects of Condition, Relatedness, or Condition by Relatedness interaction ($p \geq 0.3$). However, planned comparisons showed that the relatedness effect was similarly significant in the Literal condition only [$F(1, 10) = 6.10$; $p < .05$], but not in the two Metaphor conditions [$p > 0.5$].

4. Discussion

This present study investigated the joint influence of metaphor familiarity and mental imagery ability on how sensory-motor experiences affect the comprehension of figurative action metaphors when no real physical actions are conveyed in the sentences. ERPs were recorded while participants passively read four types of sentence: Literal, Familiar Metaphor, Unfamiliar Metaphor, and Abstract.

The first three types of sentence ended with action verbs, while Abstract sentences ended with abstract verbs. In addition to participants' brain responses, we also assessed participants' mental imagery ability using the VVIQ-2 (Chou 2007; Marks 1995).

Our data were consistent with the ERP concreteness literature in showing a sustained frontal negativity to action verbs in Literal sentences relative to abstract verbs in Abstract sentences (Holcomb et al. 1999; Huang et al. 2010; Lee & Federmeier 2008; West & Holcomb 2000). As expected, we found that the ERP imagery effect in the Literal condition was modulated by the individual's mental imagery ability (as indexed by their VVIQ-2 scores). Of central interest to the present study, our results demonstrated that both an individual's mental imagery ability and metaphor familiarity affected brain responses to metaphorical sentences. While people who tend to readily reenact sensory-motor experiences in mind (high-VVIQ participants) showed ERP frontal imagery effects in the Metaphor conditions relative to the Abstract condition (with the effects being more prolonged in the Unfamiliar Metaphor condition than in the Familiar Metaphor condition), people who are less effective in generating mental imageries (low-VVIQ participants) showed an N400 mismatch effect in the Unfamiliar Metaphor condition relative to the Literal and Familiar Metaphor conditions. This study is limited, however, by its sample sizes for the high- and low-VVIQ participants. Therefore, the results should be interpreted with caution and should be verified with a larger sample size.

4.1 The roles of mental simulation ability and metaphor familiarity in understanding metaphors

Our results showed that an individual's ability to mentally simulate sensory-motor experiences as well as metaphor familiarity jointly modulates the degree of sensory-motor involvement during metaphor processing. These results may help to account for some of the mixed findings in the embodied literature (Aziz-Zadeh et al. 2006; Boulenger et al. 2009; Chen et al. 2008; Raposo et al. 2009; Saygin et al. 2010; Wallentin et al. 2005a). Below, we discuss metaphor comprehension in participants with high and low mental simulation abilities separately.

High-VVIQ group

Our results show that high-VVIQ participants elicited a prolonged anterior negativity to the Literal relative to the Abstract condition. This negative effect is comparable in duration and scalp distribution to the ERP imagery effects reported in the literature (Huang et al. 2010; Lee & Federmeier 2008; West & Holcomb 2000), corroborating prior findings that people with high mental simulation ability routinely simulate relevant sensory-motor experiences while comprehending sentences (Haenggi et al. 1995; Kozhevnikov et al. 2005). Our results also showed that high-VVIQ participants elicited the anterior ERP imagery effects in both Metaphor conditions, but with different time courses. While the imagery effect in the Literal condition was significant from 350 to 750 ms post stimuli-onset, the effect was slightly less prolonged in the Unfamiliar Metaphors condition (350–550 ms) and much shorter in the Familiar Metaphors condition (350–450 ms), suggesting that the degree of mental simulation during metaphor understanding is modulated by metaphor familiarity.

One possible interpretation for this is that the degree of mental simulation during metaphor understanding is determined by how long the literal meanings are maintained. For literal sentences, the imagery effects should be sustained, as literal meanings are the only appropriate interpretations that should be maintained throughout the comprehension process. By contrast, for unfamiliar metaphors, although the literal meanings are salient in the initial comprehension stage as these metaphors are newly coined (Giora 1997; Peleg et al. 2001), a figurative reading will need to be obtained eventually for unfamiliar metaphors. These initially active literal meanings trigger mental imageries of the actual physical actions, which allows for comparisons between the actual physical actions and the intended figurative meanings. However, over the course of comprehension, in order for a coherent figurative interpretation to be obtained, the metaphorical meanings need to be selected over the literal meanings, which halts the mental imagery process, resulting in a less prolonged ERP imagery effect. With regard to the familiar metaphors, as they were rated as highly familiar (5.7 on a 7-point scale), their non-literal meanings should be much more salient than the literal ones (Giora 1997; Peleg et al. 2001). The non-dominant literal meanings of highly familiar metaphors nevertheless trigger the mental imagery process. However, the dominant and salient metaphorical meanings are quickly accessed, which results in the short-lived ERP imagery effect.

The results from the high-VVIQ group thus support and extend the embodied theories in important ways (Barsalou 1999; Binder & Desai 2011; Gallese & Lakoff 2005): while sensory-motor systems can be engaged in understanding metaphors when no real physical actions are indicated, the degree of sensory-motor experiences being reenacted depends on the individual's mental imagery ability and metaphor familiarity (Binder & Desai 2011).

Low-VVIQ group

Unlike the high-VVIQ group, participants who scored lower on VVIQ-2 did not show anterior negativity to any of the action verb conditions (Literal/Familiar Metaphor/Unfamiliar Metaphor) compared to the Abstract condition. Instead, low-VVIQ participants elicited more negative responses to Unfamiliar Metaphors relative to Literal and Familiar Metaphor sentences with a more central-posterior scalp distribution during the early N400 time window (200–350 ms). These results suggest that people who are less effective in mental imagery generation do not routinely engage statistically reliable mental imagery processes, even during literal sentence reading. Alternatively, they may rely more on the general mechanisms of semantic access during sentence processing (Boers & Littlemore 2000; Federmeier & Laszlo 2009; Lee & Federmeier 2008; Mathews et al. 1980).

The early central-posterior N400 effect (200–350 ms) to Unfamiliar Metaphor relative to the other two action verb conditions may reflect the semantic mismatch between the initially activated literal meanings with the preceding context. The unintended literal meanings, however, were quickly discarded as the figurative readings of the metaphors were obtained, resulting in the transient N400 effect. Similar transient N400 effects have also been found with conventional metaphors relative to literal sentences in prior studies (De Grauwe et al. 2010; Lai et al. 2009). We did not find such an effect in our data. This again may be due to the high familiarity of our Familiar Metaphors (familiarity ratings transformed to percentile for the familiar metaphors are 81.43 in the present study, 76.67 in Lai et al. 2009, and 70.8 in De Grauwe et al. 2010). The lack of differences in the brain responses between our Familiar Metaphor condition and Literal condition suggest that figurative meanings of these familiar metaphors may have been directly accessed due to high metaphor familiarity, rendering no semantic conflict with the preceding context.[2]

4.2 Different processing styles for understanding metaphors

Our results thus suggest that there may be multiple processing mechanisms or approaches that are helpful for comprehending metaphors, including the more imagery-based approach and the more general semantic access approach. Which approach(es) is/are adopted during metaphor processing may, at least partly, depend on an individual's mental imagery ability. The imagery/simulation approach facilitates unfamiliar metaphor understanding through linking the sensory-motor experiences associated with the literal meaning to the figurative reading, while the general semantic approach obtains the figurative interpretation of an unfamiliar metaphor through detecting the semantic mismatch between the literal meaning of the metaphorical word and its context. The two processing approaches are also quite different regarding understanding familiar metaphors. While the figurative meanings of familiar metaphors are more accessible due to their familiarity and salience (Giora 1997, 1999; Giora et al. 1998; Peleg et al. 2001), and are directly accessed in the semantic access approach, the imagery/simulation approach nevertheless retains the sensory-motor link between the literal and the figurative meanings.

4.3 Different processing styles, different comprehension outcome?

Although our results indicate different processing approaches, we found very similar patterns in subsequent comprehension measures, regardless of the involvement of mental imagery process. Both high- and low-VVIQ participants showed the expected reduced N400s to literal-related probes compared to unrelated probes following the sentence-final action verbs in the Literal condition. However, neither group showed any reliable N400 reductions to the literal-related probes in the metaphor conditions, suggesting that both groups were able to select out the literal meanings of the Metaphors successfully by the time the probes were presented. Furthermore, both groups showed reliable LPC effects in the Unfamiliar Metaphor condition relative to the Literal condition. The LPC component during metaphor comprehension has been suggested as reflecting additional analysis to resolve a conflict between the implausibility of the literal interpretation and the match between the metaphorical meaning, the context, and stored information within semantic memory (De Grauwe et al. 2010). Based on this interpretation of the LPC effect, our results suggest that, regardless of the involvement of sensory-motor representations or detection of semantic mismatch, participants

[2] The differences between the comprehensibility scores for the Unfamiliar Metaphor and the other conditions were statistically reliable [$p < 0.001$]. It is possible that such differences may have led to the enhanced N400 responses to the Unfamiliar Metaphors that are not related to metaphorical processing itself. However, we think that this explanation is unlikely, as no reliable N400 differences were found between the Unfamiliar Metaphors, Literal, and Familiar Metaphors in the high-VVIQ group [200–350 ms: Unfamiliar versus Literal: $p > 0.4$; Unfamiliar versus Familiar: $p = 0.6$; 350–450 ms: Unfamiliar versus Literal: $p > 0.2$; Unfamiliar versus Familiar: $p > 0.1$], despite the differences in the comprehensibility scores.

were aware of these conflicts 450–750 ms after viewing the unfamiliar metaphorical word and were able to recruit the needed cognitive-neural resources to resolve these conflicts.[3] Corroborating this finding, both high- and low-VVIQ groups were highly accurate in the off-line paraphrasing tasks.

These result patterns thus suggest that, at least with these comprehension measures, both imagery-based and general semantic access approaches could lead to a similar comprehension outcome. Thus, unlike the previous literature that investigated individual differences in metaphor understanding and showed that different cognitive capacity led to different degrees of comprehension effectiveness (Kazmerski et al. 2003: IQ; Trick & Katz 1986: analogic reasoning ability), our results showed that it is possible to achieve successful metaphor understanding via different processing routes. That said, it is possible that these different processing styles may affect how these metaphors are stored in the long-term memory (with or without sensory-motor information), which may lead to different comprehension consequences at a more global level, such as discourse or conversation, or for understanding abstract concepts that are not conveyed verbally. These conjectures will need to be further examined in future studies.

5. Limitations of the present study

In this study, we reported joint modulation of individual's mental simulation ability and metaphor familiarity on sensory-motor simulations during metaphor processing. These data provide new insights for research and theories on metaphor comprehension. However, our study is limited in terms of the small sample size, including the small numbers of participants in each VVIQ group, as well as the small number of probes following the sentence-final metaphorical words. Therefore, the results and interpretations reported here will need to be validated in future research endeavors.

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[3] As the LPC effect during metaphor comprehension indicates conflict resolution, its presence depends highly on whether the activation level of the literal interpretation is strong enough to cause a conflict with the metaphorical meaning and the context. In our results, while both high- and low-VVIQ groups showed reliable LPC effects in the Unfamiliar Metaphor condition relative to the Literal condition, neither group showed the LPC effect in the Familiar Metaphor condition. This may be explained by the high familiarity of the familiar metaphors in our study. With the metaphorical interpretation of these familiar metaphors being so salient, the much weaker activation of their literal interpretations may not cause conflicts strong enough to trigger the reanalysis process indexed by the LPC.

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隱喻熟悉度以及個人心像能力對於理解動作隱喻之影響：事件相關電位研究

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本研究操弄隱喻熟悉度及個人心像能力，藉以探討動作感覺經驗對於動作隱喻理解的影響。我們記錄受試者閱讀表達具體動作的句子、熟悉度高的隱喻、熟悉度低的隱喻，以及抽象句子時的腦波反應，並以視覺意像生動程度量表 (VVIQ-2) 測量受試者的心像能力。實驗結果顯示，心像能力與腦波圖像效果（mental imagery effect，200–750 毫秒）呈現正相關。高心像能力者在處理熟悉度低的隱喻時所引發的圖像效果（350–550 毫秒）較處理熟悉度高的隱喻所引起的效果持久（350–450 毫秒），顯示出他們傾向利用自身的動作感覺經驗來理解隱喻，只是熟悉度會影響心像模擬的時間長短。相反地，低心像能力者在理解隱喻時，並未引發圖像效果，而是在理解熟悉度低的隱喻時，引發較早的不匹配效果 (N400 mismatch effect) （200–350 毫秒），此效果反應出他們傾向採用普遍的語意處理機制，運用字面意來幫助隱喻理解。在此研究中，兩種理解方式皆受到隱喻熟悉度的影響，且即便採用不同的理解方式，亦皆可成功地獲取隱喻的抽象涵意，然而，這兩種理解方式是否會影響到不同層面如：對話或篇章結構內的隱喻理解，尚待未來的研究多加探討。

關鍵詞：隱喻理解歷程，熟悉度高的隱喻，熟悉度低的隱喻，心像形成能力，腦電波圖像效果