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EMPIRICAL STUDY

Modelling Changes in the Cognitive Processing of Grammar in Implicit and Explicit Learning Conditions: Insights From an Eye-Tracking Study

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This study used eye-tracking to examine changes in how second language (L2) learners process target grammatical exemplars in written L2 input in implicit and explicit instructional conditions and how these changes relate to learning gains. In three separate sessions, 77 L2 learners of English read a story containing seven examples of a grammatical construction. The results of a growth curve analysis indicated significant main effects for the instructional condition and test sessions on total fixation duration and a significant interaction between these two variables. There was minimal attentional processing and no improvement in processing efficiency of the target construction in the unenhanced condition. Learners' attentional processing in the textually enhanced

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conditions decreased and, by the end of the experiment, they engaged in establishing and fine tuning form–meaning links. In the two explicit instructional conditions, participants' attention decreased over time and form–meaning representations of the target structure were strengthened.

Keywords attention; eye-tracking; exposure; implicit instruction; explicit instruction

Introduction

Written texts can serve as rich sources of input for second language (L2) learning. Previous research has extensively examined the acquisition of lexical knowledge through reading and has focused on the role of frequency of exposure in successful vocabulary learning (e.g., Elgort & Warren, 2014; Pellicer-Sánchez & Schmitt, 2010; Webb, 2007). Considerably less is known, however, about how the frequency of occurrence of a novel syntactic construction contributes to learning through naturalistic unguided and guided exposure to longer and meaningful written texts. Moreover, most studies that have examined grammar learning in incidental and intentional conditions have used artificial or semiartificial languages (e.g., Morgan-Short, Sanz, Steinhauer, & Ullman, 2010; Rebuschat &Williams, 2012; Tagarelli, Borges-Mota, & Rebuschat, 2015), and less research has been conducted with languages for which learners have some prior knowledge (e.g., Cerezo, Caras, & Leow, 2016). Examining the role of frequency of exposure to syntactic constructions is crucial for understanding how grammatical knowledge develops from both pedagogical and theoretical perspectives. Such an analysis can assist in the evaluation of the effectiveness of various explicit and implicit instructional techniques used in L2 teaching and in determining how much exposure learners need for noticing and learning novel linguistic features in a written text. From a theoretical perspective, it can contribute to models of associative cognitive learning (Ellis, 2006) and clarify how L2 learners establish form–meaning associations through repeated exposure to a syntactic construction and how they encode these associations in their long-term memory.

We addressed this research niche and used eye-tracking to investigate how the processing of a target syntactic construction changes as a result of repeated exposures in short written texts and whether the patterns of change differ in implicit and explicit learning conditions. In our research, L2 learners of English were exposed to the causative *had* syntactic construction (e.g., *They had the roof repaired*) in two implicit and two explicit instructional conditions that can be considered representative of how L2 learners encounter novel syntactic constructions in written input in classroom contexts. According to Norris and

Ortega (2000), instructional conditions that have "neither rule presentation nor directions to attend to particular forms that were part of a treatment" (p. 437) can be treated as implicit instruction. The two implicit conditions in our study were (a) input flood, where the frequency of the target item was increased in the input, and (b) textual enhancement, where the target construction was highlighted in the text. The two explicit conditions included (a) instruction to pay attention to a highlighted grammatical construction and (b) an explicit metalinguistic explanation of the target construction complemented by an instruction to pay attention to it in the input (see also Spada & Tomita, 2010).

Literature Review

Cognitive Processes Involved in Acquiring Syntactic Knowledge From Written Input

In order to understand learning processes that might take place while reading a text, it is necessary to give a brief account of reading comprehension processes at the level of word and syntactic decoding. In Tunmer and Chapman's (2012) revised simple view of reading, word-level reading skills comprise orthographic processing (recognizing letters), phonological processing (phonological activation of word forms, converting letters to sounds, letter combinations to syllables), accessing semantic and syntactic information related to a word, and finally morphological processing to understand words with suffixes and prefixes. Similar to the simple view of reading, Reichle, Pollatsek, Fisher, and Rayner's (1998) E-Z reader model of eye movement control also distinguishes between orthographic familiarity check and full word identification. The above word-level reading processes, also known as word-to-text integration (cf. Perfetti & Stafura, 2014), include the syntactic analysis and assembly of phrasal and clausal constructions, as well as creating a text model, that is, processing the informational content of the text, and a situation model that helps the reader to interpret information presented in the text based on relevant background knowledge (Kintsch, 1998).

Based on this view of reading, when L2 learners encounter a previously unknown syntactic construction in a written text, they first need to decode the lexical units that constitute the syntactic construction and then analyze the relationship among the lexical units and the situation and text model to establish a form–meaning link. In exemplar-based models of first language (L1) learning, the acquisition of syntactic constructions proceeds in a similar way to the development of lexical knowledge. After exposure to sufficiently large numbers of types and tokens of a syntactic construction, children extract patterns of regularity and establish links between the form of a construction and its meaning (Tomasello, 2008). In associative cognitive models of L2 learning (Ellis, 2006), incidental learning of L2 grammar is also assumed to involve the establishment of form–meaning associations based on the frequency of co-occurrences in the input.

In the instance-based theory of contextual word learning through reading and in associative cognitive models of grammar learning, each encounter with a novel construction is hypothesized to create a memory trace of the construction and the context in which it occurs. Encounters in the same context strengthen the link between construction and context, whereas diverse contexts assist in fine tuning previously established form–meaning links (Bolger, Balass, Landen, & Perfetti, 2008). Recent research on adult vocabulary learning has also suggested that the establishment of form–meaning associations is a two-stage process (Davis & Gaskell, 2009). First, an episodic memory trace is established quickly, which is then followed by consolidation processes, "such as stabilization (strengthening of a memory trace . . .), generalization (extraction of gist/rules . . .), and integration (formation of new relations between novel and old knowledge)" (van der Ven, Takashima, Segers, & Verhoeven, 2015, p. 1).

The Role of Attention in Input Processing

One of the major factors that determine whether learners establish memory traces for unfamiliar constructions in the input and whether they make appropriate form–meaning connections is the attention paid to these constructions (Schmidt, 1990, 2010). Chun, Golomb, and Turk-Browne (2011) defined attention as "a core property of all perceptual and cognitive operations," suggesting that "[g]iven limited capacity to process competing options, attentional mechanisms select, modulate, and sustain focus on information most relevant for behavior" (p. 73). The selective nature of attention can be further elaborated on through different theoretical explanations from cognitive psychology. Fuster (2005) postulated that the human mind comprises several networks; when someone pays attention to a stimulus, resources in the mind are allocated to activate a particular network. Selective attention involves the choice of one of these networks to be attended to for further processing. Kahneman's (1973) capacity theory posited that the human mind has a limited capacity. Hence, a certain amount of information can be attended to at a given time, and the selection of stimuli to be attended to depends on task demand and importance. Inhibition is a process that takes place within selective attention in order to stop the processing of irrelevant stimuli (Smith & Kosslyn, 2006). Although inhibition plays a role in attention, Shettleworth (1998) pointed out that not all irrelevant stimuli are filtered out while one attends to stimuli. Instead, the most important stimuli at a given time are processed. In line with this argument, Treisman's attenuation model (1964) suggested that stimuli unattended to in the input are not completely blocked or ignored. Instead, they become attenuated or, in other words, less effective.

An important issue concerning the role of attention in input processing is how one's attention to stimuli changes with repeated exposure. Psychological research on infants that used either picture cards (e.g., Fantz, 1964; Slater, Morison, & Rose, 1982, 1984) or black and white checkerboard targets (e.g., Friedman, 1972) and that measured attention through eye-fixation times found that infants' attention to repeated and familiar stimuli decreased with time while attention to novel stimuli increased. There are several reasons for this behavior. First, when stimuli become familiar, they are processed rapidly, and thus the time that one needs to spend on such stimuli decreases (Mather, 2013). Second, if stimuli are less complex, the amount of time needed for processing them is also shorter. Third, when one has prior experience in processing a certain stimulus, one needs less time to process the same stimulus on another occasion because prior experience can be applied to aid subsequent processing. Prior experience, however, does not fully explain attention decrease. Thompson and Spencer (1966), who reviewed neurophysiological research on habituation, emphasized that both infants and adults prefer stimuli with an optimal level of new information. When processing stimuli, they attend to repeated stimuli until they reach an optimal level, and then their attention shifts to novel stimuli (Hunter & Ames, 1988).

Satpute, Hanington, and Barrett (2016), who used images as stimuli and measured reaction times, identified a low response level for the first presentation of stimuli, a peak response during a first repetition, and a gradual decrease in response in subsequent presentations. Yi, Kelly, Marois, and Chun (2006) argued that a decrease in response times to stimuli is task specific and controlled by attention. In an experiment, they used images as stimuli, and the participants had to decide if they had seen the images previously. Response times and brain regions of interest were used for subsequent analyses. Attentional processing was measured using functional magnetic resonance imaging in the parahippocampal area of the brain. They observed a decrease in both response times and neural activity for repeated stimuli attended to by the participants, but this decrease was not apparent for repeated stimuli that were not attended to. These researchers did not observe a reduction in brain activity for novel attended-to stimuli either. This highlights that decreases in neural and behavioral responses are related to attention regulation. Thakral, Jacobs, and Slotnick (2016) conducted an experiment with stimuli that were abstract shapes and line drawings, measuring attention through reaction times and target identification accuracy. Their results suggested that a decrease in response to repeated stimuli can indicate more fluent processing, and it might also be a reflection of efficient representation of stimuli (Müller, Strumpf, Scholz, Baier, & Melloni, 2013).

In L2 acquisition research, it is generally accepted that paying attention to certain features in the input is necessary for language development (e.g., Leow, 2013; Robinson, Mackey, Gass, & Schmidt, 2012; Schmidt, 1990, 2010), and thus a vast number of studies have attempted to investigate the effect of attention on input processing. Some of these studies used the term *attention*, while some others have applied the term *noticing*, which is attention that involves awareness according to Schmidt (1990). Most recently, eye-tracking methodology has been used to analyze attentional processing. In eye-tracking studies, it is assumed that attentional systems, to some extent, guide and control eye movements, and thus eye fixation duration indicates ongoing cognitive processing (Liversedge, Gilchrist, & Everling, 2011; Rayner & Pollatsek, 1989). Although critics of the method have noted that one can attend to a visual stimulus with no cognitive processes taking place and that not all eye movements are controlled by attention (Hunt & Kingstone, 2003; Juan, Shorter-Jacobi, Schall, & Sperling, 2004), to date, eye-tracking is the most precise tool available for investigating attention to input (Leow, Grey, Marijuan, & Moorman, 2014).

In one of the first eye-tracking studies in the field of L2 acquisition, Godfroid, Boers, and Housen (2013) used total fixation duration to measure how much attention their participants paid to targeted language forms. They found that more time spent on target lexical forms resulted in a higher likelihood of the participants recognizing those forms in a posttest. Mohamed's (2017) results in another study showed that not only lexical form recognition but also meaning recognition and meaning recall are strongly associated with total reading time. Godfroid and Uggen (2013) reported favorable effects of attentional processing on the production of a target syntactic structure when more time was spent looking at it in the input. It is important to recognize, however, that total fixation duration is not just a measure of attentional processing but includes other processes, such as familiarity checking, word recognition, word-to-text integration, and (in the case of grammatical constructions) syntactic analysis (cf. Reichle et al., 1998). Therefore, total fixation duration can also serve as a measure of efficiency and automaticity and even as an indicator of development because more effortless decoding of a word or grammatical construction is associated with shorter total fixations (cf. Elgort, Brysbaert, Stevens, & Van Assche, 2017; Godfroid et al., 2017).

The Role of Frequency in Acquiring Syntactic Knowledge From Written Input

The frequency of occurrence of a hitherto unknown construction plays a key role in both contextual word learning and the acquisition of syntactic knowledge. In order to develop a rich and accurate lexical representation in incidental learning conditions, learners might need 5 to 16 repetitions of a lexical item in the input (Pellicer-Sánchez & Schmitt, 2010; Webb, 2007). Recent eye-tracking research by Elgort et al. (2017) and Godfroid et al. (2017) have also offered insights into how many exposures might be necessary for the reliable establishment of meaning representations and the elaboration of semantic information. The eye movement patterns of L2 learners in both studies indicated that the first 2 to 10 encounters with novel words embedded in a written text served to strengthen the knowledge of the form of a word, and only after 7 to 10 encounters did learners start linking the form of words with their meaning. Mohamed's (2017) study also demonstrated a gradual decrease in total reading times for unfamiliar words with up to 11 encounters, which suggests that the integration of form–meaning links in incidental vocabulary learning is a slow process. Somewhat different findings were obtained by Pellicer-Sánchez (2016), who found that form–meaning integration had already taken place after three exposures. This relatively fast rate of learning might be explained by the fact that the target words, which were all concrete nouns, occurred in supportive contexts and that repetitions were close to each other (Elgort et al., 2017).

The role of frequency of exposure to syntactic constructions in implicit instructional conditions input has been investigated in two types of studies. The first line of investigation focused on whether input flood and input flood combined with textual enhancement yield significant learning gains. Reinders and Ellis (2009) and Loewen and Inceoglu (2016) found significant effects of input flood on the learning of L2 features. In contrast, Hernández (2008), Izumi (2002, 2003), Jahan and Kormos (2015), Rassaei (2015), and Szudarski and Carter (2016) reported no significant effects on learning and no difference between participants in input flood conditions and those in a control group. Lee and Huang's (2008) meta-analysis concluded that textual enhancement has a very small-sized effect ($d = 0.22$) on the acquisition of grammatical constructions in L2 learning. Leow and Martin's (2018) recent overview showed that to date almost 80% of studies comparing textual enhancement conditions to unenhanced conditions have failed to show significant learning gains for textual enhancement. In this line of research, the number of exposures to target structures has not seemed to be related to the success of intervention. In studies where no effect of input flood was found, the number of target items varied from 13 to 60 whereas in research that observed significant effects, the range was between 4 and 30. Among eye-tracking studies of textual enhancement, Godfroid and Uggen (2013) and Winke (2013) found increased attentional processing of highlighted structures (12 and 17 examples, respectively). Similar findings were obtained in a recent study by Issa and Morgan-Short (in press), which used 30 examples of direct object pronouns in Spanish. In Loewen and Inceoglu's research, however, no increase in attentional processing was observed (28 target examples).

A small number of studies have investigated the role of frequency of exposure in a more systematic way by manipulating the number of exemplars in the input. Leow (1997) included 10 examples of a Spanish target construction in a crossword puzzle and compared learning gains from single and double exposure. He found that learners who had solved the puzzle twice learned significantly more than those who had completed the task only once. Lee (2002) analyzed differences in learning gains from texts in which a target Spanish morphological structure occurred 6, 10, and 16 times. His results indicated that for meaning recognition, 16 exposures were significantly more effective than 10 or 6 encounters. Those who had encountered the target structure 6 times performed significantly worse in form recognition than those who had read the structure 10 or 16 times. No significant exposure effects were found in a test where learners had to use the target structure productively. In a recent study, Denhovska, Serratrice, and Payne (2016) manipulated both type and token frequency of Russian morphological constructions in the input. Interestingly, their results revealed that learners in the low type (three constructions) and low token (three occurrences) frequency condition achieved the highest level of productive accuracy. The fact that fewer exemplars supported learning better than higher types (seven constructions) and tokens (seven occurrences) was most probably due to the nature of the experiment, where participants were expected to acquire eight different types of morphological endings (masculine vs. feminine in four different cases).

Exposure frequency also plays a role in explicit learning conditions. Studies of intentional vocabulary learning have shown that an increased number of repetitions results in a higher rate of retention of lexical knowledge (e.g., Webb, 2007). Although a few recent studies have examined the role of massed and distributed practice in L2 grammar learning (e.g., Rogers, 2015; Suzuki, 2017), to our knowledge, no previous research has examined the association between learning outcomes and the number of exposures to a L2 syntactic structure in a written text in intentional learning contexts. There is a limited number of studies that asked participants to pay attention to input features

(Gass, Svetics, & Lemlin, 2003; Hernández, 2008; Reinders & Ellis, 2009) and included rule explanation conditions (Radwan, 2005; Robinson, 1997; Rosa & O'Neill, 1999; Tode, 2007). All these studies, except for Reinders and Ellis, revealed significant effects of such conditions on L2 acquisition; however, large variations in exposure were also observed, ranging from 10 to 150 items.

The Current Study

As can be seen from the review of relevant literature, there are large variations in the number of exemplars of target grammatical constructions that participants have been exposed to in implicit and explicit learning conditions in previous L2 acquisition research. Moreover, no previous research in the field of L2 acquisition has used eye-tracking to investigate how cognitive processing of grammatical constructions changes with exposure. Our study fills this research gap and addresses the following research questions:

1. How does cognitive processing across experimental sessions differ in explicit and implicit instructional contexts?
2. How does cognitive processing of a target syntactic construction change across exposures?
3. How does cognitive processing of a target syntactic construction change across sessions in explicit and implicit learning conditions?
4. How are total cognitive processing times and changes in cognitive processing time over sessions related to learning gains?

Based on our previous analysis of the same data set (Indrarathne & Kormos, 2017), we hypothesized that the participants in the two explicit instruction groups would demonstrate increased cognitive processing compared to the participants in the implicit conditions. In line with our previous analysis and based on Loewen and Inceoglu's (2016) study, we expected no difference in participants' looking behavior—measured through total fixation duration (TFD)—targeting exemplars of structures across the three sessions in the implicit conditions. Because one group of participants in the explicit condition received metalinguistic explanation immediately before the second session, this group was expected to engage in more intensive cognitive processing in this session compared to the other sessions and the participants in the other three experimental conditions. As regards changes across exposures, we envisaged either no change or random fluctuations in TFD in the unenhanced condition. This prediction was based on our previous study (Indrarathne & Kormos, 2017), which found no increased attentional processing and on research by Hernández (2008), Issa and Morgan-Short (in press), Izumi (2002, 2003), Jahan and

Kormos (2015), Rassaei (2015), and Szudarski and Carter (2016), which showed no substantial learning gains in input flood conditions. TFDs of participants in the enhanced-only condition were expected to decrease linearly due to attenuation effects in attentional processing, which have been reported in previous studies in the field of cognitive psychology (e.g., Satpute et al., 2016; Yi et al., 2006). It was also hypothesized that participants in the two explicit conditions would demonstrate an S-shaped curve, suggesting an initial decline in attentional processing followed by a plateau indicative of the establishment of form–meaning associations (cf. Davis & Gaskell, 2009) and a final decline resulting from an increase in processing efficiency (cf. van der Ven et al., 2015). This hypothesis was established on the basis of recent eye-tracking studies conducted by Elgort et al. (2017), Godfroid et al. (2017), and Mohamed (2017).

We also formed hypotheses about the strength and direction of correlations between learning gains and mean TFD in each session and magnitude of change of TFD within a session, calculated using the following formula: ΔTFD (TFD change) = TFD for Exemplar 7 – TFD for Exemplar 1. Previous research indicated that long TFDs reflect high-level attentional processing (Liversedge et al., 2011; Rayner & Pollatsek, 1989). Therefore, significant positive correlations between TFD and learning gains, that is, an association between long TFD and high increase in posttest scores, signals learning through conscious attentional processes. Conversely, shorter TFD can be a sign of either automatic processing or a rapid decrease of attention across the session (cf. Elgort et al., 2017; Godfroid et al., 2017). Consequently, significant negative correlations between TFD and learning gains, that is, when low TFD values are associated with large increases in posttest score, might point to increased automaticity.

The investigation of the link between the magnitude of change in TFD within a session and learning gains helped us refine temporal dynamics of attentional processing during learning (see Table 1). We expected that strong positive correlations between TFD and learning gains, together with positive correlations with ΔTFD and learning gains, would indicate that learning primarily happens through attentional processing of form–meaning links. In this case, attention would be initially high and then decrease, which would be reflected in a large ΔTFD value. Strong correlations between ΔTFD and learning gains with potentially weak or negative correlations between total TFD would show increased processing efficiency. In this case, participants would pay a generally low level of attention to the targets, which are processed increasingly faster. However, because the participants in this study had little prior knowledge of the target construction (see Indrarathne & Kormos, 2017, and Appendix S1

Table 1 Hypotheses relating to correlations between eye-tracking measures and learning gains

TFD and learning gain	ΔTFD and learning gain	Attention decrease or increase in processing efficiency?
Strong and positive	Positive	Attention decrease
Moderate and potentially negative	Positive	Increase in processing efficiency
Moderate and positive	Strong and positive	Attention decrease and increase in processing efficiency

Note. TFD = total fixation duration; ΔTFD = magnitude of change of total fixation duration.

in the Supporting Information online), we did not expect to observe increased processing efficiency in the absence of initially high attentional processing. In cases where attention decreases at the same time as processing efficiency increases, there is a large change in TFD because both processes result in lower TFD values. The link between mean TFD and learning gains might be weak because an initially high TFD quickly drops. In our previous study, we found strong positive relationships between TFD and learning gains in all conditions except the unenhanced one. Earlier research by Godfroid et al. (2013), Godfroid and Uggen (2013), and Mohamed (2017) also showed a close link between total reading times and lexical development. This led us to assume that a decrease in TFD across sessions would primarily indicate a decrease in attentional processing.

Method

Context and Participants

The data collection took place at a public university in Sri Lanka, where the medium of instruction is English for both undergraduate and postgraduate courses. English is also taken as a credit subject by all students. The student population in this university is mostly L1 Sinhalese students, but it also includes smaller percentages of L1 Tamil speakers and foreign students. The majority of these students have received school education in their L1 and have learned English as a school subject from Grade 1 to university entrance. A total of 100 first-year students (29 females, 71 males) in a Bachelor of Commerce degree program took part in this study. According to the university entrance examination, they had either a B1 or B2 proficiency level in the Common European Framework of Reference (Council of Europe, 2001) and had been at university for 5 months when the data collection took place. All participants were L1 Sinhalese speakers. They were between 19 and 21 years of age and had learned English for at least 10 years. None spoke any other language except Sinhala and English or had experience of learning another foreign language. Among the 100 participants, 80 were assigned to one of four experimental conditions (20 each), and the remaining 20 were assigned to the control condition. All 100 participants took the pretests and posttests, but only those who were in the experimental conditions participated in the eye-tracking phase of the research.

Materials

The researchers wrote three short stories as input texts, each of which contained seven examples of the target construction, yielding 21 examples in total (all materials are publicly available in the IRIS repository at https://www.iris-database.org). The topics of the stories were: (a) New house, (b) Mary's aunt's shopping, and (c) Joe's interview. The first was about a house renovation, the second was about a girl taking her aunt shopping, and the third was about a man getting ready for an interview. The first and third stories contained 230 words each, and the second contained 227 words. The texts were checked for lexical complexity using Vocabprofile (Heatley, Nation, & Coxhead, 2002) and for readability indices using Coh-Metrix (Graesser, McNamara, Louwerse, & Cai, 2004). The three texts had very similar readability, lexical, and syntactic characteristics (see Appendix S2 in the Supporting Information online). The texts were checked for grammatical accuracy by one British and one Canadian native speaker of English.

The target structure was the causative *had* construction: *had* + (article) noun + (verb) past participle. It was assumed that the Sri Lankan language learners in this study, who were at preintermediate and intermediate levels of proficiency, would have either very little or no preexisting knowledge of this construction. The choice was also motivated by the need to create areas of interest for eye-tracking that would be easily identifiable. In addition, in order to detect measurable gains in performance during the course of the study, we focused on a construction that had a one-to-one form–meaning mapping and a meaning that could be inferred from the context. All target examples were taken from the British National Corpus (2007) to ensure that the examples were frequently used samples of the target construction, and all verbs in the target examples belonged to either the first most frequent 1,000 words (K1) or the second most frequent 1,000 words (K2) in English. The nouns in the examples were slightly altered to make them compatible with the storyline (e.g., *letters* *delivered* became *tools delivered*). Each target example contained four to eight syllables (for details, see Appendix S3 in the Supporting Information online). In order to provide a purpose for reading, each text contained four comprehension questions that the participants had to answer at the end of the text. Two of the four questions sought to assess the participants' understanding of the meaning of the target construction, and the other two measured their general comprehension of the text (see Appendix S4 in the Supporting Information online for the texts and comprehension questions and for the comprehension scores of the target construction).

The pretest and posttest included a sentence reconstruction task and a grammaticality judgment task (available in the IRIS repository at https://www.iris-database.org; see Indrarathne & Kormos, 2017, for more information). There were 20 sentence reconstruction items, including six target items. In this task, the participants were asked to reconstruct the sentences supplied, keeping their meaning the same. The first words were given as a cue. A sample sentence reconstruction item is shown in Example 1.

Example 1
Sara got someone to print invitation cards for her party.
Sara had ....

The grammaticality judgment task was aural and timed. The participants listened to a recording of 40 items, including 10 target items presented with an interval of 5 seconds between items, and they were asked to tick the relevant column depending on the accuracy of the sentences. A sample grammaticality judgment item is presented in Example 2. The length of both sentence reconstruction and grammaticality judgment items was controlled, and the British National Corpus (2007) was consulted in writing target items.

Example 2
My dad had his lunch delivered to his office yesterday. Correct/Incorrect

Procedure

The four experimental groups corresponded to the four conditions: (a) enhanced + instructions condition, (b) enhanced + instructions + explanation condition, (c) enhanced-only condition, and (d) unenhanced condition. First, the participants in all experimental conditions took as pretests the sentence reconstruction task followed by the grammaticality judgment task. On the first day of the following week, the participants, who met the first author individually, read the first text with their eye movements tracked using a Tobii X2-60 portable eye tracker attached to a laptop computer. The second and third input texts were presented with a 1-day interval between texts. Immediately after reading the third text, the posttest was administered. Figure 1 illustrates the experimental design of the study.

The enhanced + instructions group received input texts with the target items boldfaced, that is, with enhanced input (see Figure 2 for an enhanced sample slide). At the beginning of each input session, participants were also asked to pay attention to the boldfaced phrases. The enhanced + instructions + explanation group received similar input to that of the enhanced + instructions group, but they were also given an explanation of the meaning and form of the target construction in a PowerPoint presentation immediately before the second session. The examples used in this presentation were taken from Text 1. The enhanced-only group also received the texts with boldfaced items; however, these participants were not asked to pay attention to the target items. The items in the texts that the unenhanced group read were not boldfaced (see Figure 2 for an unenhanced sample slide), nor were the participants in this group asked to pay attention to any particular items in the text.

At the beginning of the first eye-tracking session, the participants were informed about the function of the eye tracker and read a trial slide. At the beginning of each eye-tracking session, a 9-point calibration was performed. The data collection took place in a quiet room and the participants sat approximately 67 centimeters away from the computer monitor. The three input texts were first prepared as PowerPoint slides, then were converted into eye-tracking slides for the Tobii software. The slides included text printed in a 24-point double-spaced Calibri font because this font has been found suitable for screen display (Erickson, 2013). The areas of interest, that is, examples of the target construction (e.g., *had the tools delivered*), were placed in one line of the text to facilitate extracting eye-tracking data for these areas (see Figure 2). Each eye-tracking slide contained four to five lines and one or more areas of interest. It was difficult to place all areas of interest in the same location on each slide because the areas of interest occurred in different parts of sentences as the storyline required. All three stories were spread over seven slides.

Before the eye-tracking sessions, the participants were informed that they could spend as much time as they needed on each slide and then go to the next one, but they were not allowed to go back to a previous slide. All participants were told that they were going to read a story on a computer monitor, after which they would have to answer four comprehension questions that would appear on the screen. In addition to these general instructions, the different

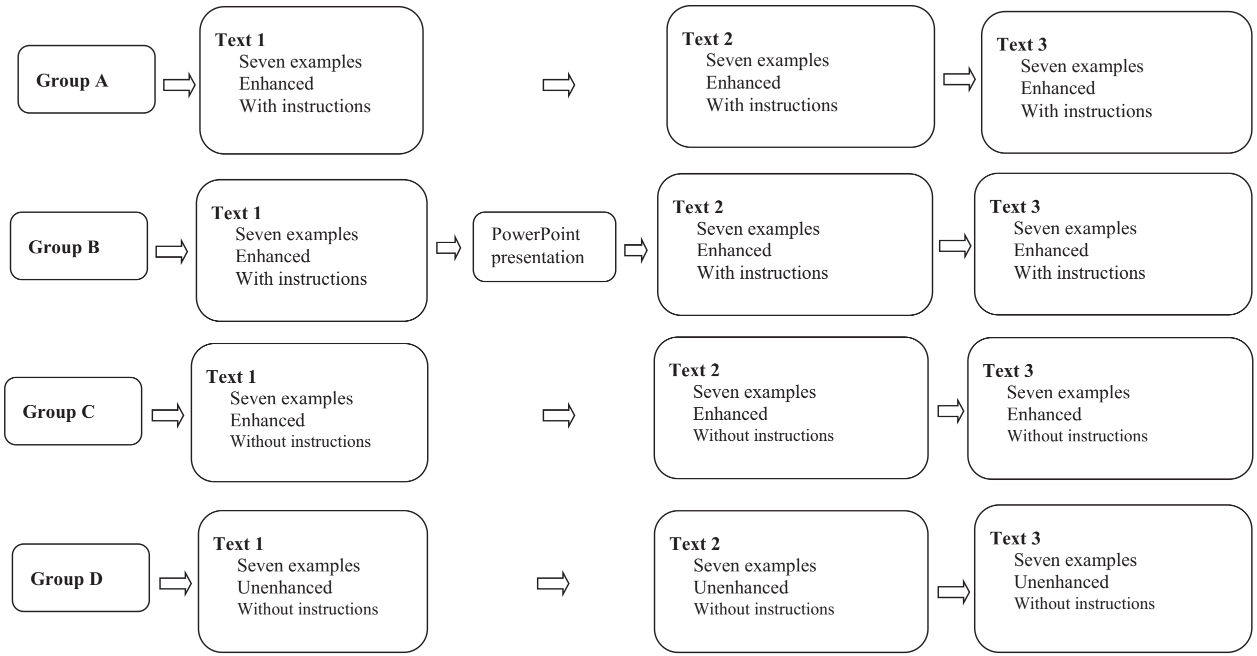

Figure 1 Experimental design.

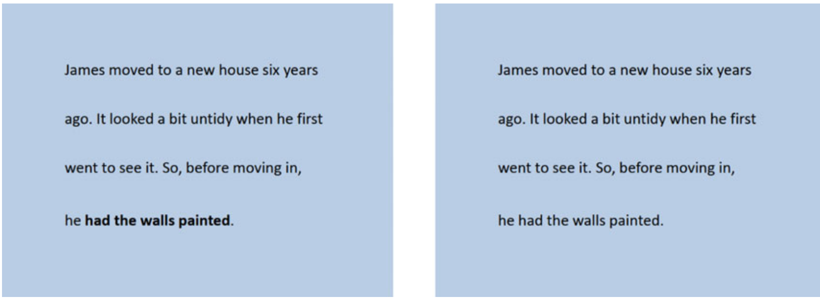

Figure 2 Example of the enhanced (left) and unenhanced (right) input slides. [Color figure can be viewed at wileyonlinelibrary.com]

experimental groups received condition-specific instructions regarding what they needed to attend to.

Data Analysis

The eye-tracking variable assessed in this study was the TFD (described previously), a commonly used measure to investigate overall cognitive processing load. For the analysis of the relationship between learning gains and eye-tracking measures (see Research Question 4), we calculated the mean TFD and the magnitude of change in TFD in each session using the formula for ΔTFD given previously. The ΔTFD and TFD values for the separate sessions were averaged and used in Spearman rank-order correlations with learning gains in the sentence reconstruction and grammaticality judgment tasks.[1] These learning gains were calculated by deducting the pretest scores from the posttest scores (see Appendix S1 for descriptive statistics).

In order to answer our first three research questions, we used growth curve analysis (Mirman, 2014) and analyzed the effects of repeated exposure to a target syntactic construction on TFDs over three reading sessions. The fixed effects included: group (enhanced + instructions, enhanced + instructions + explanation, enhanced only, and unenhanced) and session (1, 2, and 3). The unenhanced group and the first reading session were considered as the baseline. Exposure was treated as a continuous time-course variable, with each occurrence of the target construction representing one point in time. Because changes over time are often nonlinear (Mirman), in addition to linear term of exposure ($Exposure_1$), we included higher-order polynomial terms such as quadratic ($Exposure_2$) and cubic ($Exposure_3$). Following Mirman's recommendations, we orthogonalized polynomial terms to address the problem of collinearity between them. We used natural logarithm transformation to account for the positive skewness of the TFDs. Considering this, the coefficients of our model are interpreted as changes in log-transformed TFDs.

We fitted our models with random effects due to variation in the log TFDs (random intercepts) and in the slopes of fixed effects (random slopes) associated with differences between participants or the materials used (Baayen, Davidson, & Bates, 2008). This allowed us to accurately estimate the fixed effects while accounting for random variations in the log TFDs associated with the differences between participants. Consequently, we minimized the chance of Type I errors because our approach was much less likely to detect spurious significant results than analyses that do not consider random effects (Matuschek, Kliegl, Vasishth, Baayen, & Bates, 2017).

Three participants had to be excluded from the data analysis because they were found to have existing knowledge of the target condition in the sentence reconstruction task on the pretest, that is, they scored 2 or above on this test. The data set also contained several missing responses. Unfortunately, in each testing session, some data had to be omitted because participants' eye fixations went beyond the screen for a considerable amount of time. Overall, we analyzed 1,309 observations out of the possible 1,617 data points—77 participants reading three texts with seven target constructions per text. This represents approximately 80% of the originally collected eye-tracking data relevant to the target constructions. The lmer function in the lme4 package (Bates, Maechler, Bolker, & Walker, 2015) in R (R Core Team, 2016) was used for the statistical analyses. We tested whether the addition of fixed effects and interactions improved the model fit with pairwise likelihood ratio test comparisons of simpler models with more complex models (Baayen, 2008). We summarize the results of the likelihood ratio test comparisons, but we report the estimates of the final model only.

A series of models had been tested. We started with a minimal model containing just the random effects of participants on intercepts and then progressively increasing the model complexity by adding fixed effects, polynomial terms of exposure ($Exposure_1$, $Exposure_2$, $Exposure_3$) and interaction terms. The minimal model (Model 1) was compared to a model with the effects of: $Exposure_1$, group, and session (Model 2). The likelihood ratio test revealed that the additional complexity of the model was justified. Model 2 provided a better fit to the data than Model 1, $\chi^2(6) = 225.27$, $p < .001$. Next, we included all the polynomial terms of exposure to improve the model fit. The model with $Exposure_1$ and $Exposure_2$ (Model 2i) had a significantly better fit to the data than the model without $Exposure_2$, $\chi^2(1) = 9.42$, $p < .01$, and the model with Exposure_1, Exposure_2, and Exposure_3 (Model 2ii) offered a better fit than the model with Exposure_2 and Exposure_1 only, $\chi^2(1) = 14.85$, $p < .001$. The quartic polynomial term of exposure (Exposure_4) did not improve the fit further, $\chi^2(1) = 1.60$, $p = .21$, thus we removed it from the model.

To investigate the explanatory value of interaction terms, we compared Model 2ii to a model that added $\text{Exposure}_{1,\,2,\,\text{and}\,3} \times$ Group; $\text{Exposure}_{1,\,2,\,\text{and}\,3} \times$ Session; and Group $\times$ Session interactions (Model 3). We found that Model 3 was a better fit to the data than Model 2ii, $\chi^2(20) = 126.52$, $p < .001$. Thus, the inclusion of two-way interactions was justified. Following this, we compared Model 3 to a model with added $\text{Exposure}_{1,\,2,\,\text{and}\,3} \times$ Group $\times$ Session interactions (Model 4). Once again, increasing the model complexity further improved the model fit, and Model 4 was significantly closer in approximating to reality than Model 3, $\chi^2(18) = 59.60$, $p < .001$.

Following the recommendations of Bates, Kliegl, Vasishth, and Baayen (2015) for creating a parsimonious model supported by the data, we established the utility of random effects in our model. First, as suggested by Mirman (2014), we tried to nest the participants within the four different experimental groups. However, this led to convergence problems, so consequently, we did not nest participants within the four groups. Next, we determined whether the inclusion of random slopes, that is, random differences between participants in the slopes of fixed effects, improved the model fit to the data. This approach was motivated by the wish to provide stringent tests for the significance of main effects and interactions, allowing us to balance Type I error rate and power (Matuschek et al., 2017). We used pairwise likelihood ratio test comparisons to examine whether the goodness of fit of the model was improved after the addition of terms corresponding to random effects of participants on the slopes of fixed effects. Treating the difference between groups as a random slope did not resolve this problem because, even with this more flexible random effect structure, the model did not converge (Mirman). We found that the inclusion of random effects of participants on the slopes of session significantly improved the goodness of fit of Model 4, $\chi^2(5) = 67.92$, $p < .001$. Moreover, the addition of random effects of participants on the slopes of Exposure_1, Exposure_2, and Exposure_3 also improved the goodness of fit, $\chi^2(15) = 26.83$, $p < .05$. We report a summary of the final model in Table 2 and show the code used to fit the final model below.

$$\text{logTFD} \sim (\text{Exposure}_1 + \text{Exposure}_2 + \text{Exposure}_3) * \text{Group} * \text{Session}$$
$$+ (\text{Session} + \text{Exposure}_1 + \text{Exposure}_2 + \text{Exposure}_3 + 1|\text{Participants})$$

Table 2 Summary of the final statistical model with unenhanced group as the reference level

Parameter	Estimate	*SE*	*t*
Fixed effects			
Intercept	−0.28	0.12	−2.26*
$Exposure_1$	−0.45	0.16	−2.86**
$Exposure_2$	−0.11	0.16	−0.65
$Exposure_3$	−0.05	0.15	−0.36
Enhanced instructions	0.99	0.16	6.14***
Enhance + instructions + explanation	0.97	0.16	6.06***
Enhanced only	0.40	0.16	2.40*
Session 2	−0.13	0.12	−1.04
Session 3	−0.22	0.15	−1.51
$Exposure_1$ × Enhanced + instructions	−0.25	0.20	−1.25
$Exposure_1$ × Enhanced + instructions + explanation	−0.34	0.20	−1.69
$Exposure_1$ × Enhanced only	0.10	0.21	0.50
$Exposure_2$ × Enhanced + instructions	0.33	0.21	1.56
$Exposure_2$ × Enhanced + instructions + explanations	0.13	0.21	0.62
$Exposure_2$ × Enhanced only	0.10	0.21	0.48
$Exposure_3$ × Enhanced + instructions	0.06	0.20	0.28
$Exposure_3$ × Enhanced + instructions + explanations	−0.21	0.19	−1.10
$Exposure_3$ × Enhanced only	−0.07	0.20	−0.37
$Exposure_1$ × Session 2	0.22	0.20	1.08
$Exposure_1$ × Session 3	0.43	0.19	2.22*
$Exposure_2$ × Session 2	0.72	0.20	3.53***
$Exposure_2$ × Session 3	0.09	0.19	0.48
$Exposure_3$ × Session 2	−0.17	0.20	−0.87
$Exposure_3$ × Session 3	−0.58	0.19	−2.98**
Enhanced + instructions × Session 2	0.08	0.16	0.49
Enhanced + instructions + explanations × Session 2	0.49	0.16	3.17**
Enhanced × Session 2	0.37	0.16	2.29*
Enhanced + instructions × Session 3	−0.15	0.21	−0.73
Enhanced + instructions + explanations × Session 3	0.33	0.20	1.64
Enhanced × Session 3	0.42	0.20	2.09*
$Exposure_1$ × Enhanced + instructions × Session 2	−0.45	0.27	−1.67
$Exposure_1$ × Enhanced + instructions + explanations × Session 2	−0.02	0.27	−0.06
$Exposure_1$ × Enhanced only × Session 2	0.01	0.27	0.03

(*Continued*)

Table 2 Continued

Parameter	Estimate	SE	t
$Exposure_1$ × Enhanced + instructions × Session 3	−1.32	0.28	−4.78***
$Exposure_1$ × Enhanced + instructions + explanations × Session 3	−0.40	0.26	−1.51
$Exposure_1$ × Enhanced only × Session 3	−0.05	0.27	−0.18
$Exposure_2$ × Enhanced + instructions × Session 2	−0.91	0.27	−3.36***
$Exposure_2$ × Enhanced + instructions + explanations × Session 2	−0.44	0.27	−1.66
$Exposure_2$ × Enhanced only × Session 2	−0.76	0.27	−2.76**
$Exposure_2$ × Enhanced + instructions × Session 3	−0.48	0.28	−1.73
$Exposure_2$ × Enhanced + instructions + explanations × Session 3	0.19	0.26	0.72
$Exposure_2$ × Enhanced only × Session 3	0.30	0.27	1.11
$Exposure_3$ × Enhanced + instructions × Session 2	0.17	0.27	0.63
$Exposure_3$ × Enhanced + instructions + explanations × Session 2	0.31	0.26	1.19
$Exposure_3$ × Enhanced only × Session 2	0.37	0.27	1.37
$Exposure_3$ × Enhanced + instructions × Session 3	0.04	0.28	0.14
$Exposure_3$ × Enhanced + instructions + explanations × Session 3	0.81	0.26	3.10**
$Exposure_3$ × Enhanced only × Session 3	0.52	0.27	1.95

Random effects (intercept)	Random slopes	Variance	SD
Participants		0.16	0.40
	Session 2	0.09	0.31
	Session 3	0.22	0.47
	$Exposure_1$	0.04	0.19
	$Exposure_2$	0.06	0.25
	$Exposure_3$	0.02	0.14

Information criteria	Estimate
Log-Likelihood	−1106.60
Defiance information criterion	2213.30
Akaike information criterion	2353.30
Bayesian information criterion	2715.70

(*Continued*)

Table 2 Continued

R^2	Estimate
Marginal[a]	.43
Conditional[b]	.64

Notes. Exposure_1 = the linear term of exposure; Exposure_2 = the quadratic term of exposure; Exposure_3 = the cubic term of exposure. [a]Marginal R^2 describes the proportion of variance explained by the fixed factors alone. [b]Conditional R^2 describes the proportion of variance explained by both the fixed and random factors. $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$.

Results

Differences in Eye-Tracking Measures Across Groups and Sessions

In our first research question, we asked how the cognitive processing of a target syntactic construction differs in explicit and implicit instructional conditions and across experimental sessions. We adjusted the p value for multiple comparisons using the single-step method, in which p values are computed from the joint normal or t distribution of the linear function. Using these adjustments, we found several differences in TFD between groups and across sessions. In every session, participants in both explicit groups fixated for significantly longer on target constructions than did those in the unenhanced group (see Table 3). In the same way, across all sessions, those in the enhanced + instructions + explanation group looked at the target constructions significantly longer than those in the enhanced-only group. In contrast, only in Session 1 did participants in the enhanced + instructions group fixate for significantly longer on target constructions than those in the enhanced-only group. In the remaining two sessions, there were no significant differences between these two groups. In Sessions 2 and 3 in the two implicit groups, participants in the enhanced-only group fixated for longer on the target constructions than participants in the unenhanced group. However, there were no significant differences between unenhanced and enhanced-only groups in Session 1.

Looking at the Group × Session interactions, we found that the effects of session varied across groups (see Table 4). Participants in the enhanced + instructions + explanation group fixated for longer in Session 2 compared to Sessions 1 and 3. In contrast, participants in the enhanced + instructions group fixated for a shorter time on target constructions in Session 3 than in Sessions 1 and 2. There were no significant differences between sessions in the two implicit groups.

Table 3 Multiple comparisons of groups within sessions

Comparison	Estimate	*SE*	*z*
Session 1			
Enhanced + instructions + explanations vs. Unenhanced	0.97	0.16	6.06***
Enhanced + instructions vs. Unenhanced	0.99	0.16	6.14***
Enhanced only vs. Unenhanced	0.40	0.16	2.40
Enhanced only vs. Enhanced + instructions + explanations	−0.57	0.15	−3.85***
Enhanced only vs. Enhanced + instructions	−0.59	0.15	−3.95***
Enhanced + instructions + explanations vs. Enhanced + instructions	−0.02	0.14	−0.15
Session 2			
Enhanced +instructions + explanations vs. Unenhanced	1.46	0.12	11.81***
Enhanced + instructions vs. Unenhanced	1.07	0.13	8.53***
Enhanced only vs. Unenhanced	0.76	0.13	6.08***
Enhanced only vs. Enhanced + instructions + explanations	−0.70	0.12	−5.83***
Enhanced only vs. Enhanced + instructions	−0.31	0.12	−2.51
Enhanced + instructions + explanations vs. Enhanced + instructions	0.39	0.12	3.29**
Session 3			
Enhanced + instructions + explanations vs. Unenhanced	1.29	0.15	8.53***
Enhanced + instructions vs. Unenhanced	0.84	0.16	5.13***
Enhanced only vs. Unenhanced	0.81	0.15	5.46***
Enhanced only vs. Enhanced + instructions + explanations	−0.48	0.15	−3.13**
Enhanced only vs. Enhanced + instructions	−0.02	0.16	−0.14
Enhanced + instructions + explanations vs. Enhanced + instructions	0.46	0.17	2.74*

*$p < .05$; **$p < .01$; ***$p < .001$.

Change in Cognitive Processing Across Exposures

Averaged across groups and sessions, we found a nonlinear decrease in log TFDs (Figure 3). This decrease followed an S-shaped pattern, where at first there was a steep initial decrease in fixation durations, followed by a plateau, and then a further, more gradual decrease. However, the three-way interactions

Table 4 Multiple comparisons: Sessions within groups

Comparison	Estimate	*SE*	*z*
Enhanced + instructions + explanations			
Session 2 vs. Session 1	0.37	0.10	3.74***
Session 3 vs. Session 1	0.10	0.13	0.78
Session 3 vs. Session 2	−0.26	0.11	−2.39*
Enhanced + instructions:			
Session 2 vs. Session 1	−0.05	0.10	−0.47
Session 3 vs. Session 1	−0.37	0.15	−2.51*
Session 3 vs. Session 2	−0.32	0.13	−2.57*
Enhanced only			
Session 2 vs. Session 1	0.24	0.10	2.30
Session 3 vs. Session 1	0.20	0.14	1.45
Session 3 vs. Session 2	−0.04	0.11	−0.38
Unenhanced			
Session 2 vs. Session 1	−0.13	0.12	−1.04
Session 3 vs. Session 1	−0.22	0.15	−1.51
Session 3 vs. Session 2	−0.10	0.11	−0.86

$^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$.

of $\text{Exposure}_{1, 2, \text{and}, 3}$ × Group × Session (see Table 5) illustrate that the rate of change in log TFDs varied by group and session. Figure 4 and Table 5 show a difference in systematicity between the explicit and implicit groups.

For the two explicit groups, the rate of change in log TFDs across exposure followed a significant linear decrease in all but one session (Table 5). The exception was a significant S-shaped (i.e., cubic) decrease in log TFDs across exposures for participants in the enhanced + instructions group in Session 3. We found that for this group in this session, the reduction in log TFDs was steep at the beginning, then the rate of decrease slowed down, and finally it became steeper again. For the two implicit groups, the rate of change was less systematic. For participants in the enhanced-only group, the rate of change was a significant linear decrease in Session 1, followed by no significant change in Session 2, followed by a U-shaped pattern (i.e., quadratic) in Session 3. In Session 3, participants' log TFDs decreased until the fourth exposure, and from the fifth exposure onward their log TFDs started to increase. The participants in the unenhanced group displayed a significant linear decrease in log TFDs across exposures in Session 1, followed by a U-shaped decrease in Session 2, and an S-shaped pattern in Session 3.

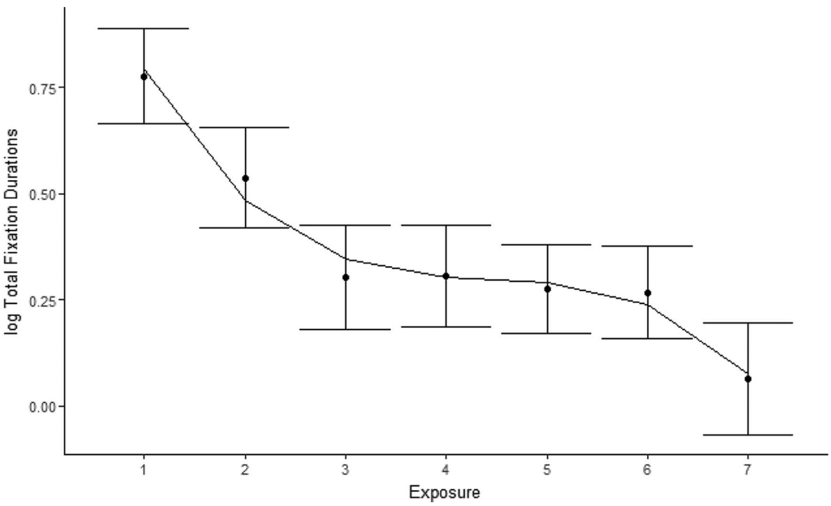

Figure 3 The effects of exposure on total fixation durations averaged across groups and sessions. Error bars represent 95% confidence intervals.

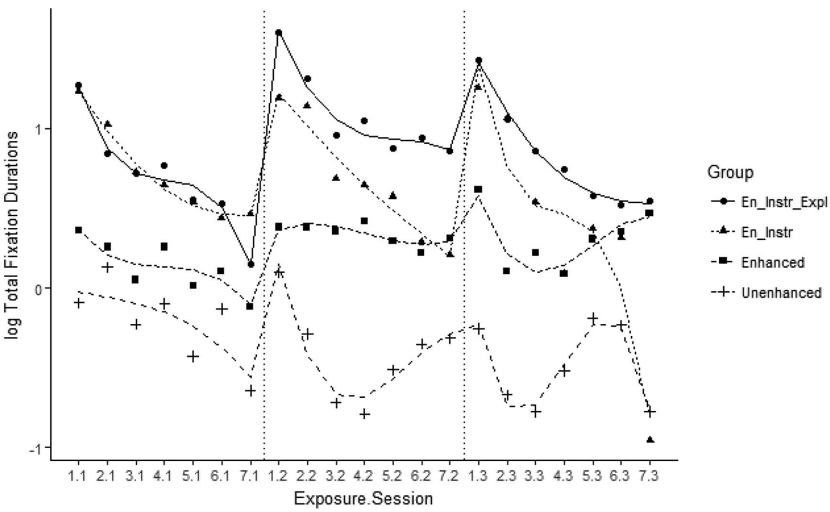

Figure 4 The effects of exposure on total fixation durations by group and session. The line fits are model predictions, derived from the growth curve model. En_Instr_Expl = Enhanced + instructions + explanations group; En_Instr = Enhanced + instructions group; Enhanced = Enhanced-only group; Unenhanced = Unenhanced group

Table 5 Multiple comparisons: Interactions of exposure, group, and session

Comparison	Estimate	*SE*	*z*
Enhanced + instructions + explanations			
$Exposure_1$ × Enhanced + instructions + explanations × Session 1	−0.78	0.13	−6.27***
$Exposure_1$ × Enhanced + instructions + explanations × Session 2	−0.58	0.13	−4.41***
$Exposure_1$ × Enhanced + instructions + explanations × Session 3	−0.75	0.14	−5.37***
$Exposure_2$ × Enhanced + instructions + explanations × Session 1	0.02	0.13	0.19
$Exposure_2$ × Enhanced + instructions + explanations × Session 2	0.30	0.14	2.20
$Exposure_2$ × Enhanced + instructions + explanations × Session 3	0.31	0.15	2.13
$Exposure_3$ × Enhanced + instructions + explanations × Session 1	−0.27	0.12	−2.20
$Exposure_3$ × Enhanced + instructions + explanations × Session 2	−0.13	0.13	−1.00
$Exposure_3$ × Enhanced + instructions + explanations × Session 3	−0.03	0.14	−0.23
Enhanced + instructions			
$Exposure_1$ × Enhanced + instructions × Session 1	−0.70	0.13	−5.45***
$Exposure_1$ × Enhanced + instructions × Session 2	−0.93	0.14	−6.83***
$Exposure_1$ × Enhanced + instructions × Session 3	−1.59	0.16	−9.79***
$Exposure_2$ × Enhanced + instructions × Session 1	0.22	0.13	1.67
$Exposure_2$ × Enhanced + instructions × Session 2	0.03	0.14	0.24
$Exposure_2$ × Enhanced + instructions × Session 3	−0.17	0.17	−0.98
$Exposure_3$ × Enhanced + instructions × Session 1	0.001	0.12	0.01
$Exposure_3$ × Enhanced + instructions × Session 2	−0.01	0.13	−0.04
$Exposure_3$ × Enhanced + instructions × Session 3	−0.54	0.16	−3.39**
Enhanced only			
$Exposure_1$ × Enhanced only × Session 1	−0.34	0.14	−2.52*
$Exposure_1$ × Enhanced only × Session 2	−0.12	0.14	−0.85
$Exposure_1$ × Enhanced only × Session 3	0.04	0.14	0.28
$Exposure_2$ × Enhanced only × Session 1	−0.003	0.14	−0.02
$Exposure_2$ × Enhanced only × Session 2	−0.04	0.14	−0.27
$Exposure_2$ × Enhanced only × Session 3	0.39	0.14	2.76*
$Exposure_3$ × Enhanced only × Session 1	−0.13	0.13	−0.97

(*Continued*)

Table 5 Continued

Comparison	Estimate	*SE*	*z*
$Exposure_3$ × Enhanced only × Session 2	0.07	0.13	0.53
$Exposure_3$ × Enhanced only × Session 3	−0.19	0.13	−1.42
Unenhanced			
$Exposure_1$ × Unenhanced × Session 1	−0.45	0.16	−2.86*
$Exposure_1$ × Unenhanced × Session 2	−0.23	0.15	−1.56
$Exposure_1$ × Unenhanced × Session 3	−0.02	0.13	−0.12
$Exposure_2$ × Unenhanced × Session 1	−0.11	0.16	−0.65
$Exposure_2$ × Unenhanced × Session 2	0.62	0.15	4.10***
$Exposure_2$ × Unenhanced × Session 3	−0.01	0.14	−0.08
$Exposure_3$ × Unenhanced × Session 1	−0.05	0.15	−0.36
$Exposure_3$ × Unenhanced × Session 2	−0.23	0.14	−1.63
$Exposure_3$ × Unenhanced × Session 3	−0.63	0.13	−4.92***

Note. $Exposure_1$ = the linear term of exposure; $Exposure_2$ = the quadratic term of exposure; $Exposure_3$ = the cubic term of exposure. $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$.

Relationship Between Eye-Tracking Measures and Learning Gains

Table 6 shows that the mean TFD value across sessions correlated significantly with the gains in the sentence reconstruction task in all experimental groups, except in the unenhanced condition.[2] Improvement in grammaticality judgment scores was significantly associated with the mean TFD values in the enhanced + instructions + explanation group and in the enhanced group. The mean ΔTFD across sessions showed significant correlations with sentence reconstruction and grammaticality judgment gains only in the enhanced + instructions group.

Discussion

Differences in Cognitive Processing Across Groups and Sessions

Our first research question asked how cognitive processing across experimental sessions differs in explicit and implicit instructional conditions. The results pertaining to differences in TFDs among experimental conditions in each session separately are only partly in line with our initial hypotheses and do not fully corroborate the findings of our previous analyses that considered the three sessions jointly (Indrarathne & Kormos, 2017). The results for Session 1, which replicated our earlier findings, show that both groups who received an explicit instruction to pay attention to a grammatical construction embedded in the text demonstrated significantly higher TFD values than did the groups in the implicit

Table 6 Correlations between sentence reconstruction (SR) and grammaticality judgment (GJ) learning gains and mean total fixation duration (TDF) and mean magnitude of change of total fixation duration (ΔTFD) across sessions

Group (*n*)	Eye-tracking *M*	SR gain *rho*	GJ gain *rho*	Psycholinguistic process
Enhanced + instructions + explanations (14)	TFD	.793***	.761***	Attention decrease and establishment
	ΔTFD	.521	.530	of form-meaning links
Enhanced + instructions (10)	TFD	.583*	.281	Attention decrease and increase in
	ΔTFD	.647*	.798***	processing efficiency
Enhanced only (11)	TFD	.612*	.654*	Attention decrease and establishment
	ΔTFD	−.256	−.040	of form-meaning links
Unenhanced (10)	TFD	−.242	−.272	Minimal attentional processing
	ΔTFD	.316	.077	

*$p < .05$; ***$p < .001$.

conditions. This yields evidence for the important role of explicit instructional conditions in drawing attention to a target grammatical construction in written input (see also Indrarathne & Kormos, 2017). The lack of any significant difference between the enhanced and unenhanced conditions in Session 1 is similar to the results of Loewen and Inceoglu (2016), who did not find increased attentional processing when exemplars were visually enhanced. Additional evidence that textual enhancement might have had benefits for the participants can also be seen in the comparisons of the enhanced-only and unenhanced groups in Sessions 2 and 3. Similar to the findings of Godfroid and Uggen (2013), Winke (2013), and Issa and Morgan-Short (in press), the results show that in these sessions the enhanced-only group fixated on the target constructions significantly longer than the unenhanced group. Based on these results, we can draw the tentative conclusion that the effects of visual enhancement might take longer to manifest themselves and might not be strong enough to be detected in the first exposure session or in the first few exemplars.

As regards the two-way interactions between experimental condition and session, our results provide support for our initial hypothesis and point to the beneficial effects of the explicit explanation in the enhanced + instructions + explanation group between Sessions 1 and 2. The results show that the enhanced + instructions + explanation group fixated longer on exemplars in Session 2 than in Sessions 1 and 3. This increased eye-fixation measure suggests that participants in this group might have engaged in a deeper level of cognitive processing while reading Text 2. This might have involved "cognitive effort, level of analysis, elaboration of intake together with the usage of prior knowledge, hypothesis testing and rule formation" (Leow, 2015, p. 204). There was no difference, however, between the TFDs in Sessions 1 and 3, which suggests that the effect of the explanation on attention may dissipate when learners encounter the target construction later. However, some kind of carryover effect can be seen because the enhanced + instructions + explanation group had higher TFD than the enhanced + instructions group in Session 3. This contrasts with the results of the enhanced + instructions group, where participants fixated on exemplars in Session 3 for a shorter time than in Sessions 1 and 2.

Changes in Cognitive Processing and Relationship to Learning Gains

Our second research question asked how the cognitive processing of the target syntactic construction changes across exposures. The growth curve for the total sample and for all three sessions combined revealed an S-shaped pattern. This pattern seems to align with conclusions from L1 and L2 vocabulary research (e.g., Davis & Gaskell, 2009; Pellicer-Sánchez, 2016; van der Ven et al., 2015) and L2 syntax research (Denhovska et al., 2016) as well as with the associative cognitive model of L2 learning (Ellis, 2006), which has shown that there is a period of stabilization after a relatively short period of intensive cognitive processing when a memory trace of the item is created following a familiarity check. During this period, a form–meaning link is established by extracting regularities and fine tuning frequency-based associations. The fact that the curve became flatter after the third exposure resembles the results of Pellicer-Sánchez's vocabulary study, which was similar to our research in that nonwords also occurred in supportive contexts and were embedded in relatively short texts. The contextual word-learning studies in more naturalistic contexts by Godfroid et al. (2017) and Elgort et al. (2017) detected a flattening curve at much later points and indicated the need for a higher number of exposures than does Pellicer-Sánchez's and our research.

We examined the growth curve for the separate groups in order to answer our third research question, which addressed the possible changes in cognitive processing of a target syntactic construction across sessions in explicit and implicit learning conditions. The analyses revealed a complex interaction between changes in processing efficiency and attention decrease. First, the results show that the decrease in TFD in Session 1 was linear for all groups. Significant linear reductions in TFD might be explained with reference to the process of habituation rather than by increases in processing efficiency, which usually follow an S-shaped curve (for a recent discussion, see Murre, 2014). As the novelty of the target construction decreases, less attention is paid to it (Turk-Browne, Scholl, & Chun, 2008). The gradual linear decrease up to seventh exposure also indicates that subsequent presentations of stimuli were still within the focus of attention because participants perceived that it contained some new information for further processing. This result is similar to that reported by Müller et al. (2013) in the field of cognitive psychology, which showed that the response to a stimulus only decreases after the sixth presentation occasion. The linear decrease in Session 1 is also in line with the research of Elgort et al. (2017) and Godfroid (2017), in which a speed-up in processing only took place between 6 and 10 exposures.

To obtain an answer to our fourth research question, the growth curve analysis was complemented by the results pertaining to the links between learning gains and TFD and ΔTFD across groups. Our results suggest minimal attentional processing and no improvement in processing efficiency of the target construction in the unenhanced group. The shape of the growth curves changed in each session and no association between eye-tracking measures and learning gains was observed. The unenhanced group seemed to be engaged in little cognitive processing other than decoding the form of the target exemplars.

In the enhanced-only group, the patterns of change in TFD showed somewhat more systematicity, but fixation durations remained short and learning gains only appeared in the grammaticality judgment task, which required the recognition of accurate target items under time constraints. There is a strong link, however, between TFD and learning gains in both tasks, and a stable speed of cognitive processing was observed in Session 2. By complementing these results with the negative correlation between ΔTFD and grammaticality judgment gain scores in Session 2, $rho = -.538$; $p = .03$, one can argue that those participants who were able to maintain their cognitive processing efforts in Session 2, when seeing visually enhanced exemplars, improved their recognition knowledge more than those who paid less attention to these exemplars. The U-shaped curve in Session 3 might indicate that participants recognized the form of the construction relatively quickly at the beginning of the session, and by the end they might have started to engage in establishing and fine tuning form–meaning links. Although this is a tentative conclusion that would need to be followed up with further observations, this explanation seems similar to the interpretation of the patterns seen in Elgort et al.'s (2017) study. In Elgort et al.'s research, their participants encountered nonwords embedded in a text, which might have raised their attentional processing due to the unexpected nature of the nonwords, just as textual enhancement might have directed our participants' attention to unfamiliar target items. Elgort et al.'s results, like ours, suggest that integrating meaning with context might only commence after 10 exposures and last well beyond 20 encounters.

The growth curves of the enhanced + instructions group were linear in Sessions 1 and 2, but in Session 3 an S-shaped pattern appeared. It is interesting to note the very sharp decrease in TFDs for the last three exemplars. Also noteworthy is the fact that members of this group spent as much time processing the last exemplar as those in the unenhanced group. This suggests that by the end of the experiment the participants in this group increased their processing efficiency. They strengthened the form–meaning representations of the target structure to the extent that their eye fixation durations were equivalent to the time needed for decoding the form of the construction in the unenhanced condition. The pattern of correlations between the learning gains and the TFD and ΔTFD values (see Table 6) as well as the fact that there were significant learning effects in both tasks—grammaticality judgment task, $t(19) = 4.34$, $p < .001$, and sentence reconstruction task, post hoc Bonferroni test $p = .018$ (for more details, see Indrarathne & Kormos, 2017)—suggests that the S-shaped curve in the last session represents not only an attenuation of attention but an observable increase in processing efficiency. The number of exposures after which this high level of processing efficiency seems to be achieved bears very close resemblance to the findings of Godfroid et al.'s (2017) study, where they also detected a sudden drop in TFD between Exemplars 16 and 23.

In the case of the enhanced + instructions + explanation group, we found only linear patterns of decrease. Each session was characterized by an initial high level of attention, with Session 2 demonstrating an even more elevated TFD due to the explicit metalinguistic explanation. The analysis of the links between learning gains and TFD and ΔTFD values also suggests that the change in TFD across exposure was primarily a reflection of the attenuation of attention and participants' conscious efforts to establish form–meaning links. Although the gains in both tasks were similar in the enhanced + instructions + explanation and enhanced + instructions conditions (see Indrarathne & Kormos, 2017), the metalinguistic explanation did not result in a sudden increase in the level of processing efficiency that we observed in the enhanced + instructions condition. A possible reason for this might be that, because there was a one-to-one form–meaning mapping in the target construction, the rule search condition and visual enhancement might have been sufficient to assist participants, and the relatively short explicit metalinguistic information might have facilitated processing only in Session 2 (cf. VanPatten, Collopy, & Qualin, 2012).

Implications for Theory and Practice

In our study, we examined changes in how L2 learners process target grammatical exemplars in written L2 input in implicit and explicit instructional conditions and how these changes relate to learning gains. We proposed a system for drawing tentative conclusions concerning cognitive processing based on eye-tracking measures and the association between learning gains and changes in fixation durations across exposures. We suggested that joint information about mean fixation duration and the rate of change in fixation duration over exposures in relation to learning gains might reveal whether L2 learners' attentional processing decreases and/or their processing efficiency increases. Our theoretical assumptions were borne out by the data, but further research is required to confirm the validity of this framework. From a theoretical perspective, our study lends support to associative cognitive models of language learning (e.g., Ellis, 2006) and highlights the similarities between learning lexical and syntactic constructions through exposure to written input.

The results of our study indicate that increased cognitive processing of visually enhanced examples of a target structure might take place only after encountering a few exemplars or after initial exposure to a short text. Therefore, when studying the effects of textual enhancement, it is important to examine the patterns of change in eye-tracking measures across exemplars and sessions and not only to consider averaged values during the whole experiment. The findings also provide evidence for the benefits of explicit metalinguistic information such as that which we provided before Session 2 for increased attentional processing. It is important to note, however, that only the participants in the guided discovery condition, that is, those in the enhanced + instructions group, demonstrated an S-shaped curve of development, which is indicative of change in processing efficiency. Although this potential difference in cognitive processing between the two explicit learning conditions did not manifest itself in differences in immediate learning gains, it would be worth exploring the long-term benefits of guided discovery and explicit metalinguistic explanations with delayed posttests.

From a pedagogical perspective, our research is important because it suggests that subsequent input sessions within a few days, with a different reading text, and different exemplars of the target structure, can sustain learners' attention if learners receive some scaffolding either in the form of textual enhancement or through guided discovery. This finding also lends support to studies demonstrating the usefulness of distributed practice (e.g., Rogers, 2015). Our study reveals that while 21 exposures divided into three sessions over a week might be sufficient for participants in explicit learning conditions to establish form–meaning links and to speed up the processing of these links, they need further opportunities for practice and feedback to develop strong representations of grammatical constructions and to be able to use them efficiently. The number of exemplars and the distributed input we provided in the unenhanced condition seemed to engage participants in decoding the form of the structure only and did not assist them in establishing form–meaning links. Textual enhancement was found to help participants maintain their attention after an initial exposure and to lead them to establish some preliminary form–meaning representations. However, these participants would have needed either more exposure or additional guidance to fully understand these form–meaning links.

An important limitation of our study is that we lost some data because participants' eye-movements were not accurately recorded. Therefore, future research with more sensitive eye-tracking tools and a larger number of participants coming from different L1 backgrounds would need to be conducted to confirm our findings. Previous studies in the field of cognitive psychology have shown that the complexity of the stimulus plays an important role in influencing a decrease in attention (Mather, 2013). Consequently, it is important to replicate our study with different syntactic constructions. In our study, we repeatedly presented the target construction with different verbs and nouns to the participants. In further studies, it would also be necessary to examine how the cognitive processing of the same token of the target construction changes through exposures and whether type and token frequency exert different influences on eye-tracking measures and on learning outcomes. In our study, the order of experimental sessions was not counterbalanced. Although we ensured that the input texts had highly similar readability statistics and linguistic characteristics, a replication study where the order of sessions is controlled is also desirable.

Conclusion

In summary, our findings lend support to the assumption that the establishment of form–meaning links in the acquisition of L2 syntactic constructions shares a number of similarities with how L2 vocabulary knowledge develops through exposure to written input (e.g., Davis & Gaskell, 2009; Pellicer-Sánchez, 2016; van der Ven et al., 2015). The observed S-shaped pattern of the growth curve suggests that when L2 learners first encounter a novel syntactic construction in a reading text, they actively engage in decoding the form and start analyzing its meaning. During the second and third exposures learners make attempts at fine tuning the form–meaning links (Bolger et al., 2008) and extracting patterns of regularities (Tomasello, 2008). Following this, in line with the associative cognitive models of L2 learning (Ellis, 2006), the flattening shape of the curve indicates that on further encounters L2 learners strengthen the form–meaning associations and accelerate the speed with which they recognize the target construction. Nevertheless, the development of the productive and receptive knowledge of the target syntactic construction seems to be a slow process similar to the process of incidental vocabulary learning. As our research indicates, after 21 exposures, even participants in the explicit instructional conditions achieved relatively modest learning gains (see Appendix S1; cf. Indrarathne & Kormos, 2017). This underscores the need for providing L2 learners not only with input but also with meaningful output and interaction opportunities to apply novel syntactic constructions, to gain feedback, and ultimately to develop automaticity in using these constructions.

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Notes

1 It would have been interesting to investigate the associations between ΔTFD, TFD, and learning gains separately for the three sessions across experimental groups. However, this would have resulted in a large number of correlational analyses. Because our sample size for these analyses was relatively low, it could have substantially increased the chances of a Type I error.

2 Group sizes in these analyses are much smaller than the group sizes in the analyses reported earlier because of data loss in the eye-tracking study. For these analyses, we only considered participants for whom reliable eye-tracking data were available for each of the three sessions.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's website:

Appendix S1. Descriptive Statistics for the Sentence Reconstruction, Grammaticality Judgement, and Comprehension Tests.
Appendix S2. Input Text Characteristics.
Appendix S3. Number of Syllables and Frequency for Target Examples in the British National Corpus.
Appendix S4. Input Texts.