

Multiple Scaffolding Mechanisms for L2 Syntactic Processing: An Event-related Potential Study^{*}

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Abstract

Native-like cognitive-neural mechanisms for syntactic processing have been shown to be less available for L2 learners. To compensate, learners may rely on lexical-semantic processing or the non-dominant hemisphere. To investigate these scaffolding effects, this study combined divided visual-field (VF) and Event-Related Potential (ERP) techniques to assess L2 learners' brain responses across the left and right hemispheres (LH and RH). Participants judged the grammaticality of Chinese two-word phrases starting with a classifier. Our data showed that, compared to native speakers, L2 learners were less accurate in grammaticality judgments and elicited qualitatively different brain responses even to correct trials. Replicating our previous findings on left-lateralized structural processing in native speakers, native participants in this present study showed a P600 grammaticality effect with RVF/LH presentation only. L2 learners showed remarkable inter-subject variability in brain responses, and as a consequence, showed no statistically reliable ERP grammaticality effects. However, correlational analysis on individual learners' brain responses and behavioral language

^{*} This research was supported by National Taiwan University (NTU-CESRP-103R104904) and a Taiwan Ministry of Science and Technology research grant (# MOST 105-2420-H-002-007-MY2). The authors would also like to thank Yueh-Tung Lin, Hsin-Pei Lin, Alexander Chen, and Hsuan-Huey Yen for help with stimuli preparation and data collection.

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performance revealed important correlations. Specifically, better language performance was associated with smaller RVF/LH N400 grammaticality effects and smaller LVF/RH P600 grammaticality effects. Quartile split based on participants' language performance showed striking patterns, showing from bottom quartile to top quartile a gradual shift from an N400 grammaticality effect to a P600 grammaticality effect in the RVF/LH condition, and a P600 grammaticality effect to a later negativity effect in the LVF/RH condition. These results thus highlight the transitional roles of scaffolding mechanisms in language learning and suggest in particular that higher L2 syntactic processing co-occurs with less reliance on lexical-semantic processing in the dominant LH and disengagement of structural analysis from the non-dominant RH.

Keywords: second language acquisition, language lateralization, hemispheric differences, divided visual-field, event-related potential (ERP)

1. Introduction

Rapid globalization boosts interconnections between various cultures, countries, and individuals around the world. Knowledge of a second language (L2) is thus deemed indispensable for a better quality of life. In view of this, abundant efforts have been poured into investigating the learning process and mechanisms involved in second language learning.

Among the issues investigated in the L2 literature, one ultimate point of interest is whether and how late L2 learners can process an L2 in a qualitatively similar fashion to native speakers (for thorough reviews, see Van Hell and Tokowicz 2010; Van Heuven and Dijkstra 2010; Kroll et al. 2015). Extant findings suggest that although L2 learners usually show native-like responses in meaning comprehension, it is not always the case for syntactic processing (Weber-Fox and Neville 1996; Hahne 2001; Hahne and Friederici 2001; Van Hell and Tokowicz 2010). For example, Weber-Fox and Neville (1996) analyzed native speakers' and L2 learners' Event-Related Potential (ERP) responses to two types of syntactic violations (1. phrase

structure, e.g. * “*The scientist criticized Max’s of proof the theorem*”, and 2. specificity constraint, e.g. * “*What did the scientist criticize Max’s proof of?*”) and found that while English native speakers elicited P600 grammaticality effects commonly seen with morphosyntactic violations (Osterhout and Holcomb 1992; Hagoort, Brown and Groothusen 1993; see Kuperberg 2007 for a review), late Chinese learners of English who were exposed to English after age 16 did not show such effects. Similarly, Hahne and Friederici (2001) tested native speakers of German and late Japanese learners of German and found that, although both native speakers and L2 learners elicited qualitatively comparable semantic congruence effects, only native speakers elicited reliable P600 responses to syntactic violations.

It has been noted that many L2 learners tend to rely on alternative processing mechanisms to apprehend syntactic information before they fully grasp the syntactic regularities in their L2. For example, syntactic violations that elicited P600 grammaticality effects in native speakers have been shown to elicit N400 effects in early stages of L2 learning; P600 grammaticality effects were not elicited until later stages when learners had more L2 experience and fluency (Hahne and Friederici 2001; Osterhout et al. 2006; Osterhout et al. 2008; Dowens et al. 2010; Tanner, Inoue and Osterhout 2014). The N400 component has been linked to semantic access, as it is quite sensitive to factors relevant to semantic processing. In language research, N400 amplitude has been found to be less negative (reduced) for semantic processing facilitated by lexical or sentential features and more negative in cases where semantic features are incongruent with the context (see Kutas and Federmeier 2011 for a comprehensive discussion). Thus, N400 effects elicited by syntactic violations (the “N400 grammaticality effects”) could be due to lexical-semantic unexpectedness accompanying syntactic errors, and some have associated the “N400 grammaticality effects” with structurally shallower but lexically- or plausibility-based “good enough” processing (see Ferreira, Bailey and Ferraro 2002 for a review of “good-enough” approach to language comprehension; Tanner, Inoue and Osterhout 2014). Under these views, the N400 grammaticality effects (as opposed to P600 grammaticality effects) in L2 learners may reflect less-proficient L2 learners’ reliance on lexical and semantic information, instead of structural analysis per se, to detect syntactic violations.

Even in cases where L2 learners elicited P600 effects, the effects were not completely ‘native-like’, with the latency and size of the effects tending to be both delayed and reduced in learners with lower proficiency (Hahne 2001; Rossi et al. 2006). Moreover, it remains unclear whether L2 learners’ P600 responses to syntactic violations are lateralized to the left hemisphere (LH), like those for native speakers, or reflect a less typical lateralization pattern such as being bilateral or even right lateralized.

The right hemisphere (RH), which is the less dominant hemisphere in language processing, has been noted to be more involved in L2 learning and may serve as another scaffolding mechanism. Dehaene et al. (1997), for example, tested moderately fluent French-English bilinguals and found a highly variable network of left and right temporal and frontal areas during L2 auditory story comprehension, even though these same individuals showed quite consistent left temporal activities during L1 processing. Similarly, increased RH involvement has been noted with Chinese learners of English during orthographic search and semantic classification tasks (Ding et al. 2003). In addition, RH involvement has been shown to be beneficial in the initial stages of learning a second language (Dehaene et al. 1997; Leonard et al. 2010; Qi et al. 2015). Qi et al. (2015), for example, examined the relation between the white matter structure (measured by diffusion tensor imaging or DTI) and the learning outcomes of a 4-week Mandarin course in a group of native English speakers. Their results showed that a more successful learning outcome was associated with higher structural integrity of the superior longitudinal fasciculus and the inferior longitudinal fasciculus in the right hemisphere. Almost all participants in the above reviewed studies were right-handers. These results thus suggest that the scaffolding mechanisms provided by RH involvement may play a critical role in the initial stages of L2 learning.

Despite findings that separately point to these two types of possible scaffolding resources in L2 processing—general lexical-semantic processing and RH support, our knowledge of how they may work together is still very limited. For example, it is not clear whether these two scaffolds co-exist, or if learners tend to rely more on one over the other. In addition, if these resources do co-exist, which is more available and at what proficiency level? To try to answer some of these questions, the present

study combined Event-Related Potential (ERP) and divided visual field presentation techniques. By presenting target words to either the left visual field (LVF) or the right visual field (RVF), we were able to induce RH- and LH-biased responses respectively¹ to investigate how L2 learners of Taiwan Mandarin process syntactic information in the two hemispheres. Specifically, learners with intermediate proficiency and native speakers of Taiwan Mandarin read two-word phrases that started with a classifier centrally presented on the screen. The classifier, creating an expectancy for a subsequent noun, was then followed by a laterally presented target word either matching or mismatching this expectancy, rendering the phrase grammatical or ungrammatical (e.g., grammatical: *sāndòng fángzi*, three-CL house, ‘three houses’; ungrammatical: *yìjiān tiàowǔ*, one-CL dance, ‘one dance’).

This design allows for the following predictions. For native speakers, we would expect to replicate results from prior studies using similar designs, obtaining more negative N400 responses to ungrammatical relative to grammatical target words with both VF presentations, but with a left-lateralized P600 grammaticality effect reliable for RVF/LH presentation only (Taiwan Mandarin: Chen and Lee 2015; Chen, Chen and Lee 2017; Lin et al. 2017; Weng, Chen and Lee 2017; English: Lee and Federmeier 2015)². For L2 learners, with the lexical-semantic scaffold, we would expect learners to show only an N400 grammaticality effect but no P600 effect. By contrast, with the non-dominant hemisphere scaffold, we would expect a more bilateral P600 or even a right-lateralized P600 effect in addition to the N400 effect.

Based on prior literature, we expect to see robust inter-subject variability in

¹ For people whose corpus callosum is intact, information presented to one hemisphere can be transferred to the other; however, such transmission occurs after a delay and with degraded information fidelity (Hoptman and Davidson 1994; Berardi and Fiorentini 1997; see Banich 2003 for a review of this method). The hemisphere that receives the information first (LH for RVF presentation and RH for LVF presentation) thus has the processing advantage, and responses measured with VF manipulation predominantly reflect the processing biases of the contralateral hemisphere.

² One may suspect that using Chinese classifiers as syntactic cues could induce distinct or additional brain responses from those elicited by pure syntactic violations (e.g., “to + noun” and “the + verb” in English). Indeed, it has been shown that semantically-mismatched Chinese classifier-noun sequences (e.g., 一張咖啡 /yīzhāng kāfēi/ ‘a sheet of coffee’) elicit larger N400s relative to semantically-matched classifier-noun sequences (e.g., 一張紙 /yīzhāng zhǐ/ ‘a sheet of paper’) (Qian and Garnsey 2016). However, previous studies using similar designs have shown that despite the additional semantic processing classifiers may introduce, reliable P600 grammaticality effects were still observed (Chen and Lee 2015; Chen, Chen and Lee 2017; Lin et al. 2017; Weng, Chen and Lee 2017).

the type and magnitude of these scaffolding effects. Indeed, of central interest to this present study is whether and how variability in these two types of scaffolding mechanisms is associated with learners' proficiency. It may be difficult to see a representative effect pattern from the grand average data as N400 and P600 effects are likely to cancel each other out across learners at different proficiency levels due to opposite polarity and overlapping duration. However, with correlational analysis, we expect that individual learners' ERP responses during the N400 and P600 time windows for each VF presentation condition would be modulated by their L2 proficiency levels. Specifically, we expect to see P600 effects emerge and the contribution of the lexical-semantic scaffold taper off as L2 proficiency increases (Osterhout et al. 2006; Osterhout et al. 2008). Furthermore, we also expect to see exclusive or concurrent P600 responses from the RH before a native-like left-lateralized P600 grammaticality effect is fully attained. Based on prior studies showing beneficial effects from increased RH involvement (Dehaene et al. 1997; Leonard et al. 2010; Qi et al. 2015), one may expect to see a positive relation between RH P600 responses and L2 proficiency. Alternatively, based on views hypothesizing that LH-equivalent language capabilities do exist in the RH but are usually masked by transcallosal interhemispheric inhibition from the dominant LH in native speakers (Karbe et al. 1998; Lee and Federmeier 2015), it is possible that the RH responses would need to be disengaged eventually in order for L2 learners to attain native-like proficiency. In this case, one would expect little or no RH P600 responses for learners at higher proficiency levels.

2. Method

2.1 Participants

Twenty-four native speakers of Taiwan Mandarin (12 females, 12 males; mean age = 23.9 years, age range = 20-32 years) and 25 learners of Taiwan Mandarin (14 females, 11 males; mean age = 25.4 years, age range = 20-41 years)³ participated. All were right-handed as measured by a Chinese-translated version of the Edinburgh

³ Eight of the L2 learners were Japanese native speakers and 17 of the L2 learners were English native speakers. These two subsets of participants were comparable in their language proficiency, as confirmed by both their performance in the Chinese reading test ($p = 0.08$) and self-rated Chinese proficiency ($p = 0.28$).

inventory (Oldfield 1971), with the mean laterality quotients not reliably different between the two groups (native speakers: $M = 0.8$, $SD = 0.15$; learners: $M = 0.89$, $SD = 0.17$; $p > 0.06$). Furthermore, none of the participants had any left-handed blood relatives as assessed by a familial handedness questionnaire (Lee and Federmeier 2015), nor did they have any history of neurological or psychiatric disorders, or brain damage.

L2 participants' L2 proficiency was assessed by a Chinese reading test consisting of 25 multiple-choice questions. These questions were adapted from the intermediate-to-advanced-level (the Band B level) reading comprehension test from the TOCFL Online Mock Test (<http://www.sc-top.org.tw/mocktest.php>)⁴. The original TOCFL test consisted of 50 questions. We asked two foreign Sinology majors to rate the difficulty levels of these 50 questions on a 5-point scale (1 = the least difficult; 5 = the most difficult) and based on the rated values we selected 25 multiple-choice questions across the whole difficulty range (10 questions below rating scores of 2.5, 6 questions between 2.5 and 3.5, and 9 above 3.5). In addition to this comprehension test, all participants were surveyed with a detailed language background questionnaire. These learners were from a wide range of proficiency levels, but with a skew towards mid-to-high proficiency. This can be seen from results of the comprehension test (range: 32%-100%; mean: 85%), self-rated Chinese ability (range: 9-20; mean: 14.9 out of 20), and the percentage of experimental stimuli rated post ERP session as familiar (4 on a 7-point scale) (range: 68.4%-100%; mean: 94.09%).

2.2 Materials and Design

Stimuli for this study consisted of grammatical and ungrammatical Chinese two-word noun phrases. Classifiers were used to create expectancy for the syntactic category of the following word-noun. Subsequent target words, either nouns or verbs, were laterally presented to either left or right VF, matching or mismatching the word class expectancy for nouns. Examples are provided in Table 1 with the syntactic cues italicized and the target words underlined. Appendix A shows more examples for each

⁴ The comprehension tests provided by the TOCFL Online Mock Test were categorized into three levels: beginner (入門基礎級 /Band A), intermediate-to-advanced (進階高階級 /Band B), and advanced (流利精通級 /Band C). Our questions were adapted from the intermediate-to-advanced level (進階高階級 /Band B) questions.

of the conditions.

Grammaticality of the stimuli was determined based on the results of a 7-point Likert scale (1 = *very ungrammatical*; 7 = *very grammatical*) by 2 native speakers of Taiwan Mandarin (1 female and 1 male, mean age = 24.5 years, $SD = 1.41$). The results showed that grammatical phrases were rated as more grammatical than ungrammatical phrases (Grammatical: $M = 6.73$, $SD = 0.40$; Ungrammatical: $M = 1.09$, $SD = 0.23$; $p < .001$).

Table 1: Examples of the Stimuli

Condition	Example 1	Example 2
Grammatical	sānzhāng shūzhuō three-CL desk 'three desks'	liǎngběn xiǎoshuō two-CL novel 'two novels'
Ungrammatical	sānběn chūqù three-CL go out 'three go out'	sānzhāng huíqù three-CL go back 'three go back'

The target words consisted of disyllabic words selected from vocabularies at Levels 1, 2, and 3 in *8000 Chinese Words* (Steering Committee for the Test of Proficiency-Huayu, SC-TOP, <http://www.sc-top.org.tw/chinese/download.php>). The words were all relatively unambiguous in their syntactic category, with their most frequent syntactic category usage (either noun or verb) accounting for at least 80 percent of their total usages based on the Academia Sinica Balanced Corpus of Modern Chinese (Sinica Corpus, <http://asbc.iis.sinica.edu.tw>; Chen et al. 1996) (mean for nouns = 99.97%, range = 97–100 %; mean for verbs = 96%, range = 80–100%). These nouns and verbs were matched for log frequency and number of strokes ($p > .1$). In addition to the testing trials, additional phrases that did not start with syntactic cues predictive of nouns were added into each list as fillers. Critical phrases and filler phrases were arranged into 4 lists such that across lists, all phrases appeared in LVF and RVF with equal frequency, and within each list, there were equal numbers of grammatical and ungrammatical phrases for each visual field of presentation. Trials were randomized within each list and presented to each participant in the same order.

Participants were randomly assigned to each list and read each phrase only once. Each participant viewed 320 trials in total, including 160 target trials (80 grammatical and 80 ungrammatical) and 160 fillers (80 grammatical and 80 ungrammatical).

2.3 Procedure

The experiment was conducted in a sound attenuated room. Participants were queried about their language background, manual preferences, and familial handedness prior to the ERP session. Event-related potentials were recorded while participants were seated 100 cm in front of a 20-in. computer screen. The experiment began with 20 practice trials to familiarize subjects with the experimental procedure. At the start of each trial, a plus sign appeared at the center of the screen for 500 ms. After a random stimulus onset asynchrony (SOA) between 1000 and 1500 ms, the syntactic cue appeared at the center for 200 ms. The offset of the cue was followed by a 300 ms inter-stimulus interval (ISI) and then the target word was randomly presented to either the RVF or the LVF for 200 ms. Visual angle from the inner edge of the target word to the center of the screen was kept at 2 degrees (from this point, words subtended 2 additional degrees of horizontal visual angle and 1 degree of vertical visual angle). The offset of the target was followed by a 2000 ms delay and then a question “通順嗎?” (*tōngshùn ma?* ‘acceptable?’) was centrally displayed on the screen. All materials were presented in traditional Chinese characters on the screen. Participants were instructed to press “yes” to phrases that were syntactically well-formed (e.g., *yíliàng gōngchē*, one-CL bus, ‘a bus’) and “no” to those that were not syntactically well-formed (e.g., *liǎngjiàn zuòfàn*, two-CL cook, ‘two cook’). Response hand for “yes” was counterbalanced across participants. The question remained on the screen for 2500 ms or until participants made a response. The next trial began after a 1500 ms delay. A small red dot was presented a few pixels below the center of the screen throughout the experiment to help participants fixate at the center and avoid orienting to laterally presented words. The entire experiment was divided into 5 blocks with short breaks in between, and lasted about 1 hour. After the ERP session, participants rated each word they saw in the experiment (syntactic cues and target words) for familiarity and completed the offline Chinese reading proficiency test.

2.4 EEG Recording and Data Analysis

The electroencephalogram (EEG) was recorded using 32 sintered Ag/AgCL electrodes from the 10-20 system (QuickCap, Neuromedical Supplies, Sterling, TX, USA). All scalp electrodes were referenced to a common vertex reference located between CZ and CPZ online and re-referenced to the average of the right and left mastoids offline. Vertical eye movements were recorded via a pair of electrodes placed on the supraorbital and infraorbital ridge of the left eye, and horizontal eye movements were recorded via electrodes placed at the outer canthus of each eye in a bipolar montage. Impedance was kept below 5 k Ω for all electrodes. The continuous EEG was amplified by the SYNAMPS2 amplifiers (Neuroscan, Inc., EL Paso, Texas, USA) with a bandpass of 0.05-100 Hz and digitized online with a 1000 Hz sampling rate.

The EEG data were segmented offline into 1400 ms epochs, spanning 200 ms pre-stimulus to 1200 ms post-stimulus. Trials contaminated by artifacts from amplifier blocking, signal drifting, muscle activity, eye blinks and movements were rejected offline before averaging. Artifact-free ERPs were averaged by stimuli type after subtraction of the 200 ms pre-stimulus baseline. Prior to measurement, ERPs were digitally filtered with a low-pass of 30 Hz. Only ERP data for trials that were responded to correctly were included in the statistical analysis. All EEG and correlational analyses were conducted on mean amplitudes of data from 30 scalp electrodes (FP1, FP2, F7, F3, FZ, F4, F8, FT7, FC3, FCZ, FC4, FT8, T7, C3, CZ, C4, T8, TP7, CP3, CPZ, CP4, TP8, P7, P3, PZ, P4, P8, O1, OZ, O2) measured between 300-600 ms for the N400 effects and 750-1200 ms for the P600 effects.

2.5 Divided Visual Field Presentation

The following measures were taken to ensure the validity of the lateralized presentation. (1) Target words were briefly presented (200ms) so that participants were unlikely to be able to orient to the target word before it disappeared. (2) Target words were also randomly presented to either VF with no more than two consecutive presentations to the same VF in order to reduce the predictability of the location of the target word. (3) In addition, we monitored participants' horizontal eye movements with an electrooculogram to rule out potential responses elicited by more centrally presented trials as a result of eye movement (Bourne 2006). In view of past findings

showing considerable variations of ERPs for horizontal eye movements due to individual differences in eye-movement control as well as the online positioning of HEO channels, we obtained individual thresholds for horizontal eye movements of 2-degrees to reject potentially invalid trials for each participant.

3. Results

3.1 Behavioral Results

3.1.1 Online Grammaticality Judgment

Native speakers showed much higher overall accuracy than did learners. For both groups, the accuracy rates were comparable across VF presentations, but were numerically higher for trials presented to the RVF than those presented to the LVF (Native speakers: RVF 92.66%, LVF 92.45%; L2 learners: RVF 69.82%, LVF 69.06%). The results of an ANOVA with a between-subjects factor of Group (native vs. learners) and within-subjects factors of VF (LVF vs. RVF) and Grammaticality (grammatical vs. ungrammatical) on participants' mean accuracy confirmed this impression. There was a significant main effect of Group [$F(1,47) = 43.31$; $p < 0.001$] that was not modulated by either Grammaticality or VF ($ps > 0.6$). Planned comparisons within each group also revealed no effects of Grammaticality, VF or interactions ($ps > 0.2$).

3.2 ERP Results

In ERP analysis, only trials correctly responded to were analyzed. In addition, to minimize the contribution of brain responses to unknown words, words that were rated lower than 4 on a 7-point scale (7 = very familiar; 0 = no knowledge at all) were excluded. The mean familiarity ratings for the remaining trials were statistically equivalent across groups—native speakers: 6.7 ($SD = 0.61$); learners: 6.68 ($SD = 0.49$) [$t(47) = -0.125$; $p = 0.9$]. Correct, familiar, and artifact-free trials that went into the final ERP analysis accounted for 79.03% and 61.94% of the trials for native speakers and learners, respectively.

3.2.1 Validity Check for the Divided Visual Field Manipulations

With divided visual field presentation, laterally presented stimuli were expected to produce a larger N1 response over the hemisphere contralateral to the visual

field of presentation, particularly at temporal and posterior sites. Indeed, as shown in Figure 1⁵, N1 responses (125-200 ms) elicited by target words were larger over the contralateral hemisphere to the visual field of presentation at 2 representative temporal-posterior sites (P7, P8) for both participant groups. These differences were quantified with a 2 (Group: native vs. learners) \times 2 (VF: LVF vs. RVF) \times 2 (Hemisphere: left vs. right recording site) ANOVA on the average ERPs measured during the 125-200 ms time window (N1) over temporal and posterior sites (left: TP7, CP3, P7, P3, O1; right: TP8, CP4, P8, P4, O2) where this component is the largest. The results showed a significant 3-way interaction among Group, VF, and Hemisphere [$F(1,47) = 11.55$; $p = 0.001$]. Follow-up ANOVA analysis done separately within each group showed VF by Hemisphere interactions [learners: $F(1,24) = 31.36$; $p < 0.0001$; native: $F(1,23) = 58.88$; $p < 0.0001$], with reliable effects of VF for both Hemispheric sites for both groups ($ps < .01$). These results thus confirmed the validity of divided visual field manipulation for both groups.

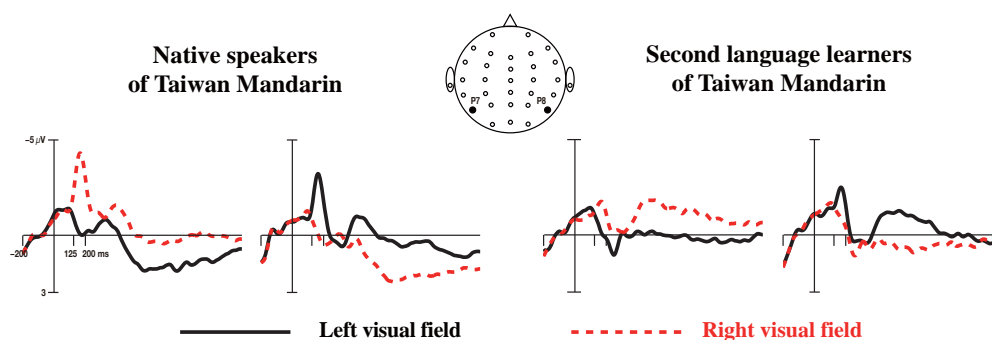


Figure 1: Grand Average Early Visual Potentials (N1)

3.2.2 Grammaticality Effects

Figure 2 shows the grand average ERPs to grammatical and ungrammatical target words presented to both visual fields (LVF/RH and RVF/LH) at the representative electrode site PZ for both native and learner groups. Native speakers showed a trend of more negative N400 responses to ungrammatical relative to grammatical words

⁵ For this and subsequent figures, positions of the plotted sites are indicated by filled circles on the head diagram (nose at top), negative is plotted up, and data are filtered at 10 Hz for illustration purposes.

within both VF presentations, but a P600 grammaticality effect with the RVF/LH presentation only. The learner group also showed skewed responses toward the RVF/LH presentation. With the RVF/LH presentation, L2 learners as a group showed no P600 effects, but instead, more negative responses to ungrammatical than grammatical words during the N400 time window and the subsequent time window. With the LVF/RH presentation, L2 learners showed more negative grammaticality effects in the post-N400 time window but no systematic differences in N400 responses.

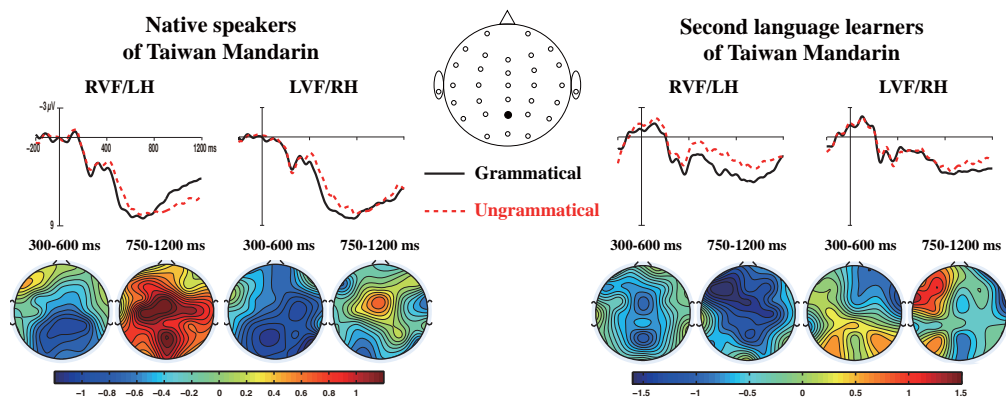


Figure 2: Grand Average Event-related Potentials (Top Panel) and Scalp-topography Illustrations (Bottom Panel)

These ERP differences were quantified using omnibus ANOVAs with the between-subjects factor of Group (native speakers vs. learners) and within-subjects factors of VF (LVF vs. RVF) and Grammaticality (grammatical vs. ungrammatical).

3.2.2.1 N400 Grammaticality Effects (300-600 ms)

The results revealed a main effect of Group [$F(1,47) = 12.19$; $p = 0.001$]. However, there were no reliable effects of Grammaticality, VF, or any other interaction effects ($ps > 0.1$). Planned comparisons with the factor of Grammaticality and VF were then conducted separately for each group, and the results again showed no reliable effects for either group ($ps > 0.1$).

3.2.2.2 P600 Grammaticality Effects (750-1200 ms)

The results showed a significant main effect of Group [$F(1,47) = 12.9$; $p < 0.001$]. There were no other reliable main effects or interaction effects ($ps > 0.1$). Planned

comparisons done within each group revealed a Grammaticality by VF interaction [$F(1,23) = 4.37$; $p < 0.05$] for native speakers, driven by the Grammaticality effect reliable with the RVF/LH presentation [$F(1,23) = 4.9$; $p < 0.05$] but not with the LVF/RH presentation ($p = 0.7$). For the learner group, however, no statistically reliable effects were found ($ps > 0.2$).

To summarize, group-level ERP analysis replicated the left-lateralized P600 grammaticality effect in native speakers reported previously (Lee and Federmeier 2015), but revealed neither reliable N400 nor P600 grammaticality effects in L2 learners as a group.

3.3 Individual Analysis

Past findings have shown robust individual variation in responses to syntactic violations, especially in L2 learners (Tanner et al. 2013; Tanner, Inoue and Osterhout 2014; Tanner and Van Hell 2014). Due to the proximity of analysis time windows and the variations in effect latencies among participants, it is likely that N400 and P600 responses could cancel each other out in the final grand average waveform as well as reduce the chances of observing a reliable effect in the ANOVA tests. To visualize the variability, the magnitudes of conditional differences during the N400 time window (grammatical - ungrammatical) and the P600 time window (ungrammatical - grammatical) are plotted on the Y and X axes respectively for each individual and each VF presentation in Figure 3. The effects shown here were averaged across all 30 scalp electrode sites that were analyzed in the statistical tests. Each dot represents a data point from a single participant. The dashed line represents equal N400 and P600 effect magnitudes. Dots in the 1st quadrant captured biphasic responses of both an N400 and a P600 grammaticality effect, with those the right/lower side of the dashed line showing primarily a P600 effect, and those to the left/upper of the dashed line showing primarily an N400 effect. Dots in the 2nd quadrant showed sustained negative grammaticality effect starting from the N400 time window and continuing on to the P600 time window. Dots in the 4th quadrant, on the other hand, showed robust P600 responses that encompass both the N400 and P600 time windows. Dots in the 3rd quadrant showed reversed grammaticality effects that are theoretically improbable and most likely due to sampling errors.

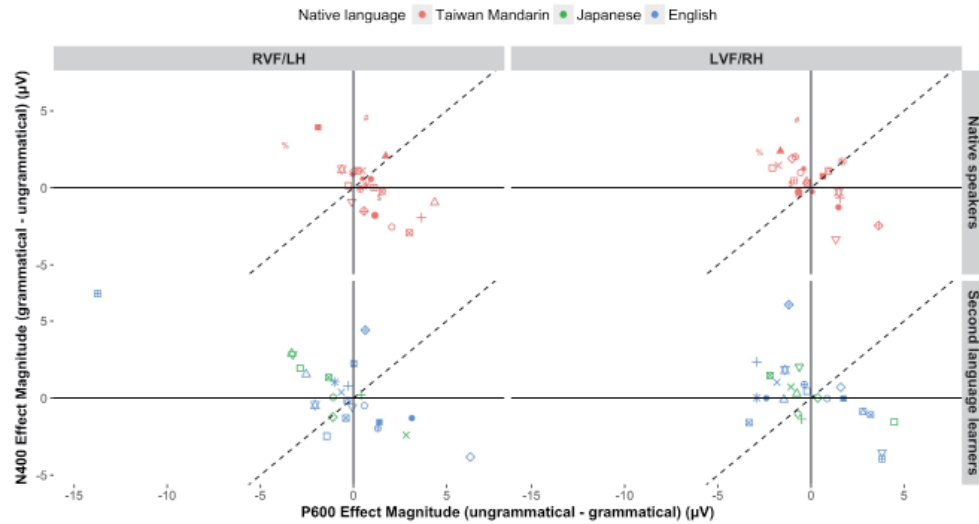


Figure 3: Individual N400 and P600 Effect Magnitudes for Each Participant and Visual Field Presentation

Different from the impression of the L2 grand average waveforms for the LVF/RH condition, Figure 3 shows robust non-zero LVF grammaticality effects in L2 learners at the individual level. Furthermore, there were also P600 grammaticality effects (1st and 4th quadrants) with both VF presentations despite P600 responses not being observable in the grand average data. These results thus highlight the diversity of L2 learners' language processing. To further understand the relation between these individual variations and language performance, the sizes of N400 and P600 grammaticality effects in L2 learners, measured as the absolute mean amplitude differences between the ungrammatical and grammatical conditions during each time window, were regressed against each learner's accuracy in the grammaticality judgment task and self-rated Chinese proficiency. The results revealed a reliable correlation between RVF/LH N400 grammaticality effects and self-rated Chinese proficiency ($r = -0.48$, $p < 0.05$), with a smaller N400 grammaticality effect associated with higher proficiency. There was also a reliable correlation between LVF/RH P600 grammaticality effects and language performance, with smaller LVF/

RH P600 responses associated with better language performance (better LVF/RH grammaticality judgment accuracy: $r = -0.42$, $p < 0.05$; higher self-rated Chinese proficiency: $r = -0.45$, $p < 0.05$) (Figure 4). Neither RVF/LH P600 grammaticality effects nor LVF/RH N400 grammaticality effects reliably correlated with self-rated proficiency and language performance ($ps > 0.2$).

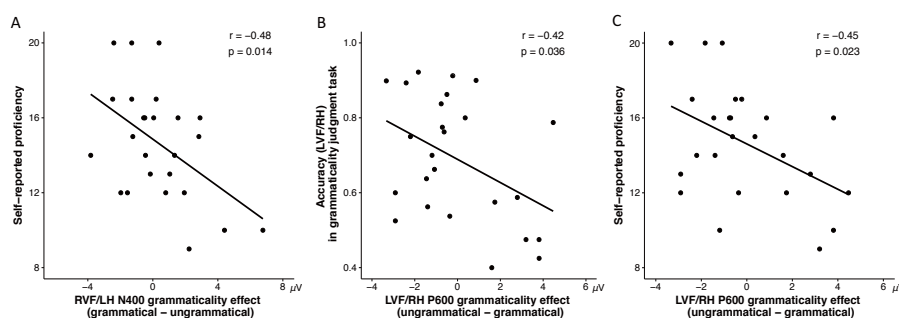


Figure 4: Correlations Between Grammaticality Effects and L2 Performance/Proficiency

Motivated by these findings, we divided L2 learners into subgroups based on their self-rated proficiency as this index correlated with both the RVF/LH N400 and the LVF/RH P600 effects. Figure 5 plots the averaged results for high proficiency (1st quartile), intermediate proficiency (2nd and 3rd quartiles), and low proficiency (4th quartile) participants. High proficiency learners (4 women and 2 men) had a proficiency rating of 18.50 ($SD = 1.64$) and an 85.22% accuracy ($SD = 8.13\%$) on average, intermediate learners (5 women and 8 men) had a proficiency rating of 14.62 ($SD = 1.39$) and a 67.02% accuracy ($SD = 16.31\%$), and low proficiency learners (5 women and 1 man) had a proficiency rating of 10.83 ($SD = 1.33$) and a 58.90% accuracy ($SD = 10.89\%$).

Figure 5 shows the grand average ERPs to grammatical and ungrammatical target words presented to both visual fields (LVF/RH and RVF/LH) at the representative electrode site P3 for learners with relatively high, intermediate, and relatively low self-rated proficiency, respectively. Confirming the correlational results, as proficiency levels increase from low to high, the magnitude of RVF/LH N400 grammaticality effects are reduced and are eventually replaced by a P600 grammaticality effect in high proficiency learners. Interestingly, there was a different transition in the LVF/RH

condition, with a clearly observable P600 grammaticality effect in the low proficiency learners that reduced as proficiency levels increased and was eventually replaced by a late negative effect in high proficiency learners.

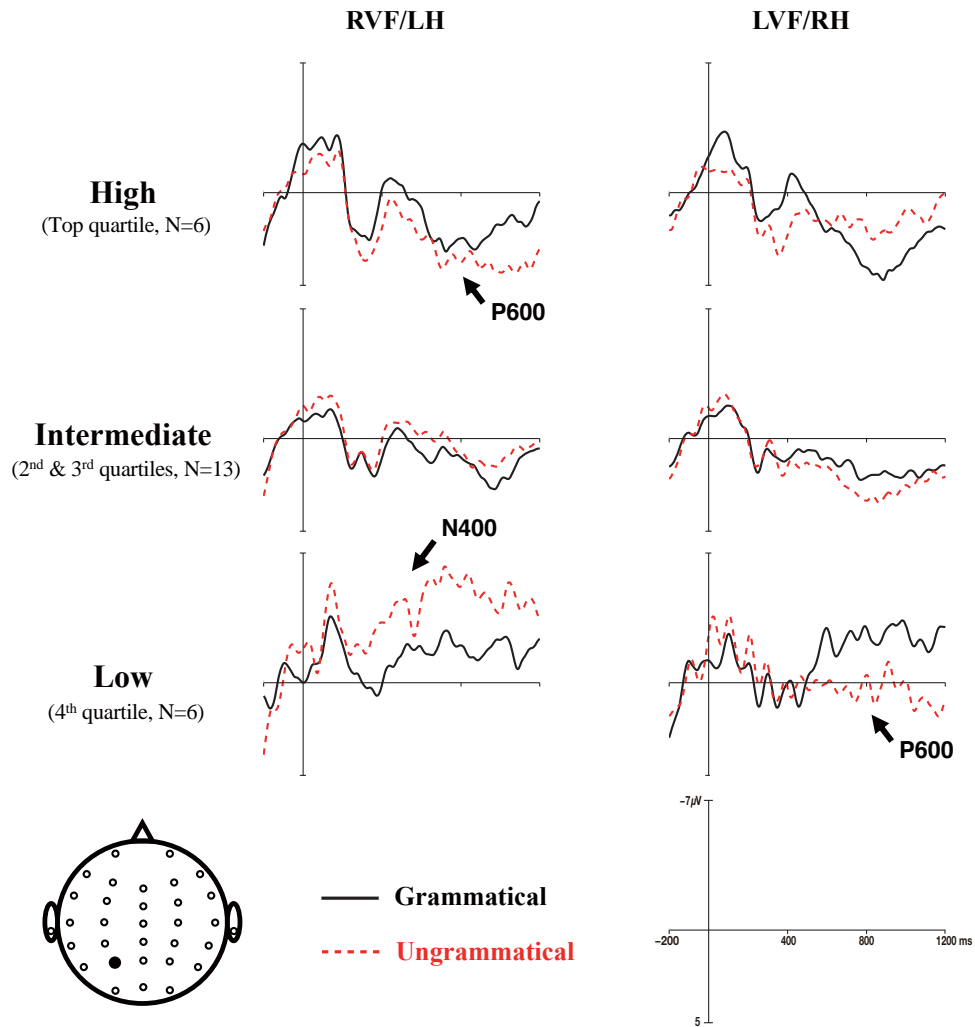


Figure 5: Grand Average Event-related Potentials as a Function of L2 Proficiency

4. Discussion

This present study investigated the cognitive-neural scaffolding resources during L2 syntactic processing before learners fully master the syntactic regularity in their L2. We assessed brain responses from learners of Taiwan Mandarin as they read grammatical and ungrammatical two-word noun phrases. Our results showed interesting response differences between L2 learners and native speakers. Replicating past findings in native speakers of Taiwan Mandarin and English (Chen and Lee 2015; Lee and Federmeier 2015), native speakers of Taiwan Mandarin elicited a left-lateralized P600 grammaticality effect that was statistically reliable only with RVF/LH presentation. L2 learners as a group did not show statistically reliable grammaticality effects due to remarkable inter-subject variability. However, correlational analyses revealed reliable negative correlations between L2 language proficiency and the two scaffolding mechanisms—lexical-semantic processing in the dominant LH (as indexed by the RVF/LH N400 effect) and structural processing in the non-dominant RH (as indexed by the LVF/RH P600 effect), indicating that advancing L2-proficiency is critically related to reduced reliance on these temporary scaffolding mechanisms. We discuss these points in turn in what follows.

Prior studies using similar paradigms have shown reliable bilateral N400 grammaticality effects in native speakers (Chen and Lee 2015; Lee and Federmeier 2015). In line with these past findings, native speakers in the present study also elicited numerically more negative N400s to ungrammatical than to grammatical trials with both VF presentations. The less robust N400 grammaticality effects in these native speakers may be due to the stimuli that were specifically selected from beginner-level Mandarin textbooks. Basic common words tend to induce lower baseline (less negative) N400s because of their high usage frequency and rich lexical associates. As a result, there may be a smaller possible range for N400 reduction in the grammatical conditions, rendering the N400 grammaticality effects in the present dataset unreliable. Though not intentional, the floor effect in N400 responses in native processing in this dataset then increased the possible range of effect sizes of the N400 grammaticality effects between beginners and advanced (and therefore more native-like) learners, which in turn provides a better chance to observe the potential modulation of L2 proficiency on the lexical-semantic scaffold indexed by the N400 effects.

4.1 The N400 Grammaticality Effect: Lexical-Semantic Scaffolding in the Dominant Hemisphere

Our results showed a negative correlation between self-rated L2 proficiency and the RVF/LH N400 effect, with a smaller RVF/LH N400 grammaticality effect associated with higher proficiency. This correlation was corroborated by subsequent analysis looking at participants sorted in quartiles of proficiency ranking. These results are consistent with prior studies in that L2 learners may rely on lexical semantic associations among constituent words to acquire syntactic structures in the initial learning stages and only come to engage structural analysis when the learners have better mastery over the syntactic structure in their L2 (Hahne and Friederici 2001; Osterhout et al. 2006; Osterhout et al. 2008; Dowens et al. 2010; Tanner, Inoue and Osterhout 2014). Consistent with several previous studies (Hahne and Friederici 2001; Chen et al. 2007; Meulman et al. 2014), our results showed that only a very small subset of L2 learners were able to process syntactic information in a native-like manner. This may also help explain that while the L2 participants in the present study performed highly accurately (mean accuracy 85%) in the Chinese reading comprehension test, something that could be achieved via several different means (vocabulary and semantic inference for example), they were nevertheless reliably less accurate than the native group in the on-line grammaticality judgment task.

Extending prior research, our results provide critical evidence that the transition from lexical-semantic scaffolding (indexed by the N400 grammaticality effect) to more native-like structural analysis (indexed by the P600 grammaticality effect) takes place in the dominant LH (with a different transition pattern happening in parallel in the non-dominant RH, which we will elaborate on next). These results are consistent with Ullman's declarative/procedural model (Ullman 2001), which proposes that the procedural system subserving processing of rule-based syntactic information in the L1 has very limited applicability in L2 processing, and as a result, the primary (but not exclusive) LH declarative memory system that is mainly involved in processing lexical information in the L1 would be "recruited" to help process the rule-based syntactic information instead (Squire and Zola 1996; Hodges and Patterson 1997).

4.2 Structural Scaffolding from the Non-dominant Hemisphere

Our results showed robust correlations between smaller LVF/RH P600 grammaticality effects and higher L2 performance indexed by both grammaticality judgment accuracy and self-rated Chinese proficiency. These results are consistent with prior findings showing beneficial influence of RH involvement in the initial stages of learning a second language (Dehaene et al. 1997; Leonard et al. 2010; Qi et al. 2015). As these prior studies used tasks that may favor RH processing strength, in which even native speakers could arguably benefit from engagement of the RH (size judgment, tone discrimination, and story comprehension), it is unclear to what extent the RH support in initial L2 learning is generalizable. As structural analysis in syntactic processing has typically been considered less effective in the RH, our results thus extend our current understanding by providing critical evidence that underscores the facilitative role of RH scaffolding in the initial stages of L2 learning.

That P600 responses can be elicited with LVF/RH presentation is consistent with prior observations based on native language processing (Kemmer, Coulson and Kutas 2014; Lee and Federmeier 2015). Lee and Federmeier (2015), for example, demonstrated that although right-handers as a group elicited a left-lateralized P600 grammaticality effect with RVF presentation only, right-handers with familial left-handedness background elicited P600 grammaticality effects with both VF presentations, suggesting that the RH is capable of processing syntactic information in a qualitatively similar manner as the LH. On the other hand, considering only learners with high proficiency elicited P600 responses in the LH-biased condition, the LVF/RH P600 effects in low and intermediate proficiency learners are striking. These data are analogous to findings that showed RH support for native language processing in cases where the LH is compromised following LH strokes (Cohen et al. 2004; Hamilton, Chrysikou and Coslett 2011). Critically, however, our data push this further and present a possibility that sensitivity to syntactic structural relations in a new language could be developed in the RH prior to or even leading to the emergence of similar sensitivity in the LH. Although this seems to be the pattern in our current dataset, our observation is made based on cross-participant comparisons and could be confounded by an individual participant's own brain lateralization bias. This bold hypothesis would thus need to be verified using longitudinal approaches tracking the changes of

brain responses during acquisition of syntactic regularity in a new language within the same set of learners⁶.

Despite the initial facilitative role of the RH structural scaffolding, our data did suggest that learners should ultimately disengage from this scaffolding in order to attain higher language proficiency. This observation is consistent with emerging data showing correlations between better language outcome and the degree of RH disengagement. Qi et al. (2017), for example, assessed brain responses from a group of English-speaking learners of Chinese prior to and after a month-long classroom-based Mandarin course. Their results showed that greater activation in the right inferior frontal gyrus (IFG) during a tone discrimination task (Mandarin speech tones vs. non-speech sine-wave tones) prior to the course predicts greater learning success in Mandarin. Interestingly, assessments taken after the course showed greater pre-to-post reduction of right IFG activation in more successful learners, suggesting the critical role of initial right-IFG engagement and subsequent right-IFG disengagement. Our results are in line with these findings and provide additional evidence from a different aspect of language processing.

Although there is a clear decrement of LVF/RH P600 responses from the bottom to the intermediate quartile learners, top quartile learners' responses in the LVF/RH condition is less clear. Due to the noise level for this quartile in this comparison, it is difficult to gauge the reliability of the conditional differences here. However, there is a resemblance between the results here and the results reported in Hahne and Friederici (2001) in that both showed a late negativity to syntactic violations in L2 learners. It is possible that this late negativity could index lexical processes similar to the LVF/RH N400 responses we observed here in native speakers but delayed due to non-fully native-like language proficiency of these L2 learners, or conceptual processes additionally recruited by L2 learners to aid syntactic processing (Hahne and Friederici 2001). However, this speculation will need to be confirmed in future studies.

⁶ Based on prior literature, we would expect to see a phase where no P600 grammaticality effects were elicited (Hahne and Friederici 2001; Osterhout et al. 2006; Osterhout et al. 2008; Dowens et al. 2010; Tanner, Inoue and Osterhout 2014). However, we did not observe such a pattern in our quartile analysis. As the present study did not cover learners at a very early learning stage (lowest score of grammaticality judgment accuracy = 47%; self-rated proficiency = 9 out of 20), thus it is likely that we missed capturing a picture of the left end of the proficiency distribution.

5. Conclusions

L2 syntactic processing is one of the most challenging aspects of L2 learning and is usually the last mile before an L2 learner becomes fully native-like. Here in this study, we took advantage of functionally separable and well-characterized ERP components to assess hemispheric differences in L2 syntactic processing. Our data provide evidence for multiple scaffolding resources available to L2 learners: lexical-semantic scaffolding in the dominant LH and structural analysis scaffolding in the non-dominant RH. Our data point out that despite the support provided by these scaffolds, it is critical for L2 learners to ultimately disengage from these temporary support systems to achieve higher language performance. Together, the present study provides critical evidence for the functional reorganization of the brain during L2 processing and learning, which could be integrated for pedagogical applications.

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[審查：2016.12.1 修改：2018.4.11 接受：2018.5.08]

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Appendix A: Examples of Grammatical and Ungrammatical Stimuli

Grammatical pair	Ungrammatical pair
yífèn one-CL ‘a menu’ càidān menu	yìzhǎn one-CL ‘*a wake’ qǐchuáng wake
yíge one-CL ‘an opportunity’ jīhuì opportunity	sānbù three-CL ‘*three speak’ shuōhuà speak
sānjiān three-CL ‘three rooms’ fángjiān room	yìjiā one-CL ‘*a rain’ xiàyǔ rain
yíjià one-CL ‘an airplane’ fēijī airplane	liǎngchǎng two-CL ‘*two cough’ késòu cough
sānwèi three-CL ‘three teachers’ lǎoshī teacher	yìtiáo one-CL ‘*a succeed’ chénggōng succeed
liǎngkē two-CL ‘two apples’ píngguǒ apple	liǎngsuǒ two-CL ‘*two grow up’ zhǎngdà grow up
sāngēn three-CL ‘three bananas’ xiāngjiāo banana	liǎngduǒ two-CL ‘*two complain’ bàoyuan complain
liǎngzhī two-CL ‘two eyes’ yǎnjīng eye	yìzhī one-CL ‘*a care’ guānxīn care
sānbù three-CL ‘three movies’ diànyǐng movie	yìshǒu one-CL ‘*a meet’ kāihuì meet
sānpīan three-CL ‘three articles’ wénzhāng article	yízuò one-CL ‘*an enter’ jìnqù enter

二語語法處理的多重支援機制： 事件相關電位研究

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摘要

二語學習者往往無法以母語者所使用的認知神經資源來處理句法資訊；為了彌補其不足，學習者常以處理語意的方式來理解句法，或是尋求語言非優勢腦的協助。為更加瞭解這些替代處理模式，本研究結合分視野呈現以及事件相關電位來量測華語學習者左右半腦的反應。在實驗中，受試者需判斷以量詞為首的雙詞短語是否符合華語的語法結構。實驗結果顯示，與母語者相比，華語學習者不僅正確率較低，即便是在正確回答的題目裡，也誘發了和母語者不同本質的腦波反應。母語者只有在右視野呈現（左腦優先處理時）有顯著的 P600 效果，複製了以往母語者的語法處理偏向左側化的研究發現。由於二語學習者的腦波反應呈現很大的個體差異，因此整體而言，華語學習組並無呈現任何統計顯著的效果。然而，當我們進一步對學習組的腦波與華語行為表現做相關分析時發現，行為表現較佳的學習者在右視野呈現時誘發較小的 N400 效果，在左視野呈現（右腦優先處理時）也誘發較小的 P600 效果。依據學習組受試者的華語表現將他們分成四等份後，腦波反應清楚呈現出以下的變化：隨著華語表現的進展，右視野呈現（左腦優先處理時）誘發的 N400 效果會逐漸轉為 P600 效果，而左視野呈現（右腦優先處理時）誘發的 P600 效果則逐漸轉為晚期出現的負向波效果。因此，我們的實驗結果不僅支持了優勢腦中詞彙語意處理以及非優勢腦中語法結構處理這兩種鷹架機制的存在，更點出其在語言學習時所扮演的過渡角色，顯示二語學習者會逐漸減弱對這兩種鷹架機制的倚賴，以提升其二語語法的處理能力。

關鍵詞：二語學習 語言側化 腦半球差異 分視野 事件相關電位