Movement and Binding-Driven Efficiencies in L2 Sentence Processing: On the Role of UG-Constrained Acquisition in L2 Cognition

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1. Introduction

The efficient processing of sentences in native speakers is the result of great automaticity and speed both in lexical retrieval and in structural computations. In lexical retrieval, all interpretations of a word are accessed, and non-convergent interpretations are quickly pruned. Garden paths also suggest the autonomy of syntactic computations from contextual knowledge, although there is semantic feedback on proposed syntactic attachments at every stage of processing. Early effects of both lexical and contextual semantic knowledge also point to immediate discourse-semantics processing. Sentence processing, therefore, involves computations in various sub-modules, in the limits of their interfaces (Crocker, 1996; inter alia). Sentence processing includes structural computations that are blind to other sources of knowledge. This blindness is a presumed source of efficiency. However, this efficiency comes at the price of a certain dumbness as the processor seems to be unable to learn from its mistakes, taking the same routes over and over even if they are dead-ends leading to garden paths (Fodor, 1983, 2000).

Grammatical research argues that a generative computational system specialized for human language (C_{HL}) plays a significant role in giving language its expressive power. C_{HL} crucially mediates between lexical information and the conceptual intentional system (CI-system) that interfaces with C_{HL} at the level of Logical Form (LF). Thus, constraints on movements and on binding appear to be specific to natural-language grammars. Indeed, formal logical systems do not have such constraints. Grammatical research in the generative paradigm has attempted to understand the role of C_{HL}, with all its idiosyncrasies, in language design in terms of mental constitution. Hence, research on the grammar of anaphora (Reuland, 2001; Reinhart & Reuland, 1993) and research on the processing of movement dependencies (Gibson, 1998, 2000; Gibson & Warren, 2004) both conclude that the computation of referential dependencies in syntax plays a central role in the management of the global processing load. Binding reduces the number of assignments of values to variables (Reuland, 2001; Reinhart & Reuland, 1993) and movement traces refresh the activation of referents in discourse-semantics (Gibson, 1998, 2000; Gibson & Warren, 2004).

Quirky grammatical dependencies are pervasive in human languages and their target-like acquisition is not trivial for the second language (L2) learner. Formal grammatical rules constitute a non-negligible portion of what needs to be acquired, in addition to vocabulary items. Beyond either the perceived or real needs of L2 learners to approximate the target-language norms or their personal desire to do so, one may wonder whether there are any benefits to formal grammatical rules in L2 acquisition. C_{HL} computations of grammatical rules clearly involve costs, but the dependencies that these computations establish might also eke out efficiencies in the CI-system in return. Benefits to discourse-semantics processing, if they can be found, could offer insights into the role of UG-constrained grammatical states in L2 cognition. Given that a range of cognitive abilities are available

* Our argument greatly benefited from feedback at the Second Language Research Forum as well as comments and advice offered by an anonymous Second Language Research Forum reviewer. We thank Stephanie Dickinson for her statistical guidance. Usual disclaimers apply.

to mature adults in the treatment of L2 input (Felix, 1985, 1988), poverty of the stimulus evidence showing that Interlanguage grammars are UG-constrained (Dekydtspotter, 2009; Slabakova, 2006, Schwartz & Sprouse, 2000; Belikova & White, 2009) present very basic questions about the nature of L2 cognition in general. Revisiting these issues in the light of conceptual and empirical advances on the epistemology of L2 grammars, we hypothesize that efficiencies resulting from domain-specific knowledge mediated by C_{HL} relative to competing domain-general knowledge would induce the executive control system to channel resources to the engagement of L2 input via C_{HL}, limiting the role of other competing cognitive routes without these efficiencies. Syntax-driven efficiencies in L2 sentence processing would speak to the conditions under which the C_{HL} route might become the superior system in a cognitive competition. This hypothesis would explain a second language instinct in adult L2 acquisition (Schwartz, 1998; 1999).

The claim that syntax-linked efficiency gains require the involvement of C_{HL} in L2 sentence processing in mental constitution is not a foregone conclusion, but an empirical matter. Indeed, a body of evidence claims that L2 sentence processing over-relies on meaning-based strategies (thematic structure, context, and world knowledge), in view of the inability of learners to fully deploy detailed grammatical knowledge of the L2 in real time (e.g., Felser & Roberts, 2007; Felser, Roberts, Gross, & Marinis, 2003; Felser, Sato, & Bertenshaw, 2009; Marinis et al., 2005; Papadopoulou & Clahsen, 2003). In this view, therefore, we do not expect grammatical knowledge of the L2 to provide efficiencies incrementally. However, a body of research argues that L2 sentence processing relies on a grammatical instinct to non-strategically compute dependencies in real time (e.g., Dekydtspotter, 2001; Dekydtspotter, Donaldson, Edmonds, Liljestrand Fultz, & Petrush, 2008; Hoover & Dwivedi, 1998; Juffs, 1998; Juffs & Harrington, 1995; Williams, Möbius, & Kim, 2001).

We, therefore, consider whether there is evidence of efficiency gains in discourse-semantics resulting from the computation of dependencies (movement and binding) in L2 sentence processing. There are general implications for this study, involving the boundary between learned grammatical knowledge—the result of general cognition whether implicit or explicit—and acquisition, the outcome of domain specific mental structures (Krashen, 1981; Schwartz, 1986; and many others). This paper examines the claim that traces of moved expressions left by cyclic movement refresh the CI-representations of these expressions (Hypothesis 1). In particular, the experiment focuses on the logical variables introduced by pronouns and anaphors in CI-representations, in view of syntactic constraints on them. It is further hypothesized that binding computations relying on the representations of (intermediate) traces at LF will lead to a reduction of processing costs in the CI-system (Hypothesis 2). Crucially, any efficiency gains that are eked out of the grammatical dependencies computed by C_{HL} will become critical when these gains are needed because processing resources are stretched. We report on supportive evidence and consider implications of these findings for L2 cognition in general.

2. Grammar and costs of referential dependencies

Grammatical research on anaphoric elements highlights the (largely) complementary distribution of anaphors such as *himself* versus pronouns such as *him* as in (1), with a few exceptions to be considered below.

(1) a. Bill_j said John_i adores $\text{himself}_{i/*j}$.
b. Bill_j said John_i adores $\text{him}_{*i/j}$.

Anaphors must be bound by a C-commanding antecedent under an indexing in a local domain (the least projection containing the anaphoric expression in which the complement and subject are realized). Pronouns must be free in this same local domain (Chomsky, 1986). Although accounts of the exact nature of the dependencies involved in the binding of anaphors have changed over time, there is consensus that anaphors must be bound in syntax (Chomsky, 1986; Chomsky, 1995; Hicks, 2009; Hornstein, 2000; Reuland, 2001, 2006).

In contrast, the condition that pronouns be locally free is reducible to language design in view of the locality of grammatical operations in C_{HL} (Chomsky, 1995; Reinhart, 1983; Reinhart & Reuland, 1993; Reuland, 2001). Thus, Reinhart (1983) notes that the conditions on pronouns need not be stipulated in the grammar; rather they arise at the interfaces with discourse: in (1a) if you intended to indicate that Bill communicated that John has the reflexive property of self-adoration, then this is precisely what you should say, by Gricean principles. If you say (1b), then in contrast with (1a), it is derived that the individual John is not the referent of the pronoun *him*. If such pragmatic reasoning is involved, then it can be expected that in some discourse cases, even though the same computations are involved, the typical complementary distribution of anaphors and pronouns breaks down in a manner that is not expected if the condition on pronouns was purely syntactic.

(2) a. I know what Mary and *Bill* have in common. Mary adores *herself* and *Bill* adores *himself* too.
b. I know what Mary and *Bill* have in common. Mary adores *him* and *Bill* adores *him* too.
(Reuland, 2001, p. 448, ex. 19)

Thus in (2a, b), although *himself* and *him* can both occur in the same syntactic environments, the representations for the anaphor (2a) and the pronoun in (2b) are not formally the same, nor are they semantically the same. In (2a), the anaphor allows the expression of a reflexive property of self-adoration, which is under discussion in the context. In (2b), the property under discussion is the property of adoring Bill. The overlap in the distribution of anaphors and pronouns in (2a, b) is illusory, given the fact that the semantics of (2a, b) differ.

If a pronoun such as *him* introduces a variable in discourse representation, the *-self* morpheme can be seen as lexically introducing an identification requirement (Reinhart & Reuland, 1993; Reuland, 2001). This requires the formation of a referential chain. In Harley and Ritter's (2002) feature geometry, this might involve the Individuation node. In language design, C_{HL} seeks to satisfy lexical requirements quickly. For exposition, we assume that identification in syntax takes place via cliticization of *-self* at LF (3a) (Chomsky, 1995).

(3) a. $[_{IP}\ \text{Bill}_{\phi}\ [_{vP}\ t_{\text{Bill}}\ \text{self-adores}\ t_{\text{self}}\ ]]$
b. $[_{IP}\ \text{Bill}_{\phi}\ [_{vP}\ t_{\text{Bill}}\ \text{adores him}_{\varphi}]]$

Thus, the syntactic chain in (3a) derived by $\text{cliticization}_{LF}$ establishes a binding relation in the semantics (4a). The LF structure involves a predication relation between an individual constant *Bill* and a reflexive predicate in which the value-assignments to thematic subject and object positions co-vary (4a). The λ-abstraction over the two thematic positions (experiencer subject and patient object) specifies the reflexive predicate capturing the nature of binding in the semantics. By virtue of the predication relation, these positions are identified in one fell swoop. In (3b) *Bill* and *him* have their own (matching) interpretable ϕ-features involved in reference that may enter into a referential dependency. Indeed, pronouns function as variables subject to valuation. However, with no lexical identification requirement, this valuation is delayed by Procrastinate, an economy principle under which nothing happens at any stage that is not strictly necessary. Thus, the LF representation for (2a) involves a predication between *Bill* and a (non-reflexive) predicate expressing the property of adoring some specific individual, semantically identified as Bill (4b).

(4) a. *Bill* $\lambda x.\ x$ *adores* x Logical Form (3a)
b. *Bill* $\lambda x.\ x$ *adores* y: y = *Bill*   Logical Form (3b)

Different occurrences of a name in positions, across which a semantic binding relation can be established, are generally understood to designate distinct individuals going under the same name. Thus, situations in which Bill adores Bill can be described via the syntactically derived property of self-adoration or the property of adoring Bill derived in the semantics. The syntactic route is, however, computationally preferred (Reuland, 2006). Indeed, as Reuland (2001) points out, a single assignment of values to experiencer and patient roles as in (4a) as a result of the computations in (3a) economizes on discourse storage relative to a co-reference structure as in (4b), in which distinct assignments of values to the experiencer and patient roles are involved.

Anaphors and pronouns also apparently overlap when they occur as complements to nouns. Examples of this are provided in (5a) and (5b) since both the anaphor *himself* in (5a) and the pronoun *him* in (5b) can be construed with *Ben*.

(5) a. Which story about himself did Ben say this week that Anna told?
b. Which story about him did Ben say this week that Anna told?

However, the semantic interpretation for (5a) and (5b) differs since anaphors enter into a binding relation in syntax, whereas pronouns do not. Pronouns are resolved in the semantic component. We consider now the precise moments in which the referential computations take place in the processing of (5a) and (5b) respectively.

Our central research question is the degree to which referential dependencies result in efficiency gains for Chinese-speaking learners of English. Crucially, interrogatives in Chinese dialects do not allow *wh*-movement and the binding options available in Chinese differ greatly. We consider two hypotheses in conjunction—the hypothesis that intermediate traces allow referents in the discourse representation structure to be refreshed, with a focus on discourse-logical variables, as well as the hypothesis that the computation of (syntactic) binding reduces processing costs. We now turn to crucial computations in which the potential efficiency gains provided by movement and binding dependencies add up.

3. Discourse storage and cost efficiencies in language design

Language design thus involves a modular structure in which syntax mediates between lexical specifications and semantic representations through a level of Logical Form. The processing of sentences involves the concomitant computation of representations in discourse-semantics and in syntax in the limits of their UG-sanctioned interfaces. As an input sentence such as (6a) and (7a) is encountered, a phrase structure representation is computed as in (6b) and (7b) in predictive fashion: A CP category implies an entire clausal architecture up to the complement to V in which lexical items are integrated. As the anaphor *himself* (6a) or the pronoun *him* (7a) is encountered, semantic values are accessed. Pronouns and anaphors are interpreted as variables with values assigned by different mechanisms. As the noun *Ben* is processed, this offers a potential value for the anaphor or pronoun.

(6) a. Which story about himself did Ben say this week that Anna told?
b. $[_{CP}$ Which story about himself $[_{C'}$ did $[_{IP}$ Ben$_{\phi}$ $[_{vP}$ t_{Ben} say this week $[_{CP}$ t_{wh}
$[_{C'}$ that Anna told t_{wh}]]]]]]?
c. $[_{CP}$ Which x $[_{C'}$ Q $[_{IP}$ Ben$_{\phi}$ $[_{vP}$ t_{Ben} self-say this week $[_{CP}$ x story about t_{self}
$[_{C'}$ that Anna told x]]]]]]?

(7) a. Which story about him did Ben say this week that Anna told?
b. $[_{CP}$ Which story about him$_{\varphi}$ $[_{C'}$ did $[_{IP}$ Ben $_{\phi}$ $[_{vP}$ t_{Ben} say this week $[_{CP}$ t_{wh}
$[_{C'}$ that Anna told t_{wh}]]]]]]?
c. $[_{CP}$ Which x $[_{C'}$ Q $[_{IP}$ Ben$_{\phi}$ $[_{vP}$ t_{Ben} say this week $[_{CP}$ x story about *him*$_{\varphi}$
$[_{C'}$ that Anna told x]]]]]]?

Rigalleau and Caplan (2000), and Rigalleau, Caplan and Baudiffier (2004) argue that contextual referents are automatically entertained as potential values of pronouns subject to feature agreement, followed by a disengagement process. There is a similar process for anaphors (Badecker & Straub, 2002; Runner, Sussman, & Tanenhaus, 2003, 2006; Sturt, 2003). Potential value assignments in discourse can be thought of as indices subject to grammatical licensing. As a reflex of language design, this referential dependency is syntactically licensed by binding theoretic computations. Specifically, complex anaphors construed with matrix clause subjects are locally bound at LF via reconstruction in the C-domain on which binding-theoretic computations rely (6c) (Barss, 1986). For pronouns in the same syntactic configuration, binding is excluded at this level (7c), forcing reconstruction in the V-domain where pronouns can be licensed. As a result, anaphors and pronouns induce different syntactically dependent reading time profiles, which have been measured in L2 English (Dekydtspotter, Wang, Kim, Kim, Kim, & Lee, 2012).

From the perspective of discourse-semantics processing, two states of affairs in valuation must be considered: the state of affairs prior to the input of syntax and the state of affairs after the input of syntax, which awaits the computation of the C-domain. Before the C-domain is computed, distinct valuations to Ben are entertained for the agent argument of *say* and for the patient argument of *story.* As the C-domain is computed, the syntactically bound argument positions of *say* and *story* require but a single valuation to Ben. In the case of pronouns, syntactic binding in the C-domain is ruled out by grammatical design. Binding is only possible in the V-domain at the LF-interface. Focusing on the discourse-semantics processing concomitant with C-domain computations, we note that there is a time of processing with a single valuation to Ben in the case of anaphors but distinct valuations to Ben in the case of pronouns, because binding for pronouns is ruled out until the V-domain. Such an effect in discourse-semantics, however, requires that C-domain computations refresh the values of anaphoric expressions in discourse-semantics. In native speakers, the effect of abstract syntactic dependencies on the activation of referents is (broadly) documented in priming studies, although this is sometimes invisible in individuals with lower working memory (WM). In the case of L2 learners, whether this occurs is considerably more controversial: Felser and Roberts (2007) argued that their priming patterns suggested that learners maintained activation on referents in a manner suggesting that their processing in discourse-semantics was unaffected by the syntactic structure of indirect object relative clauses in L2 English. Using a different priming task coupling picture classification during reading, Miller (2011) uncovered priming evidence suggestive of structural computations of dependencies with indirect objects relative clause and clefts among groups of learners. Likewise, using the same methodology, Dekydtspotter, Miller, Chang, Kim, & Schaefer (2010) reported evidence of syntactic computation at the edge of the embedded clause, relative to control positions. In addition, these authors reported patterns of facilitation in higher WM native speakers but mirror-image patterns of inhibitions in L2 learners.

4. Binding and movement in Interlanguage

The English structures such as (6a) and (7a), with derivations in (6b) and (7b) with their C-domain computations in (6c) and (7c) offer a significant challenge for Chinese-speaking learners of English. *Wh*-movement structures are not licensed by Chinese grammar. The computations in (6b, c) and (7b, c) in L1-Chinese L2-English Interlanguage require that learners access *wh*-features triggering movement in response to the morphosyntactic structure of English input. Such computations would challenge Hawkins and Chan's (1997) claims that uninterpretable features, not selected in L1 acquisition, are inaccessible in L2 acquisition (see also Hawkins & Hattori, 2006; Tsimpli & Dimitrakopoulou, 2007). In addition, anaphora resolution works differently in Chinese which allows both simplex anaphors *ziji* and a complex anaphors *ta-ziji* (*pronoun* + *self).* Both simplex and complex anaphors can appear in the complement of nouns. Crucially, however, the binding domains allowed in Chinese and English differ significantly. Different accounts have been proposed, involving either distinct syntactic computations (Cole, Hermon, & Sung, 1990; Cole & Sung, 1994; Huang & Tang, 1991; Reuland, 2001) or a logophoric treatment (Huang & Liu, 2001) or both (Kim, Montrul, & Yoon, 2009). Kim, Montrul, and Yoon (2009) found that L1-English L2-Korean learners and English-Korean heritage speakers allowed the long distance construal of *caki* measurably less than native speakers from Korea.

Any strategy allowing long distance anaphora in the processing of (6a) would allow learners to avoid the local C-domain computations. White (1995) notes that binding properties reduce to the lexical analysis of English anaphors as *pronoun* + *self.* Complex anaphors require a local binding domain. The feature bundles for English *pronoun* + *self* must to be modified to include gender. White (1995) showed that L1-Japanese L2-English learners were virtually as accurate on person, number, and gender agreement as L1-French L2-English learners. White (1995) found no L1 effects on a truth-value judgment task for L2 English: French and Japanese learners were equally accurate on local binding. Both French and Japanese learners produced long distance binding in non-finite contexts as in Hindi. This echoed previous results for L1-Korean/L1-Japanese L2-English acquisition (Broselow & Finer, 1991; Hirakawa, 1990; Wakabayashi, 1996) and L1-Spanish L2-English acquisition (Thomas, 1989, 1991, 1993). Given that (6a) involves a finite embedded clause, it is not expected that the type of long distance anaphora found in L2 English will allow learners to avoid local C-domain computations in this case.

The literature on the L2 acquisition of anaphors leads us to surmise that anaphors and pronouns will induce different processing steps in syntax in the treatment of (6a) and (7a). The resolution of anaphors in the C-domain in syntax (6c) is expected to induce efficiency gains in discourse-semantics. This operates as follows: the computation of cyclic movement traces in the C-domain as in (6b) refreshes the referents of expressions. In the case of variables, these are the (contextual) value-assignments to anaphoric expressions. Hence, it is expected that simple categorization decisions about matching probes (made by pressing a button) will be speedier than categorization decisions unrelated to such processing (Hypothesis 1). Specifically, these decisions will be modulated in the critical position, at the edge of the embedded clause, by efficiencies due to binding, induced by the resolution of anaphors in the C-domain (Hypothesis 2). Furthermore, it is expected that such efficiency gains will become measurable as the advantages they provide are recruited.

5. The study

5.1. Methods

The participants in our study completed several tasks. First they filled out a biographical questionnaire requesting information about age, native language, major, foreign language experience, weekly exposure, diagnosis of dyslexia and two questions on respondents' (perceived) reading strength: *How good are you sounding out English words?* and *How would you rate your ability to read fluently in English?* Responses were recorded on a 9-point [0-9] scale indicating *very poor* to *very good* on the first question and from *very slow reader* to *very fluent reader*. Expert reading relies on (early acquired) phonological awareness leading to efficient letter to sound mappings and automaticity of lexical retrieval. The NNSs also included the number of years of English study both prior to and at the university level and time spent in an English speaking country. Next, respondents completed a C-test composed of 50 items, which included both function and open class vocabulary. Participants were given 10 minutes to complete the task. Next, they engaged in a picture classification training activity that was run on DMDX (Forster & Forster, 2003). In this activity, they were presented with 60 pictures centered on a computer screen, one at a time, and they had to decide if the pictures depicted something alive or not alive. Pictures were preceded by the * symbol, alerting participants that a picture was coming. The inter-stimulus interval was set to 50 ticks on an LCD screen with a refresh rate of 60Hz (836ms) and screen resolution set to 1280 x 1024 pixels. Pictures were displayed for 25 ticks (418ms). Instructions and example items were presented prior to the start of the training exercise. Participants were instructed to press either the left or right arrow key depending on whether the object was alive or not alive. Stickers with either *alive* or *not alive* written on them were placed on the respective arrow keys to avoid any confusion. This training exercise took approximately 4 minutes. This ensured both respondents' familiarity with the pictures to be used in the main experiment and familiarity with the task of picture classification.

Next, respondents completed the main experimental task, which required that they classify pictures while they were reading aloud in a low voice at a set reading pace (Dekydtspotter et al. 2010; Miller, 2011). Respondents' reading was monitored to ensure that they were paying attention to the stimulus. This removed the need for comprehension checks that compete with picture decisions for conceptual resources. DMDX controlled the word-by-word presentation of the sentences at the center of an LCD screen. The task included 20 critical interrogative sentences organized in a Latin square, as well as 40 distracter items, which were also interrogative sentences. There were thus four versions of the task. The 20 experimental items involved four conditions that crossed position (control, target: clause edge) with anaphora type (anaphor, pronoun). The pictures of college-aged individuals were used as probes, which matched the pronoun or anaphor in gender. A sample quadruple is given in (8).

(8) a. Condition 1 (C1): target position, anaphor
Which / story / about / himself / did / Ben / say / this / week / that / [picture probe: a college-aged male] / Anna / told?
b. Condition 2 (C2): target position, pronoun
Which / story / about / him / did / Ben / state / this / week / that / [picture probe: a college-aged male] / Anna / told?
c. Condition 3 (C3): control position, anaphor
Which / story / about / himself / did / Ben / state / this / [picture probe: a college-aged male] / week / that / Anna / told?
d. Condition 4 (C4): control position, pronoun
Which / story / about / him / did / Ben / state / this / [picture probe: a college-aged male] / week / that / Anna / told?

The probes in target position (8a, b) appeared immediately after the complementizer *that*, the head of the C-domain. The control position (8c, d) was located within a temporal modifier. This temporal constituent offered protection from the computation of a trace in the complement position of the verb, given the anticipatory nature of the parser. Crucially, picture probes appeared after the words *this* and *that*, so that any eventuality of the respondents uttering 'this/that' and silently saying 'man, woman, etc' in response to probes, would remain a constant. However, pictorial information interfaces with the linguistic system *only* through the conceptual system, which (also) includes visual sketches (Jackendoff, 1987; Marr, 1982). This interaction of pictorial and linguistic processing in conceptual structure affects semantic [alive-not alive] decisions about the pictures, but without fully disrupting processing in C_{HL}.

Probes appeared for a short 418 milliseconds so as to lessen any effect of the interruption on the flow of reading. Ten pictures of boys and ten of girls for the critical test items as in Figure 1 cycled through the four versions of the task. The task was balanced between animates and inanimates, which involved common objects such as a book, a blender, a ruler, etc. The distracters, therefore, included ten animate probes and thirty inanimate probes. Time out was 1500 milliseconds. All pictures were obtained from Microsoft Office Clipart, and were adjusted to similar size using Photoshop. Pictures appeared uniformly at the center of the screen. Response times to pictures were measured. Examples of pictures are given in Figure 1. Pictures appeared in color during the actual experiment.

Figure 1: Sample picture probes

A scenario provided the context for a stimulus consisting entirely of 60 questions. Respondents were introduced to a character Eric who “wants to make fun of the TV show *Friends*, using his wacky friends as inspiration. He has decided to try to remember all of the crazy stuff that people have been saying about other people over the year. Eric has written up a bunch of questions to organize his thoughts.” Respondents read Eric's notes aloud in a low voice as the words appeared, classifying pictures that interrupted the reading for a short 418 milliseconds. Two scripts were used, one for NS and another for NNS, allowing for different reading speed. These were piloted to ensure that the speed was appropriate. Additionally, respondents answered questions about the difficulty and speed of the task. None of the respondents reported being overwhelmed by the task. In the NS script, each word was displayed with default duration of 25 ticks (418 ms) plus an additional 1 tick (16.72 ms) for every letter in the word after 4 letters. Each word presentation was 10 ticks (167 ms) longer for the learners.

This task took 10-15 minutes to complete. Finally, respondents were asked to quickly provide the gender of 37 names used in the experiment to ensure that L2 learners recognized whether an English name, involved in a construal with a gendered pronoun, was male or female.

5.2. Participants

The participants were 52 Chinese learners of English recruited from English-language support courses for matriculated students. They reported no history of dyslexia. They were all young adults with mean age 19 ranging from 18 to 22. Recruited from literacy sections of an English language improvement program for matriculated foreign students, they had low intermediate proficiency in English. This was verified by their performance on the C-test. They had a mean score of 21.73/50, ranging from 6 to 33. Their knowledge of the gender of the English names used in the study was very close to the ceiling: Their mean score was 36.59/37. Their average score on the two reading assessment questions on the background questionnaire was 10.16/18 with a range from 4 to 14. Using the mean as cut score, we established a group of 27 weaker readers, with a mean of 8.59/18 ranging from 4 to 10, and a group of 25 stronger readers with a mean = 11.88/18 ranging from 11 to 14. The reading-assessment score differences between the two groups was significant; $t(50) = 8.497$, $p < .0005$. The two sub-groups did not differ on the C-test: 20.78/50 for those who assessed themselves as weaker readers and 22.76 for those who assessed themselves as stronger readers.

The 53 native speakers of English were college students recruited from a basic introduction to linguistics course. They were not aware of the structural issues involved in the study. They were young adults, age-matched for the L2 learners: Their mean age was also 19, ranging from 18 to 22. They had no history of dyslexia. Their mean score on the C-test was 43/50, ranging from 30 to 50. This confirmed that the learners were clearly not close to native speaker proficiency. The native speakers were at ceiling on the identification of the gender of English names, with a 37/37 score. The native speakers generally self-identified as excellent readers: Their mean reading-assessment score was 16.94/18 with a range from 9 to 18. Using the mean as cut score, we nevertheless could identify a group of 27 expert readers, who had a mean score of 15.93 with a range from 9 to 17, and a group of 26 highly expert readers who were at ceiling: mean = 18/18. The difference between the two reading skills groups, although small, was statistically significant: $t(51) = 6.746$, $p < .0005$. Subjects in the two groups did not differ in their performance on the C-test: 42.26 for the expert readers and 44.38 for the highly expert readers. This is not surprising: Native college students with no history of dyslexia are generally masters of this craft by the time they get to the university. On this self-assessment of reading ability, Chinese learners' assessments of their reading strength in English seemed appropriate relative to native speakers' assessments. There were varying degrees of confidence in skill set across the board, which are unsurprising, and are expected to play a role in a reading task.

5.3. Experimental procedures

If cyclic movement traces refreshed assignments to pronouns and anaphors in discourse-semantics, then faster reaction times to pictures are expected at clause-edge in contrast to control positions (Hypothesis 1). Second, the speedy C_{HL}-derived resolution of anaphors (but not of pronouns) in the C-domain is expected to save on processing costs in the semantics (Hypothesis 2). This is because there is a processing stage at which the costs of anaphoric binding in which several positions receive a value in a single assignment are less than the costs of several assignments, even if these are assignments to the same individual. It is expected that such temporary efficiency gains eked out of C_{HL} will matter most when demands on resources are greatest. This aspect is expected therefore to play a greater role in L2 processing than L1 processing. Given that under-routinized reading crucially affects lexical retrieval in a L2, thereby increasing processing costs (Segalowitz, 2003), it was hypothesized that weaker readers would be in greatest need of the efficiency gains provided by syntactic computations relative to the stronger L2 readers or the (native) expert readers. Thus, weaker readers (especially) will reap more benefits from binding-induced efficiencies. The central question lies in the degree to which learners can eke out efficiencies from C_{HL} computations as processing resources are stretched. The dependent measures were reaction times in the classification of probes in milliseconds.

Following standard procedures, only measures for correct classifications were used. Classification times that were beyond two standard deviations beyond the means were removed and missing values replaced by the means. This was about 2.2 percent of the data. Hypothesis 1 claims that C-domain computations refresh variable assignments to anaphors and pronouns in discourse-semantics. This entails faster classification at the clause edge. Hypothesis 2 claims that a single assignment to bound syntactic expressions is more cost effective than two distinct assignments (even to the same value). Hypothesis 2 entails faster classifications at the clause edge for probes matching the anaphors (resolved in the C-domain) relative to pronouns (resolved in the V-domain), when every processing advantage is called upon. These hypotheses should interact, modulated by reading fluency and/or proficiency, given the presumed greater role of efficiencies when they are needed. In view of this, we conducted mixed-designed ANOVAs with position and anaphora type as within subject factors and reading fluency and proficiency as between subject factors. Hypothesis 2 was further investigated with a planned t-test, expecting faster decisions concomitant with the processing of anaphors versus the processing of pronouns. Significance for this planned comparison is set at .05 for a one-tailed comparison as the reward of design, given clear theoretically driven expectations. This result is placed in the context of theoretically significant trends in observed differences with relatively low risk of error.

5.4. Experimental results

The native speakers' results are provided in Table 2. An ANOVA yielded a main effect of position, $F(1, 49) = 10, 591$, $p < .002$. Thus, pictures in critical positions were generally classified more quickly than pictures in control position, despite the fact that they were closer to a matching antecedent. There were no effects of anaphora type. No effect of reading expertise was detected. This is not surprising given the expectation that efficiencies eked out by binding will play a crucial role when resources are stretched, and we did not expect that this would the case for expert readers.

Table 1

Native speakers' reaction times in milliseconds by proficiency and reading fluency

	Expert readers (n = 27)	Highly expert readers (n = 26)
Anaphor control	504 (36)	504 (31)
Pronoun control	508 (43)	553 (47)
Anaphor critical	503 (38)	488 (31)
Pronoun critical	494 (32)	493 (33)

We next turn to learners' results as revealed in Table 2. This is where it might be expected that binding will provide incremental efficacy gains, modulated by reading strength. An ANOVA with position and anaphora type as within subject factors revealed a main effect of position, $F(1, 48) = 7.970$, $p = .007$. Thus reaction times to pictures matching the gender of the pronouns were generally faster in critical position than in the earlier control position. In this connection, it is important to note that the picture in the (earlier) control position appears closer to the gender-matching antecedent than the picture in the (later) critical position. In terms of memory resources, the activation of a referent is expected to decay with time, so that faster reaction times in later positions are unexpected from this point of view. This finding is, however, consonant with a process whereby the computation of a cyclic movement chain, implicating an intermediate trace at clause edge, refreshes referents and the properties associated with them. In the cases of anaphora reconstruction considered here, this includes the assignments of values to the pronouns or anaphors. This supports Hypothesis 1. There was also an interaction of position and reading strength, $F(1, 48) = 8.174$, $p = .006$, and an interaction of position, reading strength and proficiency, $F(1, 48) = 6.449$, $p = .014$. Crucially, there was a theoretically significant interaction of anaphora type and position, which was mediated by reading strength, $F(1, 48) = 3,782$, $p = .058$. A perusal of Table 1 reveals the nature of the effect: It appears to be due to the weaker readers who responded faster to critical-position probes in the anaphor than in the pronoun condition, whereas reactions to probes in the control position were insensitive to the anaphor-pronoun distinction. There appears to be support for Hypothesis 2, according to which binding in syntax relieved processing load in the CI-system. For each reading strength group, a post-hoc ANOVA with proficiency as the between-subject factor was run. For the stronger L2 readers, a strong main effect of position, $F(1, 23) = 13.593$, $p = .001$ echoed the native pattern. A marginal main effect of proficiency, $F(1, 23) = 3.736$, $p = .066$, was also found. For the weaker L2 readers, proficiency interacted significantly with position, $F(1, 23) = 5.817$, $p = .024$. There were no other effects. A *planned t*-test examining weaker readers' classification times at clause edge: $t(26) = 1.874$, $p = .036$ was significant. Reaction times were flat in control position.

Table 2

Learners' reaction times in milliseconds by proficiency and reading fluency

	Weaker L2 readers		Stronger L2 readers	
	Lower proficiency (n = 14)	Higher proficiency (n = 13)	Lower proficiency (n = 12)	Higher proficiency (n = 13)
Anaphor control	550 (62)	559 (87)	524 (57)	574 (87)
Pronoun control	552 (76)	552 (72)	537 (90)	570 (86)
Anaphor critical	557 (89)	534 (68)	494 (69)	565 (71)
Pronoun critical	577 (84)	546 (84)	490 (41)	542 (70)

In sum, the L2 data revealed an interaction of anaphora type with position qualified by reading strength. Weaker readers' reaction times on picture probes suggest that the C-domain resolution of anaphors provided computational benefits over the V-domain resolutions of pronouns. The stronger L2 readers and the native speakers produced similar clause-edge priming for anaphors and pronouns.

6. Discussion

The asymmetries involving position were uncovered in the processing of visual probes by learners and by native speakers alike. These effects are extremely robust: they are found across relative proficiency levels on the C-test and they are found across reading strength, which is a dimension orthogonal to proficiency. These effects are prima facie evidence of cyclic movement. Faster classifications were found for pictures at clause edges, which are expected to induce processing costs in syntax by virtue of the cyclic movement property. At the next level of processing, i.e. in the CI-system, the opposite effect was expected. The syntactic computations should refresh referential values for anaphoric expressions in discourse-semantics. The positional asymmetries in the reaction times to probes matched this expectation precisely. These processing asymmetries seem therefore to reflect the computations of traces, specifically intermediate traces left by cyclic movement, signaling a processing mechanism specialized for language. This result reflecting the locality of operations in C_{HL} suggests that learners are guided to process abstract representation in domain-specific ways. Expectations for Hypothesis 1 were strongly verified.

This finding is unlike Felser and Roberts' (2007) results in which learners from a range of language backgrounds (including Chinese speakers) failed to show any effect of position in their stimulus. Felser and Roberts (2007) view this state of affairs as evidence of the Shallow Structure Hypothesis (Clahsen & Felser, 2006a, b) according to which learners, generally over-relying on meaning based strategies, fail to compute in real time all the fine-grained details of structure (including movement traces, and the like) that native speakers generally compute with great facility. Hence, not only was modulation of priming by position not found in (adult) L2 learners, unlike in NSs, (Felser & Roberts, 2007), but facilitations of filler integration in thematic position in bridge verb contexts were also not found in NNSs (including Chinese learners of English), unlike in NSs (Marinis et al., 2005). These facilitation effects are also different from the inhibition effects for matching probes at the clause edge found in L1-Chinese and L1-Korean L2-English learners of intermediate proficiency (unlike higher WM native speakers) with the same methodology introduced in Dekydtspotter et al. (2010). The level of robustness in the present task is therefore remarkable. A natural difference offers itself: Previous research focused on the reactivation of (properties of) constants in discourse-semantics: the values of names, definite descriptions or common noun denotations. It is well-known that access to such referents appears to be jeopardized by under-learned L2 lexical retrieval (Favreau & Segalowitz, 1983; Segalowitz & Segalowitz, 1993). This experiment focused on expressions that function as logical variables in discourse-semantics, which apparently do not suffer from the same issues.

Thus, Hypothesis 1 was supported, allowing for the examination of the effect of binding-theoretic computations in the CI-system, Hypothesis 2. Binding theoretic computations also appear to be specific to natural-language grammars, so that evidence of binding-theoretic computations mediated by cyclic movement chains during processing would suggest a domain-specific mechanism capable of relieving the processing load (Dekydtspotter et al., 2012). We focused on a specific characteristic of syntactic binding: Its ability to eke out efficiencies in discourse-semantics. Reactivation of referents should take place sooner for anaphors resolved in the C-domain computation of the chain than for pronouns bound in the V-domain, at the foot of the chain. In this connection, it was found that anaphors induced faster responses to picture probes at the clause edge only in weaker readers. This is presumably because the extra resources made available by binding were needed and therefore recruited by these learners. Again, these results are not easily reconciled with claims that L2 learners generally fail to perform binding theoretic computations in real time (Felser, Sato, & Bertenshaw, 2009).

These results speak to the (effortful) nature of L2 sentence processing. According to the shallow structure hypothesis, learners do not generally engage in fully detailed syntactic processing: parses remain largely shallow. Naturally, many of the cost savings that syntactic computations provide should be missing. This could explain the effortful nature of the processing. However, efficient processing relies on a delicate balance of information integration (Dekydtspotter, Schwartz, & Sprouse, 2006; Hopp, 2006). Under-learned L2 lexical retrieval *inter alia* (Favreau & Segalowitz, 1983; Segalowitz & Segalowitz, 1993) jeopardizes this delicate balance (Dekydtspotter et al., 2010). The evidence presented here lends support to this latter understanding of the nature of L2 sentence processing. It strongly supports the view that Chinese learners of English compute (*wh*-)movement dependencies constrained in the usual way. Evidence of syntactically induced efficiency gains found in intermediate learners with weaker reading strengths, who apparently recruited all available means to perform the task unlike stronger and expert readers, points to highly domain-specific computations in L2 processing.

7. Perspectives

Clearly, these findings have repercussions far beyond the question of the degree to which L2 learners compute representations in real time. These findings also have much broader theoretical implications for L2 cognition in general, suggesting possible answers to basic questions about the nature of adult L2 acquisition. That is to say, the fact that adults have developed cognitive capacities raises the issue of competition between cognitive systems in adult L2 acquisition (Felix, 1985, 1988). Specifically, evidence that interlanguage grammars are UG-constrained raises the central question of the conditions under which this route is selected among potential competing cognitive sub-systems in adult L2 acquisition. This traces back to the roots of L2 cognition (Felix, 1985; Krashen, 1981). Efficiencies gained through C_{HL} computations provide elements of an answer: Such efficiencies induce executive centers to direct resources to the engagement of the input by C_{HL}, limiting the role of other routes that do not provide these efficiencies. Efficiency gains, if they indeed continue to be found in future L2 processing research, can speak to the conditions for engaging C_{HL}. Understanding the conditions under which C_{HL} wins out in the cognitive competition entertained by Felix (1985) may provide a new doorway to a fuller understanding of L2 cognition more generally.

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Selected Proceedings of the 2011 Second Language Research Forum: Converging Theory and Practice

edited by Erik Voss,
Shu-Ju Diana Tai, and Zhi Li

Cascadilla Proceedings Project Somerville, MA 2013

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ISBN 978-1-57473-458-4 library binding

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Dekydtspotter, Laurent, Michael McGuire, and Sabrina Mossman. 2013. Movement and Binding-Driven Efficiencies in L2 Sentence Processing: On the Role of UG-Constrained Acquisition in L2 Cognition. In *Selected Proceedings of the 2011 Second Language Research Forum*, ed. Erik Voss et al., 104-117. Somerville, MA: Cascadilla Proceedings Project. www.lingref.com, document #2909.