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Mental Simulation in L2 Processing of English Prepositional Phrases

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Abstract

Embodied simulation hypothesis supposes that language processing involves the activation of perceptual-motor systems to recreate the described scene (Bergen, 2012, 2019). The paper investigates whether and how adolescent second language (L2) learners' online processing of prepositions engages mental simulation. Specifically, the study examines whether any observed mental simulation effect was modulated by prepositions, abstractness of senses, and Stimulus Onset Asynchrony (SOA). 40 Chinese adolescents completed a diagram-picture matching task followed by a semantic priming task in English, where participants saw a diagrammatic prime and made phrasal acceptability judgement. Results showed a compatibility effect of schematic diagrams on adolescent L2 English learners' accuracy rates (ARs) of processing prepositional phrases (PPs), while response times (RTs) results did not reveal mental simulation effects. The findings suggest that schematic diagrams could serve as effective perceptual cues to prime adolescent L2 learners' processing of schema-compatible English PPs by improving judgement accuracy but not processing speed.

Keywords: mental simulation; second language processing; schematic diagram; semantic priming; English preposition

Introduction

The theory of embodied cognition claims that conceptual structure is grounded in human perceptual experiences and that language and cognition are shaped through human interactions with the world (Evans & Green, 2006; Johnson, 1987; Lakoff, 1987). As a language-induced cognitive phenomenon, embodied mental simulation refers to the ability to mentally recreate perceptual-motor experiences in the absence of external physical stimuli (Barsalou, 1999, 2008). From the perspective of mental simulation, language processing involves the activation of perceptual-motor components in the brain to comprehend the perceptual-motor content in linguistic input and generate responses to its meanings and usage (Bergen, 2012, 2019).

The examination of mental simulation is through comprehension-based perceptual tasks, which involve visual properties of objects in the world, such as orientation, shape, size, colour, and distance. The mental simulation studies follow behavioural experimental principles and conducted response times (RTs) and accuracy rates (ARs) analyses, from which how the mental simulation process is enacted can be inferred (Bergen, 2015). The two mental simulation effects that have been found in previous research are compatibility and interference effects (Bergen, 2007).

The compatibility effect assumes that perceptual components are activated during bottom-up language comprehension, which facilitates the speed or accuracy of a following response to a consistent visual representation than an inconsistent visual representation (Bergen, 2007). For example, hearing or seeing a sentence like "*put up your hands*" yields faster and more accurate responses to perceive images that visually represent a UP schema compared to a DOWN schema. When the shared schema between the image and linguistic input is activated, understanding the perceptual-motor content of the sentence leads to the excitation of corresponding perceptual-motor neurons to work more actively than other neurons in the brain (Stanfield & Zwaan, 2001).

The interference effect of mental simulation has an opposite pattern. It occurs when language processing interferes with the perception of a compatible image and hence generates slower and less accurate responses than perceiving an incompatible image. The underlying argument is that language-based mental simulation and visual perception may recruit the same perceptual-motor neurons at the same time. The simultaneous recruitment may result in mutual inhibition between the two tasks with more cognitive loads being added to the central executive system of the brain (Bergen, 2007; Bergen et al., 2003).

Previous mental simulation studies mainly focused on first language (L1) processing by native speakers (NSs) (Stanfield & Zwaan, 2001; Zwaan et al., 2002; Zwaan & Pecher, 2012). Several influential factors that were found to modulate the mental simulation effects include target languages (Chen et al., 2020) and linguistic features, such as grammatical aspects (Bergen & Wheeler, 2010; Liu & Bergen, 2016; Madden & Therriault, 2009; Madden-Lombardi et al., 2017; Vanek & Mertins, 2020) and abstractness of meaning (Bergen et al., 2007; Liu & Bergen, 2016; Richardson et al., 2003; Richardson & Matlock, 2007). Besides, Stimulus Onset Asynchrony (SOA), referring to the presentation time between the prime and target in priming tasks (McNamara, 2005), has also been found to modulate L1 mental simulation effects with interference effects being found in relatively shorter SOA durations due to simultaneous recruitment of the same cognitive resources to perform language and perceptual processing at the same time (e.g., Richardson et al., 2003) and compatibility effects being found in longer SOA durations (Bergen et al., 2007). However, interference effects were also observed in some longer SOA conditions (e.g., 1500 milliseconds) in L1 (Bergen et al., 2003) and second language (L2) mental simulation studies (Wheeler & Stojanovic, 2006).

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Mental simulation was examined through a variety of behavioural tasks, in which the sentence-picture verification task (SPVT) was one of the most widely used tasks. In the SPVTs, participants are asked to verify whether the object in the picture is mentioned in a previous sentence they just saw or heard (Chen et al., 2020; Stanfield & Zwaan, 2001; Winter & Bergen, 2012; Zwaan et al., 2002, 2004; Zwaan & Pecher, 2012). Although it was argued that similar mental simulation effects should be observed when reversing the order of linguistic stimuli (prime) and images (target) (Bergen et al., 2003), it was less frequently examined using alternative task formats such as image-verb matching tasks (Wheeler & Stojanovic, 2006).

In previous L1 mental simulation studies, adult English NSs were primarily targeted and widely examined (Bergen et al., 2007; Richardson et al., 2003; Winter & Bergen, 2012; Zwaan et al., 2002, 2004). Richardson et al. (2003) is one of the few studies that used schematic diagrams as the visual stimuli. They used a forced-choice object discrimination task to test the mental simulation effects on adult NSs' processing of English verbs. Participants heard a sentence containing a verb (e.g., *climb, respect*) associated with the UP-DOWN schema and judged whether the object being displayed horizontally or vertically was a circle or square. Slower responses were found in English NSs' discrimination of objects that were presented in the compatible vertical orientation, whereas similar interference effects were not observed in the verbs (*walk*, *argue*) that contain the LEFT-RIGHT schema in the horizontal axis. The interference effects were applied to both concrete and abstract verbs, which constitutes experimental evidence from adult NSs that image schema underlies the semantic association between literal and metaphorical senses (Gibbs, 1996; Lakoff, 1987). Their finding also shows that schematic diagrams could be used as visual stimuli to reveal the relationship between image schema and semantic association.

According to the embodied assumption of language in cognitive linguistics (Bergen, 2019; Lakoff, 1987), mental simulation in L2 processing should share some fundamental features like L1 mental simulation, since L2 speakers' perceptions and conceptualisation also arise from bodily perceptual-motor experiences in their cognitive development and interactions with the world. However, given the much fewer L2 mental simulation studies compared to L1 mental simulation studies, it remains controversial how L2 learners enact the mental simulation process in L2 processing.

Mental Simulation in L2 Processing Research

Among the limited L2 mental simulation research, almost all studies targeted adult L2 learners. The existing L2 findings showed compatibility effects (Ahn & Jiang, 2018; Koster et al., 2018; Tomczak & Ewert, 2015) and interference effects (Vukovic & Williams, 2014; Wheeler & Stojanovic, 2006) that were comparable to L1 mental simulation effects, while a reduced to no effect was also observed in a few studies (Norman & Peleg, 2022; Wu, 2016).

Wheeler and Stojanovic (2006) used image-verb matching tasks to examine the mental simulation effects on non-native speakers' (NNSs) L2 English processing. Participants were presented with a sketch-like image followed by a verb and judged whether the word matched the preceding image. Slower responses were observed when participants rejected a mismatching verb that shared the same effector with the image, such as *run* and *kick*, compared to a mismatching verb with a different effector, such as *run* and *drink*. The interference effects on L2 learners' processing of English verbs increased as L2 proficiency developed and were comparable to NSs' automatic processing in Bergen et al. (2003), who attributed interference effects to the strong competition and mutual inhibition in the brain circuits involved in the motor control of similar motor actions. However, Wheeler and Stojanovic (2006) did not control L2 participants' L1 backgrounds which may have an influence on L2 verb processing. Also, although it was claimed that the L2 participants have reached advanced English proficiency, their duration of English learning (from 2 to 29 years) still showed a large within-group discrepancy. These factors added "noises" to the mental simulation results, which could be controlled in future L2 mental simulation research.

Compatibility effects were also found in previous L2 mental simulation studies. Ahn and Jiang (2018) examined L2 Korean learners' mental simulation by using SPVTs and compared them with Korean NSs' performances. Results showed that both Korean NSs and L2 learners had faster responses in the matched condition than in the mismatched condition, indicating compatibility effects on both L1 and L2 processing. The comparable L2 mental simulation effects also revealed that L2 learners have native-like mental simulation and semantic integration abilities to process linguistic input and real-world knowledge and to form semantic representations of sentences.

Besides, reduced compatibility effects were observed in Norman and Peleg (2022). Participants completed two versions of SPVT in L1 Hebrew and L2 English. After reading a sentence, RTs to verify a pictorial object in the shape-matched condition (e.g., *The girl saw the lemon in the garden*) were faster than in the shape-mismatched condition (e.g., *The girl saw the lemon in the tea*). The compatibility effects were only found in processing the sentences in L1 Hebrew but not L2 English. The authors concluded the results as reduced mental simulation effects in L2 relative to L1 processing and attributed them to the fact that participants were late Hebrew-English bilinguals who acquired Hebrew in naturalistic settings but received English instructions mainly in formal settings.

Norman and Peleg's (2022) findings also suggest that L2 comprehension may not be grounded in sensorimotor knowledge and embodied experience as much as L1 comprehension. This is consistent with the argument that language and sensory-motor systems may not co-develop across developmental stages, especially for L2 learners who grow up as late bilinguals (MacWhinney, 2005), i.e., those who learn L2 after adolescence (Ng & Wigglesworth, 2007).

So far, adolescence has been argued as a period with rapid neurocognitive development in memory and executive function systems (Murty et al., 2016), but adolescents' mental simulation process was rarely investigated (Tomasino et al., 2018).

The current study is the first study that focuses on adolescent L2 learners' mental simulation process in L2 online processing. The study aims to address several important research gaps. Firstly, almost all existing L2 mental simulation studies targeted adult L2 learners with little attention being paid to adolescents, which has been argued as a sensitive age period for L2 acquisition (DeKeyser, 2000). It is worth exploring how adolescent L2 learners simulate perceptual scenes in L2 processing.

Secondly, schematic diagrams have not been used as visual cues in L2-based processing studies. With diagrams being increasingly adopted in L2 pedagogical research, such as English preposition instructions (Wong et al., 2018), there is a stronger empirical need to examine L2 learners' online perceptual processing via diagrams. Such investigations may yield important findings on the extent to which diagrams activate the predicted schematic representations in L2 learners' conceptualisation and the extent to which they facilitate or interfere with L2 processing. The findings will in turn provide plausible accounts for the (lack of) effectiveness of diagram-related cognitive linguistics (CL) pedagogy.

Thirdly, previous studies investigated mental simulation in the processing of nouns (Bergen et al., 2007; Zwaan & Yaxley, 2003) and verbs (Bergen et al., 2003; Richardson et al., 2003). We investigate prepositions which is an important lexical category that encodes spatial functions in English but has not been widely studied for mental simulation.

Finally, factors such as semantic abstractness and SOA are reported to be important modulators for L1 mental simulation effects, but these factors have not been examined in the existing L2 mental simulation studies.

Therefore, we aim to address these research gaps and examine mental simulation effects in the context of L2 processing of English prepositions. We hypothesise that schematic diagrams that align with the meaning of English prepositional phrases (PPs) trigger the activation of spatial configurations and facilitate adolescent L2 learners' online processing of English PPs.

Method

Participants

40 adolescent Chinese-L1 learners of English (18 males and 22 females) participated in the study. All of them were 9th-grade students (mean age = 14.63, *SD* = 0.87) recruited from a public secondary school in Beijing, China. They spoke Mandarin Chinese as their first language and had been learning English for 9.50 years on average (*SD* = 1.84). They attended six 40-minute regular English classes at school and were exposed to English for an average of 1.55 hours after school each week (*SD* = 2.05). Their average self-rated English proficiency was 70.15 out of 100 (*SD* = 1.84).

Design and Materials

In the current study, *over* and *in* were selected as the target prepositions, as they allow us to attest two different schemas (i.e., UP-DOWN and CONTAINMENT respectively) in mental simulation. English prepositions have attracted wide attention from cognitive linguists who create abundant materials of schematic diagrams and accounts that explain the relationship between the spatial and extended (metaphorical) senses of prepositions (Lakoff, 1987; Lindstromberg, 2010; Tyler & Evans, 2003). The schematic diagrams (adopted from Tyler & Evans, 2003) are visually distinct and are less likely to be mixed up in timed online processing (Figure 1). In the polysemy systems, there is at least an extended sense that is chained to its prototypical spatial sense (Tyler & Evans, 2003), motivated by conceptual metaphor (MORE IS UP and STATE IS A CONTAINER for *over* and *in* respectively) (Lakoff, 1987; Lakoff & Johnson, 1980).

Figure 1: Schematic diagrams of *over* (a) and *in* (b).

We selected *higher than* (spatial sense) and *more than* (extended sense) for *over*, and *containment* (spatial sense) and *state* (extended sense) for *in*. Example sentences for each prepositional sense are listed in Table 1 below.

Table 1: Target prepositions, senses and examples.

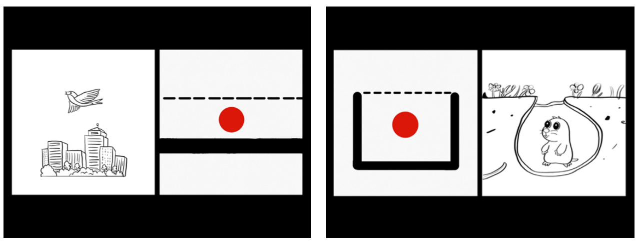
Preposition	Sense	Example (Tyler & Evans, 2003)
over	Spatial	*The bee hovers over the flower.*
	Extended	*He weighs over 150 pounds.*
in	Spatial	*The pear is in the bowl.*
	Extended	*They always get in trouble.*

A diagram-picture matching task and a semantic priming task were implemented in the study. As the target diagrams are abstract images that may not be easy to interpret, the diagram-picture matching task was given to participants, which trained them to achieve a relatively consistent level of understanding of the spatial configurations of the trajector (TR) - landmark (LM) relationships represented by the diagrams via concrete pictures in preparation for the priming task. The main instrument of the study is the semantic priming task, in which the schematic diagrams of *over* and *in* were used as the primes and PPs were targets.

Diagram-Picture Matching Task 30 black-and-white pictures were designed to illustrate the sentences that express the proto-spatial senses of the target and filler prepositions (out, behind). The sentences were selected from exemplar sentences in the CL descriptions of prepositions

(Lindstromberg, 2010; Tyler & Evans, 2003; Zhao et al., 2020) and from the Corpus of Contemporary American English (COCA)(Davies, 2008).

In the matching task, participants were first given L1 descriptions that explained the key features of the two diagrams (e.g., the red dot means a movable object; the black line marks the area of the static background; below the dashed line is an area where the object can have potential contact with the background) without being explicitly informed of two corresponding prepositions. Then they saw 20 matched and 20 mismatched diagram-picture pairs. Figure 2 presents the matched pair samples for *over* (Figure 2a: *The bird flies over the city*) and for *in* (Figure 2b: *A mole lives in a burrow*) with the diagram and the picture being randomly placed on the left-hand and right-hand side of the screen.



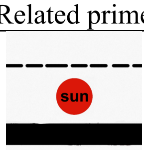
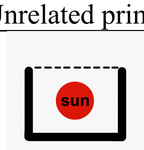
(a) (b)

Figure 2: Diagram-picture pairs of *over* (a) and *in* (b).

Participants took their time to judge whether the diagram and the picture were matched or mismatched and received immediate corrective feedback on each judgment. Participants who achieved above 70% accuracy after the 40 trials proceeded to the priming task. If not, they continued with the task on randomly selected matched or mismatched pairs until they reached above 70% accuracy.

Semantic Priming Task The task adopted a 2 relatedness (related, unrelated) × 2 preposition (*over*, *in*) × 2 sense (spatial, extended) × 2 SOA (1040ms, 2040ms) factorial Latin square design. The task was structured as a binary acceptability judgement task (Figure 3). The prime consists of the *over* or *in* diagram with an embedded word (e.g., *sun*) that marks the TR of the configuration in relation to the LM in the corresponding target PP (e.g., *over the horizon*). The related and unrelated primes share the same TR word but with different diagrams. For example, the TR word *sun* annotated in the *over* diagram is a related prime to the target PP *over the horizon,* whereas the same TR word annotated in the *in* diagram is an unrelated prime to the same target PP (Table 2).

Table 2: Sample related prime, unrelated prime, and target.

Related prime	Unrelated prime	Target
		*over the horizon*

Two versions of task stimuli were created by using a Latin square design so that each prime word was shown to participants once without overlaps across prepositions and senses. In each version, there were 160 stimuli that consisted of 96 target PPs (24 per preposition per sense × 2 prepositions × 2 senses) and 64 fillers. All the target PPs were selected from COCA (Davies, 2008) and contain three words (*preposition* + *determinative/adjective* + *noun*). Filler PPs contained ungrammatical uses of both target prepositions and non-target prepositions (e.g., *on, to, from, under*), which were all ungrammatical phrases (e.g., *the to city*, *in room our*).

We checked the frequency of prime words and target PPs across conditions by using COCA (Davies, 2008). No difference was found in the prime word frequency between *over* and *in* (t = –1.404, p = 0.164) and between spatial and extended senses (t = –1.573, p = 0.119). No difference was observed in the PP string frequencies between prepositions (t = 0.166, p = 0.869) or senses (t = 0.046, p = 0.964). Finally, we normed the event plausibility of the prime-PP combinations (e.g., *sun* | *over the horizon*) across conditions. 58 adult NSs of English recruited from Amazon Mechanical Turk (4 participants' data were excluded due to low reliability) rated the event plausibility of prime-PP combinations (e.g., *helicopter* | *over the city*) on a 7-point Likert scale from 1 (*absolutely impossible*) to 7 (*definitely possible*). No event plausibility difference was observed between prepositions (t = –0.038, p = 0.970) or senses (t = 0.590, p = 0.557).

The procedure of the semantic priming task (Figure 3) was modelled on de Wit and Kinoshita (2015). Participants first saw a 250-milliseconds spot fixation (+) and were shown the diagrammatic prime for 1000 or 2000 milliseconds (depending on the SOA condition) followed by a 40-milliseconds blank. Then, participants were asked to judge the acceptability of the target PP by pressing 'F' or 'J' on the keyboard as quickly as possible. The target phrase remained on the screen until participants pressed a key or after 5000 milliseconds at maximum. Finally, a 500-milliseconds blank for adjustment was placed at the end of each trial, after which the screen returned to the spot fixation for the next trial. All stimuli were presented to participants in a random order. Five training trials were set before the formal trials in the priming task, which were excluded from data analysis. Data of ARs of judgment and RTs on correct responses were analysed.

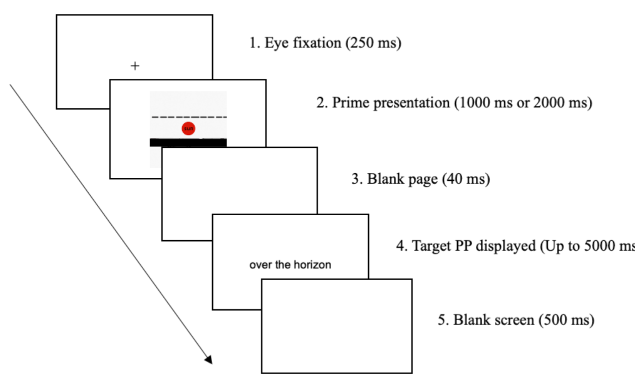


Figure 3: A sample trial of the semantic priming task.

Procedure

The study was conducted online and implemented via PsyToolkit (version 3.3.2)(Stoet, 2010, 2017). All participants first filled in a demographic questionnaire in L1 Chinese and completed the diagram-picture matching task. Then, they were randomly assigned one of the two SOA conditions of the semantic priming task (n = 23 in 1040ms SOA; n = 17 in 2040ms SOA) and completed 5 practice trials and 160 formal trials. Participants took a short break between the two tasks, but they were not allowed to go back and change their previous responses or do the same task twice.

Results

The R statistical software (version 4.0.3)(R Core Team, 2020) was used for data analysis. Before the analysis, we performed data trimming by removing responses that were shorter than 200 milliseconds and longer than 3000 milliseconds (2.3% of the data points). Generalised linear mixed-effects models were used to analyse ARs, and linear mixed-effects models were adopted to analyse RTs (Linck & Cunnings, 2015). A contrast numeric coding scheme (–0.5, 0.5) was applied to the categorical variables (i.e., relatedness, preposition, sense and SOA). A dummy-coding scheme (1, 0) was applied to the accuracy status of each item in the priming task (correct phrasal judgement was coded as 1; incorrect judgement was coded as 0). The RTs and covariates (i.e., prime word frequency, target PP string frequency, prime-PP event plausibility, number of matching task trials, matching task accuracy, and priming task accuracy) were all log-transformed (natural log). All models were fitted with participants and items as random effects.

Diagram-Picture Matching Task

Results of paired-sampled *t*-tests showed there were no differences between the two SOA conditions in terms of the L2 proficiency ($t = -0.374$, $p = 0.710$), the number of trials ($t = 0.137$, $p = 0.892$), the overall ARs of the matching task ($t = 0.116$, $p = 0.908$), and the ARs of *over* ($t = -0.603$, $p = 0.550$) and *in* ($t = 0.615$, $p = 0.542$). However, the overall matching task AR for *over* diagram-picture pairs ($M = 85.495$, $SD = 9.925$) was significantly higher than the overall AR for *in* diagram-picture pairs ($M = 79.670$, $SD = 12.834$) ($t = 2.500$, $p = 0.017$, Cohen's $d = 0.400$, 95% CI [1.111, 10.538], corresponding to a small effect).

Semantic Priming Task

Accuracy Rate The generalised linear mixed-effects model showed event plausibility was the only significant covariate on ARs ($b = 7.187$, $SE = 3.456$, $z = 2.080$, $p = 0.038$, 95% CI [0.41, 13.96]). It indicated the higher the event plausibility, the higher the accuracy for making the phrasal judgement. The model also revealed that relatedness had significant fixed effects on ARs ($b = -0.385$, $SE = 0.187$, $z = -2.054$, $p = 0.040$, 95% CI [–0.75, –0.02], $OR = 1.470$). It implied the ARs in the related condition were estimated to be 2.1% higher than the ARs in the unrelated condition (Figure 4).

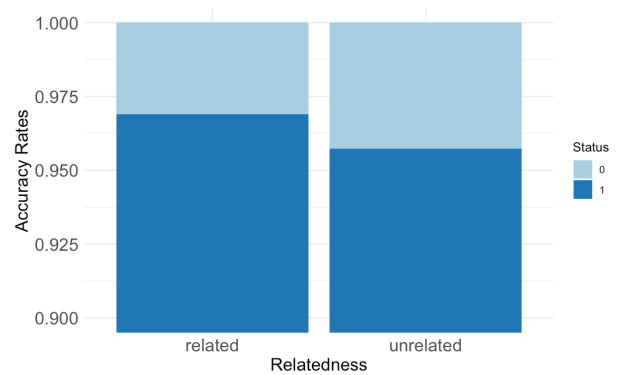


Figure 4: Accuracy rates for related and unrelated trials.

Response Time The linear mixed-effects model with all the covariates showed that only abstractness of sense had a significant fixed effect on RTs with a small effect size ($b = 0.116$, $SE = 0.026$, $t = 4.455$, $p < 0.001$, 95% CI [0.06, 0.17], Cohen's $d = 0.386$). Post-hoc analyses indicated that RTs for spatial senses were estimated to be 133 milliseconds shorter than extended senses (Figure 5). However, relatedness was not significant ($t = 0.029$, $p = 0.977$).

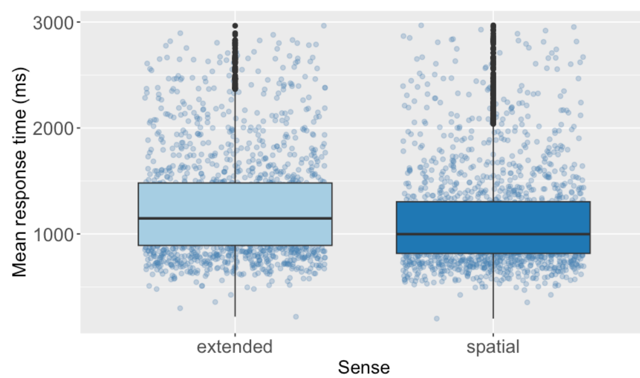


Figure 5: Response times for extended and spatial senses.

General Discussion

The current study investigates L2 mental simulation effects on adolescent L2 learners' online processing of English PPs via schematic diagrams. Results showed a compatibility effect of schematic diagrams on adolescent L2 learners' accuracy but not the speed of phrasal judgement. Such compatibility mental simulation effects on accuracy were not modulated by factors of preposition, abstractness of sense, and SOA, but were consistent in processing and judging *over* and *in* phrases, spatial and extended senses, and under 1040-milliseconds and 2040-milliseconds SOA conditions.

The current findings support the psychological reality of image-based semantic representations and provided new empirical evidence of an interplay between visual perception, mental imagery, and linguistic processes (Ferretti et al., 2001; Rommers et al., 2013) among young L2 learners. While previous research of mental simulations in spatial language processing investigated L1 verb or noun comprehension (Bergen, 2005; Bergen et al., 2003; Richardson et al., 2001, 2003), this study observed evidence in the context of L2 preposition comprehension. The study implemented an innovative experimental paradigm by integrating TR objects as verbal information in the schematic diagrams. The semantic information of the TR word and of the image-schematic representation were blended to create a mental construal that encapsulated a TR-LM relation, which exerted influences on L2 spatial language processing. In the related condition, the relevant visual traces were already activated via construal before the phrase was seen. In the unrelated condition, a dynamic trace was activated by the visual stimulus that was the reverse of the one activated by the phrase. Conceptual alignment that confirmed the correspondence between perception, embodied experience, and linguistic meaning yielded a facilitation effect.

Such facilitation effect was observed on the L2 processing of both prepositions. *Over* and *in* have very high frequencies of usage according to COCA (Davies, 2008) (1,222,405 for *over* and 16,541,037 for *in*). Following the usage-based assumptions (Bybee, 2010; Langacker, 2008), a high frequency implies that language speakers have a high chance of encountering their contextual uses, which could lead to a higher quality of conceptual understanding of the semantics of the two prepositions. The accumulated knowledge of the prepositions due to a high frequency of L2 exposure has provided adequate linguistic resources for the enactment of L2 mental simulation.

The compatibility simulation effects on L2 processing of spatial and extended senses were comparable to the findings in Richardson et al. (2003), who also observed consistent mental simulation effects on processing concrete and abstract senses of English verbs. A comparable effect on spatial and abstract prepositional senses could be attributed to the underlying conceptual metaphors which motivated the association between the spatial and extended senses (Lakoff, 1987). The diagrams which represent the shared prototypical spatial configuration of TR and LM effectively triggered L2 learners' comprehension of spatial and extended meanings.

Nevertheless, it was found that L2 learners' phrasal judgement of extended senses was more effortful than that of spatial senses based on the results of the response times. This also aligns with Richardson et al. (2003). It could be explained by previous findings that figurative language comprehension was often more difficult than literal language comprehension for L1 and L2 speakers (Horvat et al., 2021; Littlemore et al., 2011). Since extended senses are inherently figurative, their processing may take more cognitive efforts to activate the conceptual mapping between the target and source domains (Lai & Curran, 2013; Lakoff, 1992).

The compatibility simulation effect on L2 processing of PPs was consistent under 1040-milliseconds and 2040-milliseconds SOAs. Different from previous studies that used 1500-millisecond SOA and observed interference effects on adult NSs' and L2 learners' verb processing (Bergen & Wheeler, 2005; Wheeler & Stojanovic, 2006), the facilitation effect found in the current study suggests that schematic diagrams embedded with TR words could activate adolescent L2 learners' mental image of English prepositions and improve their accuracy of phrasal judgement when given a relatively wide SOA range. The findings are also supported by previous CL-inspired L2 instructional research where schematic diagrams were used as visual imagery tools that were explained in the corrective feedback with facilitation effects being found in adolescent Cantonese L2 English learners' accuracy of judging English preposition use (Wong et al., 2018). Another possible account might be the development of executive function systems reaches a peak level in adolescence (Murty et al., 2016), so the shorter or longer presentation time of the prime did not exert high pressure on their processing of PPs.

One of the possible reasons for compatibility effects on ARs but not on RTs could be due to the nature of language learning among these classroom-based L2 learners. Similar to the L2 learners in Norman and Peleg (2022) that reported reduced compatibility effects in L2 mental simulation, the current participants' L2 exposure was mainly through classroom instruction. The learners had almost no experience using English in naturalistic environments and did not receive enough natural input to establish a direct association between L2 lexical forms and concepts (Kroll & Stewart, 1994). Additionally, these classroom-based L2 learners might have relied more on explicit metalinguistic knowledge in grammaticality judgment. The explicit knowledge might not have fully automatised into implicit knowledge for effortless fluent judgment. Thus, diagrams were found to only affect the accuracy in the application of explicit knowledge but not fluency of judgment as revealed by RTs. Future research can adopt more sensitive measures such as via anticipatory eye fixations to capture more fine-grained processing behaviours (Stone et al., 2021; Vanek, 2019).

Due to the limited time and resources, one of the limitations of the current study is the lack of comparisons with an adolescent English NS group and with L2 learners' Chinese-L1 locative particle processing. Given that bilinguals' spatial conceptualisations in L2 could be affected by L1 and showed a convergence pattern between L1 and L2 (Park & Ziegler, 2014; Pavlenko, 2011), future studies could include these comparisons to demonstrate a more complete picture of mental simulation in L1 and L2 processing.

Conclusion

To summarise, the study investigates adolescent L2 learners' mental simulation in processing English prepositions via visual cues of schematic diagrams. Results showed compatibility effects on adolescent L2 learners' accuracy but not the speed of phrasal judgement. The findings are mainly attributed to the semantic properties of English prepositions, the nature of schematic diagrams, and adolescents' second language development. Future mental simulation research can consider investigating monolingual and bilingual adolescents' L1 and L2 spatial language processing.

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References

Ahn, S., & Jiang, N. (2018). Automatic semantic integration during L2 sentential reading. *Bilingualism: Language and Cognition*, *21*(2), 375–383.

Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences*, *22*(4), 577–660.

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology*, *59*(1), 617–645.

Bergen, B. K. (2005). Mental simulation in spatial language processing. *Proceedings of the Annual Meeting of the Cognitive Science Society*, *27*.

Bergen, B. K. (2007). Experimental methods for simulation semantics. In M. Gonzalez-Marquez, I. Mittelberg, S. Coulson, & M. J. Spivey (Eds.), *Human cognitive processing* (Vol. 18, pp. 277–301). John Benjamins Publishing Company.

Bergen, B. K. (2012). *Louder than words: The new science of how the mind makes meaning* (Vol. 50). Basic Books.

Bergen, B. K. (2015). Embodiment, simulation and meaning. In N. Riemer (Ed.), *The Routledge handbook of semantics* (pp. 142–157). Routledge.

Bergen, B. K. (2019). Embodiment. In E. Dąbrowska & D. Divjak (Eds.), *Cognitive linguistics—Foundations of language* (pp. 11–35). De Gruyter.

Bergen, B. K., Lindsay, S., Matlock, T., & Narayanan, S. (2007). Spatial and linguistic aspects of visual imagery in sentence comprehension. *Cognitive Science*, *31*(5), 733–764.

Bergen, B. K., Narayan, S., & Feldman, J. (2003). Embodied verbal semantics: Evidence from an image-verb matching task. *Proceedings of the Annual Meeting of the Cognitive Science Society*, *25*.

Bergen, B. K., & Wheeler, K. (2005). Sentence understanding engages motor processes. *Proceedings of the Annual Meeting of the Cognitive Science Society*, *27*.

Bergen, B. K., & Wheeler, K. (2010). Grammatical aspect and mental simulation. *Brain and Language*, *112*(3), 150–158.

Bybee, J. (2010). *Language, usage and cognition*. Cambridge University Press.

Chen, S.-C., de Koning, B. B., & Zwaan, R. A. (2020). Does object size matter with regard to the mental simulation of object orientation? *Experimental Psychology*, *67*(1), 56–72.

Davies, M. (2008). *The Corpus of Contemporary American English (COCA)*. Available online at https://www.english-corpora.org/coca/.

de Wit, B., & Kinoshita, S. (2015). The masked semantic priming effect is task dependent: Reconsidering the automatic spreading activation process. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *41*(4), 1062–1075.

DeKeyser, R. M. (2000). The robustness of critical period effects in second language acquisition. *Studies in Second Language Acquisition*, *22*(4), 499–533.

Evans, V., & Green, M. (2006). *Cognitive linguistics: An introduction*. Edinburgh University Press.

Ferretti, T. R., McRae, K., & Hatherell, A. (2001). Integrating verbs, situation schemas, and thematic role concepts. *Journal of Memory and Language*, *44*(4), 516–547.

Gibbs, R. W. (1996). Why many concepts are metaphorical. *Cognition*, *61*(3), 309–319.

Horvat, W. A., Bolognesi, M., & Kohl, K. (2021). The status of conventional metaphorical meaning in the L2 lexicon. *Intercultural Pragmatics*, *18*(4), 447–467.

Johnson, M. (1987). *The body in the mind: The bodily basis of meaning, imagination, and reason*. University of Chicago Press.

Koster, D., Cadierno, T., & Chiarandini, M. (2018). Mental simulation of object orientation and size: A conceptual replication with second language learners. *Journal of the European Second Language Association*, *2*(1), 38–48.

Kroll, J. F., & Stewart, E. (1994). Category interference in translation and picture naming: Evidence for asymmetric connections between bilingual memory representations. *Journal of Memory and Language*, *33*(2), 149–174.

Lai, T. V., & Curran, T. (2013). ERP evidence for conceptual mappings and comparison processes during the comprehension of conventional and novel metaphors. *Brain and Language*, *127*(3), 484–496.

Lakoff, G. (1987). *Women, fire, and dangerous things: What categories reveal about the mind*. University of Chicago Press.

Lakoff, G. (1992). The contemporary theory of metaphor. In A. Ortony (Ed.), *Metaphor and thought* (2nd ed., pp. 202–251). Cambridge University Press.

Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. University of Chicago Press.

Langacker, R. W. (2008). *Cognitive grammar: A basic introduction*. Oxford University Press.

Linck, J. A., & Cunnings, I. (2015). The utility and application of mixed-effects models in second language research: Mixed-effects models. *Language Learning*, *65*(S1), 185–207.

Lindstromberg, S. (2010). *English prepositions explained*. John Benjamins Publish Company.

Littlemore, J., Chen, P. T., Koester, A., & Barnden, J. (2011). Difficulties in metaphor comprehension faced by international students whose first language is not English. *Applied Linguistics*, *32*(4), 408–429.

Liu, N., & Bergen, B. K. (2016). When do language comprehenders mentally simulate locations? *Cognitive Linguistics*, *27*(2), 181–203.

MacWhinney, B. (2005). A unified model of language acquisition. In J. F. Kroll & A. M. B. de Groot (Eds.), *Handbook of bilingualism: Psycholinguistic approaches* (pp. 49–67). Oxford University Press.

Madden, C. J., & Therriault, D. J. (2009). Short article: Verb aspect and perceptual simulations. *Quarterly Journal of Experimental Psychology*, *62*(7), 1294–1303.

Madden-Lombardi, C., Dominey, P. F., & Ventre-Dominey, J. (2017). Grammatical verb aspect and event roles in sentence processing. *PLoS ONE*, *12*(12), e0189919.

McNamara, T. P. (2005). *Semantic priming: Perspectives from memory and word recognition*. Psychology Press.

Murty, V. P., Calabro, F., & Luna, B. (2016). The role of experience in adolescent cognitive development: Integration of executive, memory, and mesolimbic systems. *Neuroscience & Biobehavioral Reviews*, *70*, 46–58.

Ng, B. C., & Wigglesworth, G. (2007). *Bilingualism: An advanced resource book.* Routledge.

Norman, T., & Peleg, O. (2022). The reduced embodiment of a second language. *Bilingualism: Language and Cognition*, *25*(3), 406–416.

Park, H. I., & Ziegler, N. (2014). Cognitive shift in the bilingual mind: Spatial concepts in Korean–English bilinguals. *Bilingualism: Language and Cognition*, *17*(2), 410–430.

Pavlenko, A. (2011). Thinking and speaking in two languages: Overview of the field. In A. Pavlenko (Ed.), *Thinking and speaking in two languages* (pp. 237–257). Multilingual Matters.

R Core Team. (2020). *R: A language and environment for statistical computing.* R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Richardson, D., & Matlock, T. (2007). The integration of figurative language and static depictions: An eye movement study of fictive motion. *Cognition*, *102*(1), 129–138.

Richardson, D., Spivey, M. J., Barsalou, L. W., & McRae, K. (2003). Spatial representations activated during real-time comprehension of verbs. *Cognitive Science*, *27*(5), 767–780.

Richardson, D., Spivey, M. J., Edelman, S., & Naples, A. J. (2001). “Language is spatial”: Experimental evidence for image schemas of concrete and abstract verbs. *Proceedings of the Annual Meeting of the Cognitive Science Society*, *23*.

Rommers, J., Meyer, A. S., & Huettig, F. (2013). Object shape and orientation do not routinely influence performance during language processing. *Psychological Science*, *24*(11), 2218–2225.

Stanfield, R. A., & Zwaan, R. A. (2001). The effect of implied orientation derived from verbal context on picture recognition. *Psychological Science*, *12*(2), 153–156.

Stoet, G. (2010). PsyToolkit: A software package for programming psychological experiments using Linux. *Behavior Research Methods*, *42*(4), 1096–1104.

Stoet, G. (2017). PsyToolkit: A novel web-based method for running online questionnaires and reaction-time experiments. *Teaching of Psychology*, *44*(1), 24–31.

Stone, K., Veríssimo, J., Schad, D. J., Oltrogge, E., Vasishth, S., & Lago, S. (2021). The interaction of grammatically distinct agreement dependencies in predictive processing. *Language, Cognition and Neuroscience*, *36*(9), 1159–1179.

Tomasino, B., Nobile, M., Re, M., Bellina, M., Garzitto, M., Arrigoni, F., Molteni, M., Fabbro, F., & Brambilla, P. (2018). The mental simulation of state/psychological verbs in the adolescent brain: An fMRI study. *Brain and Cognition*, *123*, 34–46.

Tomczak, E., & Ewert, A. (2015). Real and fictive motion processing in polish L2 users of English and monolinguals: Evidence for different conceptual representations. *The Modern Language Journal*, *99*(S1), 49–65.

Tyler, A., & Evans, V. (2003). *The semantics of English prepositions: Spatial scenes, embodied meaning and cognition*. Cambridge University Press.

Vanek, N. (2019). *Anticipatory eye-fixations guided by two grammatical aspect systems* [Conference presentation]. Psycholinguistics in Iceland: Parsing and Prediction, Iceland.

Vanek, N., & Mertins, B. (2020). Defying chronology: Crosslinguistic variation in reverse order reports. *Linguistics*, *58*(2), 569–603.

Vukovic, N., & Williams, J. N. (2014). Automatic perceptual simulation of first language meanings during second language sentence processing in bilinguals. *Acta Psychologica*, *145*, 98–103.

Wheeler, K. B., & Stojanovic, D. (2006). Non-Native language processing engages mental imagery. *Proceedings of the Annual Meeting of the Cognitive Science Society*, *28*.

Winter, B., & Bergen, B. K. (2012). Language comprehenders represent object distance both visually and auditorily. *Language and Cognition*, *4*(1), 1–16.

Wong, M. H. I., Zhao, H., & MacWhinney, B. (2018). A cognitive linguistics application for second language pedagogy: The English preposition tutor. *Language Learning*, *68*(2), 438–468.

Wu, S.-L. (2016). Listening for imagery by native speakers and L2 learners. *Languages*, *1*(10), 1–18.

Zhao, H., Huang, S., Zhou, Y., & Wang, R. (2020). Schematic diagrams in second language learning of English prepositions: A behavioral and event-related potential study. *Studies in Second Language Acquisition*, *42*(4), 721–748.

Zwaan, R. A., Madden, C. J., Yaxley, R. H., & Aveyard, M. E. (2004). Moving words: Dynamic representations in language comprehension. *Cognitive Science*, *28*(4), 611–619.

Zwaan, R. A., & Pecher, D. (2012). Revisiting mental simulation in language comprehension: Six replication attempts. *PLoS ONE*, *7*(12), e51382.

Zwaan, R. A., Stanfield, R. A., & Yaxley, R. H. (2002). Language comprehenders mentally represent the shapes of objects. *Psychological Science*, *13*(2), 168–171.

Zwaan, R. A., & Yaxley, R. H. (2003). Spatial iconicity affects semantic relatedness judgments. *Psychonomic Bulletin & Review*, *10*(4), 954–958.