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**'Bread and butter' or 'butter and bread'? Non-natives' processing of novel lexical patterns in context**

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The authors declare none

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**Abstract**

Little is known about how non-native speakers process novel language patterns in the input they encounter. The present study examines whether non-natives develop a sensitivity to novel binomials and their ordering preference from context. Thirty-nine non-native speakers of English (L1 Arabic) read three short stories seeded with existing binomials (*black and white*) and novel ones (*bags and coats*) while their eye movements were monitored. The existing binomials appeared once in their forward (conventional) form and once in their reversed form. The novel binomials appeared in their experimentally defined forward form in different frequency conditions (two vs. four encounters) and once in the reversed form. Results showed no advantage for existing binomials over their reversed forms. For the novel binomials, the non-native speakers read subsequent encounters significantly faster than initial ones for both frequency conditions. More importantly, the final reversed form also led to faster reading, suggesting that L2 speakers process the reversed form of a novel binomial as another encounter, ignoring the established order.

**Keywords:** binomials, L2, processing, eye-tracking, formulaic language, multiword sequence

## Introduction

English speakers say that things go together like *bread and butter*, not like *butter and bread*. Lexical patterns like these (often referred to as formulaic language or multiword sequences) account for up to half of spoken discourse (Erman & Warren, 2000; Pawley & Syder, 1983). One example of such lexical patterns is binomials, defined as “coordinated word pairs whose lexical elements share the same word class” (Mollin, 2014, p. 1). Binomials abound in English (e.g., *aches and pains*, *fair and square*, *high and low*, *life and death*, etc.), and vary in their degree of reversibility along a cline (Malkiel, 1959). At one end of the cline are frozen binomials, which are very clearly irreversible (e.g., *hit and run*, *chalk and cheese*) because of their highly idiomatic meaning. However, the focus of the present study is not on such idiomatic binomials, but rather on semantically compositional (i.e., transparent) binomials. Transparent binomials exist along a continuum of fixedness, where components may have a preferred sequence even when the order could in theory be reversed without fundamentally changing the meaning (e.g., *public and private*, *mother and father*). Therefore, binomials have two important properties: co-occurrence restrictions (like other lexical patterns) and configuration restrictions, and this unique nature has led to interest in how they are processed and acquired.

One line of research has explored the factors that determine the preferred order of binomials, particularly in terms of diachronic changes (e.g., Goldberg & Lee, 2021; Mollin, 2014). Goldberg and Lee (2021) found that binomials like *uncles and aunts* / *nephews and nieces*, which were in common use prior to the 1930s, have more recently reversed their preferred order to *aunts and uncles* / *nieces and nephews*. Goldberg and Lee proposed several cognitive explanations for the change, including the accessibility of the individual components of binomials in memory and their

cluster strength. Others have attributed the ordering preferences in binomials to sociocultural factors (e.g., Mollin, 2013) and factors such as the semantic, phonological and lexical properties of component words, as well as how much experience an individual has with the binomial in question (Morgan & Levy, 2016).

Another research area is concerned with how binomials are acquired by native and non-native speakers. Some studies have addressed this question using post-treatment tasks (Alotaibi et al., 2022) or using eye-tracking to examine the processing of novel binomials as it unfolds in real time (Alotaibi, 2020; Conklin & Carrol, 2021). The current study aims to contribute to research on the processing of novel binomials (i.e., infrequent phrases which do not have a conventionalized word order) by extending the work of Conklin and Carrol (2021), who examined the processing of novel binomials in native speakers, to a population of non-native speakers of English. The study investigates whether non-native speakers show a processing sensitivity (i.e., speeded recognition) to novel binomials in a natural reading context, as was the case with native speakers in the original study. More specifically, we examine whether non-native speakers can associate pairs of words in memory and register their preferred word order (e.g., *wires and pipes* instead of *pipes and wires*) over the course of reading short texts seeded with the novel binomials. Thus, the current study examines L2 processing of novel binomials rather than their acquisition (i.e., there is no post-treatment measure of knowledge).

The following sections will review two relevant strands of literature to situate the current study: the processing of lexical patterns by native and non-native speakers and the acquisition of single-word vocabulary and lexical patterns by non-native speakers.

## Literature Review

### Processing of lexical patterns

It is well-established that native speakers recognize lexical patterns faster and process their phrase-level meaning more easily than other nonrecurrent combinations of words that do not show any significant degree of cohesion or fixedness. This has been shown for idioms (e.g., Carrol & Conklin, 2020; Conklin & Schmitt, 2008; Libben & Titone, 2008; Rommers et al., 2013), phrasal verbs (e.g., Blais & Gonnerman, 2013; Matlock & Heredia, 2002; Tiv et al., 2019) and binomials (e.g., Arcara et al., 2012; Carrol & Conklin, 2020). The processing advantage for lexical patterns by native speakers has prompted researchers to explore these patterns in non-native speakers.

Several studies have explored the determinants of non-native processing of lexical patterns. One important factor is first language (L1) – second language (L2) similarity. When single words are the same (or very similar) across languages (e.g., *piano* in both English and French), there is considerable evidence of cross-language activation, or a cognate effect, in non-native lexical processing (for an overview, see van Hell & Tanner, 2012). More recently, researchers have started to examine the effect of L1-L2 similarity on the processing of lexical patterns. This has been referred to as the congruency effect (i.e., the availability of a literal translation equivalent). Studies have examined the congruency effect using different types of lexical patterns including collocations (e.g., Wolter & Gyllstad, 2011, 2013; Yamashita & Jiang, 2010) and idioms (e.g., Carrol & Conklin, 2014; Carrol et al., 2016; Irujo, 1986; Pritchett et al., 2016; Titone et al., 2015). The general finding is that congruency has a

clear influence on the processing of lexical patterns in the L2 with a processing advantage for congruent items ( $L1 = L2$ ) over incongruent items ( $L1 \neq L2$ ).<sup>1</sup>

Another important determinant of the processing of lexical patterns is transparency. One relevant study here is by Gyllstad and Wolter (2016), who employed a semantic judgment task to examine how advanced L1 Swedish - L2 English learners processed English free combinations and collocations. Reaction times and error rates showed a processing cost for collocations compared to free combinations, due to the semantically semi-transparent nature of collocations. In the same vein, Yamashita (2018) explored the potential contribution of semantic transparency in explaining the congruency effect, and found that congruent items were dominated by transparency while incongruent items were generally characterized by opacity, indicating a clear overlap between these variables.

A third determinant of the processing of lexical patterns is frequency. A study by Sonbul (2015) explored the sensitivity of native and non-native speakers of English to the corpus-derived frequency of collocations using both off-line (typicality rating task) and on-line (eye-movements) measures. There was a clear sensitivity to corpus-derived frequency among both natives and non-natives in the off-line task. The frequency effect was also notable in the early stages of reading but disappeared later for both groups. Wolter and Gyllstad (2013) examined the influence of frequency on the processing of congruent and incongruent collocations. They found that advanced Swedish learners of English were highly sensitive to the frequency of collocations, regardless of whether or not the collocations had a congruent form in the L1. Likewise, Wolter and Yamashita (2018) used an acceptability judgment task to examine the processing of collocations by intermediate and advanced Japanese speakers of English and native English speakers. They found effects of both word-

level and collocation-level frequency among the three groups of participants. Such results support usage-based models of language acquisition, whereby experience with the language predicts language processing and acquisition (e.g., Bybee, 2006; Ellis, 2002).

In addition, L2 proficiency seems to influence the processing of lexical patterns. For example, Sonbul (2015) found that the effect of corpus-derived frequency on the processing of collocations was greater among non-native speakers of English as their proficiency increased. Similarly, Ding and Reynolds (2019) found that the influence of congruency was clearer among highly proficient than less proficient Chinese EFL (English as a foreign language) learners. Sonbul and El-Dakhs (2020) showed that the estimated proficiency of Arab learners of English influenced the processing of collocations, with congruency effects slowly diminishing as proficiency increased (and see similar effects of increasing proficiency from Yamashita & Jiang, 2010).

The research reviewed thus far has mainly focused on the processing of collocations and idioms. To the best of our knowledge, only one study has examined the processing of binomials by non-natives. Siyanova-Chanturia et al. (2011) employed eye-tracking to examine how native and non-native English speakers, of varied levels of proficiency, processed binomials that differed in phrasal frequency. The participants read sentences containing binomials in their preferred, frequent, order (*bride and groom*) or their reversed, less frequent, form (*groom and bride*). The results showed that both natives and non-natives were generally sensitive to the frequency of occurrence of binomials, but only natives and higher proficiency non-natives also exhibited a sensitivity to the canonical configuration.



## **Incidental acquisition of L2 vocabulary**

Most of the available evidence on the incidental acquisition of L2 vocabulary from context has focused on single words (e.g., Pellicer-Sánchez & Schmitt, 2010; Pitts et al., 1989; Waring & Takaki, 2003). These studies mainly relied on off-line tests to assess gains and showed that L2 speakers do retain vocabulary from exposure, but the rate might be relatively low. Only recently have studies used eye-tracking, which allows for the examination of on-line processing as it unfolds in real time. Among the earliest eye-tracking studies to examine the incidental acquisition of word knowledge is Godfroid et al. (2013). In their study, Godfroid et al. (2013) had advanced Dutch-speaking learners of English read short English extracts that contained target known words and unknown pseudowords. Their results showed that participants spent more time processing the unknown pseudowords than the known words, and that longer fixations to the pseudowords were associated with better scores in an unannounced vocabulary posttest. Similarly, Pellicer-Sánchez (2016) combined off-line (paper-and-pencil) and on-line (eye-tracking) measures to examine the incidental acquisition of unknown words by non-native English learners. Notably, the participants read a full story, not simply short extracts. The story contained pseudowords, each repeated eight times. The reading time (RT) for pseudowords decreased significantly after three to four encounters, and they were read in a similar manner to known real words after eight encounters. The paper-and-pencil tests showed that incidental acquisition of unknown words is possible. However, the acquisition of word meaning lagged behind the acquisition of word form.

Godfroid et al. (2018) conducted a study that involved participants reading an authentic novel. The participants (native and non-native English speakers) read five chapters of an English novel that included foreign Dari (Farsi) words ranging in frequency (1-23 occurrences). After reading, the participants were given a comprehension test and surprise vocabulary tests. Using growth curve analysis to model form knowledge development, the results showed that both the quantity (number of exposures) and the quality (total RT) of lexical processing facilitated incidental vocabulary acquisition. The results showed a non-linear, S-shaped pattern of RTs for newly acquired words with an initial speed up (one to four exposures) followed by a plateau with a slight increasing trend (seven to 10 exposures) before further decreases in RTs (11 to 23 exposures). Posttest scores suggested that the frequency of occurrence of the new words and how long the participants read them at each encounter predicted the acquisition of knowledge.

The research reviewed in this section has focused on the acquisition of individual words. In contrast to single words, lexical patterns are often claimed to be less noticed by non-natives (e.g., Boers & Lindstromberg, 2012; Christiansen & Arnon, 2017; Wray, 2000). However, some studies have suggested that non-native speakers are able to notice lexical patterns in context. For example, Durrant and Schmitt (2010) assigned non-native speakers of English to one of three training conditions: single exposure, verbatim repetition and varied repetition, followed by a naming task. Participants in both repetition conditions recalled the target collocations better than those in the single exposure condition. The authors concluded that adult non-native learners retain information about the lexical patterns they are exposed to in input, in line with usage-based models of language acquisition (Bybee, 2006).

Evidence for the incidental acquisition of lexical patterns has accrued over the past few years. Some studies have focused on incidental vocabulary acquisition from television/video viewing (e.g., Majuddin et al., 2021; Puimège & Peters, 2020). More relevant to the present study is research investigating the incidental acquisition of lexical patterns from a reading context (Pellicer-Sánchez, 2017; Webb et al., 2013). Webb et al. (2013) investigated the effect of repetition on the incidental acquisition of collocations. Taiwanese EFL learners simultaneously read and listened to one of four versions of a modified graded reader that included target collocations, with 1, 5, 10 and 15 encounters. Immediate-posttest results indicated that encountering collocations repeatedly when reading while listening contributed to incidental acquisition of form and meaning, with collocation acquisition increasing as a factor of frequency. Pellicer-Sánchez (2017) examined the incidental acquisition of collocational knowledge, focusing on adjective-pseudoword collocations in reading. L2 learners read a story seeded with target collocations that were repeated either four or eight times. The scores on a one-week delayed post-test lent support to the benefits of collocation acquisition from a reading context, even suggesting that ESL learners can incidentally develop collocational knowledge at a similar rate to individual words. However, there was not a significant effect of the frequency manipulation on collocation acquisition.

While most studies have focused on collocations, very few studies have examined the incidental acquisition of binomials. In one such study, Alotaibi et al. (2022) investigated the effect of input mode (reading-only, listening-only and reading-while-listening) and frequency of exposure (2, 4, 5 and 6 occurrences) on declarative binomial knowledge. Based on performance on immediate paper-and-pencil tests, results indicated that it was possible for non-native learners of English

(L1 Arabic) to develop declarative knowledge of the preferred order of binomials from the various input modes; novel binomials encountered six times showed similar familiarity ratings as existing binomials.

While previous studies indicate that lexical patterns (including binomials) can be acquired incidentally in L2 speakers, they are limited in that they used post-hoc measures of knowledge and did not examine processing as it unfolds in real time. Only a few studies have employed eye-tracking to examine the on-line processing of lexical patterns (Alotaibi, 2020, Study 2; Choi, 2017). The aim of Alotaibi's (2020) Study 2, for example, was to examine how non-native learners process novel binomials in different input modes. The findings showed that repeated exposure to novel binomials led to fewer fixations and shorter RTs. Additionally, with increased exposure, the processing of novel binomials gradually became comparable to existing ones. It should be noted that since the focus of Alotaibi's (2020, Study 2) was on mode of processing rather than acquisition per se, she did not include a reversed form of the novel binomials. Including a reversed form can help address the special nature of binomials (see *Introduction*) which does not merely involve co-occurrence restrictions but also entails word order preferences.

### **The present study**

As noted earlier, the current study is an extension of Conklin and Carrol (2021), who investigated the processing of novel binomials amongst native speakers, exploring sensitivity to co-occurrence information and canonical word order. They monitored the eye movements of 40 native English speakers while reading short stories which contained existing binomials in their common forward form (e.g., *time and money*),

seen once, and novel binomials (e.g., *wires and pipes*), seen one to five times in their experimentally defined forward form. Then, the readers saw the existing and novel patterns in the reversed order (e.g., *money and time, pipes and wires*). The results revealed an initial co-occurrence memory effect for the components of novel binomials (i.e., 'wires' and 'pipes') regardless of direction whereby the last 'reversed' form was processed similar to or even significantly faster than the first forward occurrence. However, when frequency of encounter was considered, an advantage emerged for forward novel patterns over subsequently encountered reversed forms after four to five exposures, suggesting that natives could develop a sensitivity to the order of novel binomials rapidly from exposure.

The current study aims to examine whether the effect found for natives by Conklin and Carrol (2021) emerges for non-native speakers. More specifically, we are interested in whether non-native speakers rapidly develop a sensitivity to the preferred word order of novel binomials through natural reading. The current study addresses the following questions:

- 1- Is the language processing system sensitive to novel binomials in L2 input that simulates a real-world context?
- 2- What is the effect of frequency of exposure on non-natives' sensitivity to novel binomials in a real-world context?

Similar to Conklin and Carrol (2021), the current study presented existing binomials only once in their forward form followed by once in their reversed form. However, unlike Conklin and Carrol (2021) who included five frequency levels for novel binomials, the design of the present study included two frequency categories

only (2-repetition vs. 4- repetition) to increase item power. In Conklin and Carrol (2021) as the number of repetitions increased, the number of items per frequency level decreased. For example, 25 items were read once, but only five items were read five times. Thus, there was much less item power at the fifth occurrence versus the first. By only looking at two frequency levels, we were able to include the same number of items for both categories.<sup>2</sup> We selected two versus four repetitions for our frequency categories based on Conklin and Carrol's (2021) finding that natives showed a clear sensitivity to a given configuration after four exposures but not after two exposures. Thus, the novel binomials in the current study involved two main factors. The first factor was *Category* with two levels: 2-repetition vs. 4-repetition, and the second factor was *Iteration* with three levels: first, last (i.e., second occurrence for 2-repetition items and fourth occurrence for 4-repetition items) and reversed.

In order to evaluate an emerging sensitivity to novel binomials (RQ1), we will compare RTs of existing and novel binomials in the forward (first) and reversed iterations only. When examining the effect of frequency on sensitivity to novel binomials (RQ2), we will include the first, last, and reversed forms of both frequency categories.

In order to establish any similarities or differences between native and non-native processing of novel binomials, the current findings from non-native speakers will be discussed in relation to those of the native speakers from Conklin and Carrol (2021). It is important to point out, that while we have introduced certain changes to the design (see above), the experiments are very similar (i.e., use the same items and the same texts with minor modifications). Thus, comparing the findings of the current study to that of Conklin and Carrol (2021) should be justified.<sup>3</sup>

We do not expect non-natives in the present study to necessarily have a sensitivity to the canonical order of existing binomials across all proficiency levels. Similar to Siyanova-Chanturia et al. (2011), we anticipate that sensitivity to binomials' word order should only emerge for participants with high L2 proficiency. For the novel binomials, based on Alotaibi (2020, Study 2), we expect our non-natives to show on-line memory effects for the co-occurrence of novel binomials' components, that is, shorter RTs for the last over the first encounter in the forward form. However, non-natives might or might not develop sensitivity to the canonical order of novel binomials (*wires and pipes* vs. *pipes and wires*). If non-natives follow the same pattern as natives (Conklin & Carrol, 2021), they should show a processing advantage (i.e., shorter RTs) for novel binomials in the forward form over the backward form after four exposures, but likely not after as few as two encounters. If, however, non-native speakers are not sensitive to word order differences in lexical patterns, our non-native participants might not show such a processing advantage even after four exposures. Rather, they might treat the backward form as another co-occurrence of the components and overlook the direction preference. In that case, the final backward occurrence should demonstrate an additional processing advantage over the last encounter with the forward form.

## **Experiment**

### Methods

#### *Participants*

Initially, 40 participants took part in the experiment. One participant was excluded as her score in the V\_YesNo vocabulary test was below 4,000 word families, suggesting

that she might not know all words comprising the target binomials (see below for more details).

The final pool of 39 participants were all non-native speakers of English who were academic and administrative staff at a university in Saudi Arabia (L1 Arabic; 30 females, average age = 34.39,  $SD = 10.61$ ).<sup>4</sup> They started learning English at an average age of six and a half years ( $M = 6.46$ ;  $SD = 5.19$ ). Their self-reported proficiency scores (on a scale from 1 = very poor to 5 = excellent) were: reading  $M = 4.63$ ,  $SD = 0.55$ ; writing  $M = 4.60$ ,  $SD = 0.55$ ; speaking  $M = 4.63$ ,  $SD = 0.60$ ; and listening  $M = 4.57$ ,  $SD = 0.61$ .

In order to obtain a rough estimate of their proficiency in English, the participants completed the V\_YesNo online vocabulary test (Meara & Miralpeix, 2017; maximum score = 10,000). The test presents participants with 200 items (half real words and half imaginary pseudowords), and instructs them to press 'Yes' if they know the meaning of the presented form and 'Next' if they do not. The score is adjusted downwards based on guessing (i.e., pressing 'Yes' for pseudowords) using an equation (see Meara & Miralpeix, 2017, p. 120). Uchihara and Clenton (2020) found a significant association between the V\_YesNo test scores and speaking ability. Moreover, previous versions of the Yes/No vocabulary test format demonstrated a medium to strong correlation with proficiency measures (e.g., Meara & Jones, 1988; Miralpeix & Muñoz, 2018). The scores of our participants in the V\_YesNo test ranged between 4,000 and 9,302 ( $M = 6712.05$ ,  $SD = 1323.96$ ), which roughly indicates a good to high level of proficiency (Meara & Miralpeix, 2017). The vocabulary test score was added as a covariate in all mixed-effects models (see *Analysis*) in order to control for the effect of proficiency on RTs.



## *Materials*

Thirty-two 'noun-and-noun' binomials were selected for the present study, taken from Conklin and Carrol (2021), to represent two categories of binomials: existing ( $n = 12$ ) and novel ( $n = 20$ ). The full list of 32 items and their features is presented in Appendix S1 (Online Supplementary Materials). All constituent words belonged to the most frequent 4,000 word families in English (BNC/COCA List with 25 1,000-word bands, Nation, 2012), meaning that our participants should be familiar with them.

The existing binomials were highly frequent phrases (BNC frequency per million) and had a conventionalized order: forward  $M = 351.58$ ,  $SD = 305.74$ ; reversed  $M = 23.25$ ,  $SD = 27.00$ ;  $t(11) = 3.71$ , 95% CI [144.59, 512.08],  $p < .001$ ,  $d = 1.51$ . The novel binomials were infrequent phrases (1-11 occurrences in the BNC) constructed using two common nouns (most frequent 4,000 word families). They did not have a typical configuration (forward  $M = 3.90$ ,  $SD = 2.75$ ; reversed  $M = 3.35$ ,  $SD = 2.91$ ;  $t(19) = 0.82$ , 95% CI [-0.86, 1.96],  $p = .43$ ,  $d = 0.19$ ). More details on item selection and categorization can be found in Conklin and Carrol (2021). Appendix S2 (Online Supplementary Materials) presents characteristics of the target stimuli.

Since participants in the present study were non-natives from the same L1 background (Arabic), we also considered L1-L2 congruency of the existing and novel binomials. We operationalized congruency in two steps: existence (exists as a common binomial in both language vs. only exists in one language) and configuration or direction (same in both languages vs. different in the two languages). The two steps

are explained in detail in Appendix S3 (Online Supplementary Materials). Based on this operationalization, eighteen out of the 20 novel English binomials were not common in Arabic (two existed in Arabic in the opposite direction) but only six out of the 12 existing English binomials had the same direction in Arabic (six had a different direction in Arabic). To check whether the pattern of results reported below (see *Results*) was influenced by existence and direction in Arabic, we fit all models with and without the eight non-matching items. The pattern of results remained the same.<sup>5</sup>

We also considered how familiar our participants are likely to be with the English form of the binomials. To test this, a familiarity rating task was administered to 23 L1 Arabic – L2 English speakers who were comparable to our main participant pool.<sup>6</sup> They were instructed to rate both existing and novel binomials (inter-mixed in a list) for familiarity on a scale from 1 = very unfamiliar to 7 = very familiar. The results showed significantly higher familiarity ratings for existing binomials ( $M = 6.51$ ,  $SD = 0.79$ ) than novel binomials ( $M = 4.86$ ,  $SD = 0.84$ ;  $t(30) = 5.52$ , 95% CI [1.05, 2.27],  $p < .001$ ,  $d = 2.03$ ). To examine the potential effect of familiarity on the pattern of results, we fit all models (see *Results*) with the average familiarity rating score as a covariate, and found no significant effect of rating scores. More importantly, including familiarity as a covariate in the analysis did not alter the pattern of results. It should be noted that the novel binomials were rated towards the middle of the scale. We will return to this point in the *Discussion*.

Three stories of approximately 1,100 words each were adapted from Conklin and Carrol (2021) to include the 32 target items. The passages were simplified to ensure suitability for our non-native participants (99% of words belonged to the most frequent 4,000 word-families in English). All target 'existing' and 'novel' binomials were presented once in the forward form and once in the reversed form. Half of the

novel binomials ( $n = 10$ ) were then presented one more time in the forward form to make a total of two exposures and the other half ( $n = 10$ ) were presented three more times in the forward form to make a total of four exposures. The reversed form for both existing and novel binomials occurred once after all occurrences of the corresponding forward form. Conklin and Carrol (2021) conducted a predictability norming task with native speakers of English. We included their predictability scores as a potential covariate in the analysis. The passages, full data and R codes are available via Open Science Framework at:

[https://osf.io/kymisp/?view\\_only=ec6b2f7e9ac74f15be7afcd864373f07](https://osf.io/kymisp/?view_only=ec6b2f7e9ac74f15be7afcd864373f07).

It is important to note here that the novel binomials in Conklin and Carrol (2021) were counterbalanced across two lists, such that one order (*wires and pipes*) was the forward direction on one list and the other (*pipes and wires*) was the forward direction on the other list. This was done to account for any inherent word order preferences in the novel items. However, no list differences were found, thus, in the current study, items appeared in a single list with one version designated as the forward version.

### *Procedure*

Upon arrival at the lab, the participant signed a consent form and completed the vocabulary test, then the eye-tracking experiment started. Eye movements were recorded monocularly using an SR Research EyeLink 1000+ eye-tracker. A desk-mounted chinrest was used to minimize head movement. A 9-point grid calibration procedure was conducted before the experiment and each screen was preceded by a fixation point for drift correction. The eye-tracker was re-calibrated before each story and whenever needed. The stories were presented in Courier New, 18-point font and

were double-spaced. Participants were told to read the stories as naturally as possible for comprehension and to press the space bar to go to the next screen. In the texts, neither existing nor novel binomials appeared at the beginning or end of a line or across a line break. Each story was followed by five comprehension questions to ensure that participants attended to the text (average percentile score: 94.36%,  $SD = 6.41$ ). Performance on the comprehension questions indicates that participants understood the stories.

### *Analysis*

Data cleaning was done prior to the analysis according to the four-stage process in the DataViewer software. Single fixations shorter than 100ms and longer than 800ms were removed (5% of all fixations). Then, following Conklin and Carrol (2021), we excluded trials which were discontinued or where track loss was experienced. Any phrase that was completely skipped was also excluded from the analysis. In such cases, all subsequent occurrences of the item, including the reversed form, were also removed. This resulted in a loss of 1% of the data points in both analyses. We also conducted the analysis with the full data set and the resulting models were the same.

The analysis was conducted with R version 4.0.5. (R Core Team, 2021). Linear mixed-effects models were constructed and analysed using the *lme4* (version 1.1-26; Bates et al., 2015) and *lmerTest* (version 3.1-3; Kuznetsova et al., 2017) packages. Three interest areas were analysed for each model: the whole phrase, word 1 and word 3. The middle word 'and' was skipped more than 45% of the time, so it was excluded from the analysis. Separate models were constructed for two eye movement measures: first-pass RT and total RT. RTs were log-transformed to reduce

skewness in the data. All analyses adopted the maximal random effects structure justified by the design (see below for more details). Final models were checked for collinearity, and no issues were observed (all VIFs < 7). Words and phrases that received no fixations during first-pass reading were excluded from subsequent analyses.

We conducted two separate analyses to answer the research questions. First, we compared the RTs of forward and reversed forms for both the existing and novel binomials (RQ1). Then, RTs for novel binomials only were compared across three iterations (first, last, reversed) for both the 2-repetition and 4-repetition binomial categories (RQ2).

## **Results**

Table 1 presents mean RTs for both existing and novel binomials for all occurrences in both directions. Existing binomials showed no clear pattern, with slower RTs for the forward form under some measures and for the reversed form under other measures. For novel binomials, however, the pattern was much clearer. RTs were shorter (i.e., faster processing) with more exposure to target items (first vs. last vs. reversed) for both repetition categories (2 vs. 4). It should be noted that for the 4-repetition novel binomials, occurrences in the middle (second, third, last) did not always exhibit this processing advantage as exposure increased; the last exposure for 4-repetition items had a longer average RT than the third exposure under all measures. We will return to this in the *Discussion*.

Table 1: Mean RTs in milliseconds with standard deviation in parentheses for existing binomials and novel binomials for first-pass and total RT

		Existing binomials		Novel binomials (2-repetition)			Novel binomials (4-repetition)				
		<i>(n = 12)</i>		<i>(n = 10)</i>			<i>(n = 10)</i>				
		Forward	Reversed	First	Last	Reversed	First	Second	Third	Last	Reversed
<b>First-pass RT</b>	Whole phrase	675.40 (356.80)	680.05 (353.31)	763.44 (403.68)	694.87 (420.53)	621.97 (351.04)	714.18 (422.02)	703.98 (371.75)	634.39 (349.77)	665.51 (329.41)	617.69 (358.59)
	Word 1	321.64 (166.95)	306.31 (160.09)	333.47 (159.59)	310.78 (179.50)	294.71 (137.04)	323.37 (161.27)	338.05 (159.16)	312.62 (146.35)	317.13 (131.14)	303.75 (165.90)
	Word 3	294.30 (121.34)	300.83 (129.12)	383.40 (187.98)	340.34 (146.29)	316.84 (148.04)	364.65 (182.04)	321.26 (153.03)	303.80 (130.20)	322.79 (149.21)	301.58 (127.86)
<b>Total RT</b>	Whole phrase	834.17 (444.75)	836.53 (418.00)	1056.09 (516.29)	936.25 (509.15)	819.46 (464.86)	1022.63 (548.71)	879.49 (452.93)	812.03 (393.67)	848.79 (416.21)	783.62 (402.40)
	Word 1	386.85 (252.48)	368.86 (216.63)	426.54 (239.51)	403.96 (265.08)	369.10 (219.55)	431.44 (263.00)	403.85 (232.57)	372.54 (210.83)	395.85 (207.74)	370.15 (215.15)
	Word 3	349.14 (198.10)	356.97 (187.07)	486.21 (293.06)	410.89 (231.55)	373.87 (228.87)	452.22 (264.99)	375.41 (219.22)	335.21 (162.40)	368.65 (217.74)	339.19 (174.60)

For word 1 and word 3 values, words that received no fixations are discounted; values for the whole phrase include trials where either word 1 or word 3 (but not both) was skipped.

*RQ1: Is the language processing system sensitive to novel binomials in L2 input that simulates a real-world context?*

To compare the mean RTs (first-pass and total) of existing and novel binomials, we constructed linear mixed-effects models for the whole phrase, word 1 and word 3. Following Conklin and Carrol (2021), we included Type (existing vs. novel) and Direction (forward vs. reverse) as fixed effects in all models. Word-level factors including length (in letters) and frequency (on the Zipf scale) were also included as fixed factors.<sup>7</sup> Additionally, number of repetitions (1, 2, 4) was added as a covariate in all models to control for the effect of variation in encounters on the subsequent reverse form of existing and novel binomials. All models included random intercepts for subjects and items. The *optimx* optimiser was used to avoid convergence errors when needed. Initially, by-subject random slopes for the effects of Type and Direction were included,<sup>8</sup> but this led to unavoidable convergence errors. As a result, only by-subject random slopes for Type were included in all models. Three other factors were then added stepwise one-by-one to each original model to examine their potential effect on RTs: phrase frequency on the Zipf scale, forward association strength and cloze probability. Log-likelihood ( $X^2$ ) tests and AIC values were used to compare the resulting model with the original model, and only factors that significantly improved the model fit were kept. All models also included the log-transformed vocabulary test score as a proxy for L2 proficiency.

All resulting models are presented in Table 2. Vocabulary Score was a significant predictor in all models but not for the word 3 first-pass measure, pointing to shorter RTs as proficiency increased. The Type x Direction interaction was significant for all first-pass and total reading measures except for the word 1 first-pass analysis. The *diffsmeans* function in the *lmerTest* package was used to compute

pairwise comparisons (see Appendix S4, Online Supplementary Materials). We calculated Cohen's  $d$  for pairwise comparisons as a standardized measure of effect size based on the guidelines provided by Brysbaert and Stevens (2017). Results suggest that non-natives were not sensitive to the established configuration of frequent existing binomials in English. There were no significant differences between the processing of forward and reversed forms for existing binomials (whole phrase) in first-pass RT ( $\beta = -0.01$ ,  $t = -0.24$ , 95% CI [-0.08, 0.06],  $p = .81$ ,  $d = -0.01$ ) or total RT ( $\beta = -0.01$ ,  $t = -0.39$ , 95% CI [-0.06, 0.04],  $p = .69$ ,  $d = -0.02$ ). These findings stand in sharp contrast with those reported in Conklin and Carrol (2021) for native speakers who showed a clear processing advantage for the forward form of existing binomials over their reversed forms. It seems that our non-native speakers are not sensitive to the established word order of common binomials in English.

For the novel binomials, pairwise comparisons suggest significantly shorter RTs for the reversed forms in comparison to the forward forms for all measures with a small to medium effect. This is most clearly seen for the whole phrase, for both first-pass RT ( $\beta = 0.15$ ,  $t = 5.11$ , 95% CI [0.09, 0.21],  $p < .001$ ,  $d = 0.25$ ) and total RT ( $\beta = 0.28$ ,  $t = 13.95$ , 95% CI [0.24, 0.31],  $p < .001$ ,  $d = 0.62$ ). This result is similar to (but more robust than) the findings reported in Conklin and Carrol (2021) for native speakers, suggesting that just like natives, non-natives seem to quickly develop a link between the two words in memory, exhibiting an advantage in processing, even when they appear in a different order than previous encounters.



Table 2: Linear mixed-effects model for existing vs. novel binomials in forward and reversed forms for whole phrase RTs, word 1 and word 3

	First pass RT					Total RT				
	<i>Intercept</i>	<i>SE</i>	<i>t</i>	<i>p</i>		<i>Intercept</i>	<i>SE</i>	<i>t</i>	<i>p</i>	
<b>Whole phrase</b>										
(Intercept)	12.34	1.33	9.31	< .001	***	15.47	1.41	10.96	< .001	***
Type (novel)	0.05	0.07	0.71	.48		0.19	0.09	2.07	.048	*
Direction (reverse)	0.01	0.04	0.24	.81		0.01	0.03	0.39	.69	
Type x Direction	-0.16	0.05	-3.32	< .001	***	-0.29	0.03	-8.86	< .001	***
Repetitions	-0.02	0.02	-0.77	.45		-0.01	0.03	-0.39	.70	
W1 Length	0.02	0.02	0.96	.35		0.02	0.02	0.80	.43	
W3 Length	-0.02	0.02	-1.12	.27		0.00	0.02	0.06	.95	
W1 Zipf	-0.06	0.05	-1.28	.21		-0.10	0.06	-1.64	.11	
W3 Zipf	0.05	0.06	0.96	.35		-0.02	0.07	-0.24	.81	
Vocabulary Test Score (log)	-0.67	0.15	-4.55	< .001	***	-0.95	0.15	-6.128	< .001	***
<b>Random effects:</b>	<b>Variance</b>	<b>SD</b>				<b>Variance</b>	<b>SD</b>			
Subject	0.02	0.15				0.03	0.18			
Subject Type	0.00	0.04				0.00	0.03			
Item	0.01	0.08				0.02	0.13			
Residual	0.33	0.57				0.15	0.39			

	First pass RT					Total RT				
	<i>Intercept</i>	<i>SE</i>	<i>t</i>	<i>p</i>		<i>Intercept</i>	<i>SE</i>	<i>t</i>	<i>p</i>	
<b>Word 1</b>										
(Intercept)	10.27	0.96	10.68	< .001	***	12.90	1.14	11.34	< .001	***
Type (novel)	0.01	0.05	0.15	.88		0.02	0.07	0.26	.80	
Direction (reverse)	-0.03	0.03	-0.99	.32		-0.02	0.03	-0.50	.62	
Type x Direction	-0.07	0.04	-1.82	.07		-0.14	0.04	-3.50	< .001	***
Repetitions	-0.00	0.02	-0.15	.89		0.01	0.02	0.53	.60	
W1 Length	0.01	0.01	0.72	.48		0.02	0.02	0.82	.42	
W3 Length	-	-	-	-		0.00	0.02	0.20	.84	
W1 Zipf	-0.07	0.03	-2.33	.03	*	-0.15	0.05	-2.93	.007	**
W3 Zipf	-	-	-	-		-0.07	0.06	-1.18	.25	
Vocabulary Test Score (log)	-0.49	0.11	-4.53	< .001	***	-0.70	0.12	-5.60	< .001	***
<b>Random effects:</b>	<b>Variance</b>	<b>SD</b>				<b>Variance</b>	<b>SD</b>			
Subject	0.02	0.13				0.02	0.14			
Subject Type	0.00	0.01				0.00	0.02			
Item	0.00	0.06				0.01	0.09			
Residual	0.17	0.41				0.21	0.46			

	First pass RT					Total RT				
	<i>Intercept</i>	<i>SE</i>	<i>t</i>	<i>p</i>		<i>Intercept</i>	<i>SE</i>	<i>t</i>	<i>p</i>	
<b>Word 3</b>										
(Intercept)	7.44	0.82	9.07	< .001	***	10.01	1.07	9.36	< .001	***
Type (novel)	0.18	0.05	3.34	.002	**	0.28	0.09	3.21	.003	**
Direction (reverse)	0.02	0.03	0.84	.40		0.03	0.03	1.08	.28	
Type x Direction	-0.18	0.03	-5.54	< .001	***	-0.28	0.04	-7.36	< .001	***
Repetitions	-0.02	0.02	-0.93	.36		-0.03	0.03	-1.02	.32	
W1 Length	0.02	0.01	1.48	.15		0.02	0.02	0.87	.39	
W3 Length	0.00	0.01	0.37	.72		0.00	0.02	0.05	.96	
W1 Zipf	-0.08	0.04	-2.31	.03	*	-0.10	0.06	-1.74	.09	
W3 Zipf	-0.04	0.04	-0.90	.38		-0.00	0.07	-0.07	.95	
Vocabulary Test Score (log)	-0.15	0.09	-1.68	.10		-0.43	0.11	-3.77	< .001	***
<b>Random effects:</b>	<b>Variance</b>	<b>SD</b>				<b>Variance</b>	<b>SD</b>			
Subject	0.01	0.08				0.02	0.13			
Subject Type	0.01	0.08				0.01	0.08			
Item	0.00	0.06				0.01	0.11			
Residual	0.15	0.38				0.20	0.44			

p-values are estimated using the *lmerTest* package in R (Kuznetsova et al. 2017). \*  $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < .001$

As a final step in the analysis, we also tested for the contribution of the Type x Direction x Vocabulary Score interaction to the model fit.<sup>9</sup> This was intended to reveal any modulating effect of L2 proficiency, that is, to examine if non-natives with higher vocabulary scores read existing and novel binomials in the forward and reverse direction differently. This three-way interaction did not significantly contribute to any of the models, suggesting similar patterns regardless of L2 proficiency.

One final notable finding in Table 2 is that number of repetitions was not significant in all models, suggesting no difference between items that were seen twice and those that were seen four times. The next research question aimed to examine the possibility that number of encounters might modulate this effect in more detail.

*RQ2: What is the effect of frequency of exposure on non-natives' sensitivity to novel binomials in a real-world context?*

The effect of frequency of exposure on RTs of novel binomials (word 1, word 3 and whole phrase) was explored in Analysis 2. This analysis included Category (2-repetition vs. 4-repetition) and Iteration (first, last, reversed) as fixed effects and by-subject random slopes for Category. All other fixed factors and covariates were the same as those included in Analysis 1. Additionally, we examined the three-way interaction between Category, Iteration and Vocabulary Score, but it did not significantly improve any of the models.

The resulting models are presented in Table 3. Overall, there appears to be a main effect for Vocabulary Score (but see the total RT measure for Word 3) and a main effect for Iteration, but not Category (but see first-pass RT for the whole phrase). Pairwise comparisons across the three Iteration levels, regardless of

repetition, are presented in Appendix S5 (see Online Supplementary Materials). These are computed using the *diffsmeans* function in the *lmerTest* package.

The general pattern seems to suggest significantly different RTs across the three iterations with a small to medium effect (first > last > reversed). Thus, it appears that with more exposure to binomials, non-natives developed a sensitivity to the co-occurrence of the content words, spending less time reading them each time they appeared together. As for the reversed form, which was always included after all occurrences of the forward form, the results suggest that non-natives dealt with it as another exposure to the binomial, ignoring the configuration mismatch.

Table 3: Linear mixed-effects model for novel binomials in different iterations (first, last and reversed) for whole phrase RTs, word 1 and word 3

	First pass RT					Total RT				
	<i>Intercept</i>	<i>SE</i>	<i>t</i>	<i>p</i>		<i>Intercept</i>	<i>SE</i>	<i>t</i>	<i>p</i>	
<b>Whole phrase</b>										
(Intercept)	11.99	1.45	8.25	< .001	***	15.26	1.49	10.25	< .001	***
Category (4-repetition)	-0.12	0.05	-2.40	.02	*	-0.05	0.07	-0.73	.47	
Iteration (last)	-0.12	0.04	-2.78	.006	**	-0.14	0.03	-5.14	< .001	***
Iteration (reversed)	-0.20	0.04	-4.73	< .001	***	-0.28	0.03	-10.22	< .001	***
Category (4-repetition) x Iteration (last)	0.12	0.06	2.04	.04	*	-0.03	0.04	-0.73	.47	
Category (4-repetition) x Iteration (reversed)	0.10	0.06	1.70	.09		0.01	0.04	0.33	.74	
W1 Length	0.04	0.02	2.42	.03	*	0.03	0.03	0.78	.45	
W3 Length	-0.02	0.02	-1.29	.22		0.01	0.03	0.40	.69	
W1 Zipf	-0.02	0.06	-0.36	.72		-0.21	0.11	-1.95	.07	
W3 Zipf	0.04	0.06	0.72	.49		0.03	0.09	0.34	.74	
Vocabulary Test Score (log)	-0.69	0.16	-4.28	< .001	***	-0.95	0.16	-6.00	< .001	***
Phrase Zipf	0.17	0.09	1.91	.08		0.33	0.16	2.12	.054	
Forward Association	1.59	0.78	2.05	.06		-	-	-	-	
<b>Random effects:</b>	<b>Variance</b>	<b>SD</b>				<b>Variance</b>	<b>SD</b>			
Subject	0.04	0.20				0.04	0.21			
Subject Category	0.00	0.01				0.00	0.02			

	First pass RT					Total RT				
	<i>Intercept</i>	<i>SE</i>	<i>t</i>	<i>p</i>		<i>Intercept</i>	<i>SE</i>	<i>t</i>	<i>p</i>	
Item	0.00	0.04				0.02	0.12			
Residual	0.35	0.59				0.15	0.38			
<b>Word 1</b>										
(Intercept)	10.16	0.89	11.42	< .001	***	13.18	1.15	11.44	< .001	***
Category (4-repetition)	-0.05	0.03	-1.52	.13		0.00	0.06	0.00	1.00	
Iteration (last)	-0.09	0.03	-3.02	.003	**	-0.08	0.03	-2.46	.01	*
Iteration (reversed)	-0.13	0.03	-4.12	< .001	***	-0.16	0.03	-4.75	< .001	***
Category (4-repetition) x Iteration (last)	0.10	0.04	2.34	.02	*	0.02	0.05	0.36	.72	
Category (4-repetition) x Iteration (reversed)	0.06	0.04	1.41	.16		0.01	0.05	0.16	.88	
W1 Length	0.02	0.01	2.20	.04	*	0.00	0.03	0.11	.91	
W3 Length	-	-	-	-		0.03	0.03	1.08	.30	
W1 Zipf	-0.01	0.03	-0.32	.76		-0.12	0.08	-1.52	.15	
W3 Zipf	-	-	-	-		-0.06	0.07	-0.83	.42	
Vocabulary Test Score (log)	-0.52	0.10	-5.17	< .001	***	-0.75	0.12	-6.23	< .001	***
Forward Association	0.73	0.37	1.96	.07		-	-	-	-	
<b>Random effects:</b>	<b>Variance</b>	<b>SD</b>				<b>Variance</b>	<b>SD</b>			
Subject	0.02	0.13				0.03	0.17			
Subject Category	0.00	0.05				0.01	0.09			
Item	0.00	0.02				0.01	0.10			

	First pass RT					Total RT				
	<i>Intercept</i>	<i>SE</i>	<i>t</i>	<i>p</i>		<i>Intercept</i>	<i>SE</i>	<i>t</i>	<i>p</i>	
Residual	0.17	0.41				0.21	0.45			
<b>Word 3</b>										
(Intercept)	9.11	1.05	8.70	< .001	***	10.87	1.16	9.39	< .001	***
Category (4-repetition)	-0.04	0.04	-0.96	.35		-0.08	0.06	-1.18	.25	
Iteration (last)	-0.10	0.03	-3.67	< .001	***	-0.15	0.03	-4.74	< .001	***
Iteration (reversed)	-0.17	0.03	-5.78	< .001	***	-0.25	0.03	-7.57	< .001	***
Category (4-repetition) x Iteration (last)	0.00	0.04	0.11	.91		-0.03	0.05	-0.71	.48	
Category (4-repetition) x Iteration (reversed)	0.01	0.04	0.19	.85		-0.00	0.05	-0.08	.93	
W1 Length	0.03	0.02	1.45	.17		0.03	0.03	0.96	.36	
W3 Length	0.00	0.02	0.13	.90		0.01	0.03	0.33	.75	
W1 Zipf	-0.12	0.06	-1.92	.08		-0.18	0.10	-1.79	.10	
W3 Zipf	0.00	0.05	0.09	.93		0.05	0.08	0.61	.55	
Vocabulary Test Score (log)	-0.36	0.11	-3.21	.003	**	0.32	0.15	2.15	.051	
Phrase Zipf	0.19	0.10	1.93	.08		-0.56	0.12	-4.77	< .001	***
<b>Random effects:</b>	<b>Variance</b>	<b>SD</b>				<b>Variance</b>	<b>SD</b>			
Subject	0.02	0.13				0.02	0.14			
Subject Category	0.00	0.00				0.00	0.01			
Item	0.00	0.07				0.01	0.11			
Residual	0.15	0.39				0.20	0.44			

p-values are estimated using the *lmerTest* package in R (Kuznetsova et al. 2017). \*  $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < .001$



## Discussion

Research examining how non-native speakers process novel lexical patterns in context is fairly limited. The present study aims to fill this gap by recording the eye movement patterns of non-native speakers of English (L1 Arabic) as they read stories seeded with novel binomials to address two research questions. First, we examined whether the non-natives developed a sensitivity to the canonical order of novel binomials after exposure and compared their processing to existing binomials (Research Question 1). Second, we looked at the effect of frequency (two vs. four exposures) on the development of sensitivity to the novel binomials (Research Question 2).

In response to the first research question, results showed no processing advantage for existing, common, binomials (*time and money*) over their less frequent reversed forms (*money and time*). Thus, unlike natives in Conklin and Carrol (2021), non-natives in the present study were generally not sensitive to binomials' canonical word order. This result seems to support Siyanova-Chanturia et al.'s (2011) finding for a limited non-native sensitivity to word order preferences that emerged only as proficiency increased. In the present study, however, proficiency did not seem to modulate sensitivity to binomials' configuration. While participants in Siyanova-Chanturia et al. (2011) came from a variety of L1 backgrounds, we targeted a homogenous non-native population (L1 Arabic – L2 English). Previous research on collocations and idioms often report congruency as an important factor in the non-native processing of lexical patterns (e.g., Carrol et al., 2016; Sonbul & El-Dakhs, 2020). A follow-up analysis that was conducted on a subset of binomials that matched in the two languages showed the same pattern of results, namely, no sensitivity to the canonical configuration (see *Materials* for details). The fact that the L1-L2 matched

existing binomials in the present study comprised only six items might explain the lack of effect. Future research on non-native binomial processing should address the congruency effect more directly with a larger set of congruent and incongruent items. Another factor to consider in future research is binomial familiarity. The norming study that we conducted with a group of L1 Arabic – L2 English speakers comparable to the main participant pool (see *Materials*) showed that familiarity with novel binomials elicited ratings toward the mid-point of the scale and was only slightly (though significantly) lower than the ratings for existing binomials. More research is needed in this area to tease apart off-line familiarity ratings and on-line real time performance.

For novel binomials, the results of Analysis 1 (initial forward exposure vs. reversed forms) showed a robust significant advantage (with a small/medium effect) for the reversed form over the forward form for all eye-movement measures (both early and late). As indicated above, this result complements Conklin and Carroll's (2021) finding for natives who initially exhibited sensitivity to the combination of single words ('wires' and 'pipes') regardless of direction. Thus, like natives in Conklin and Carroll's (2021) study, non-natives in the present study seem to keep a record of all occurrences of lexical patterns in the input; but unlike native speakers, they might not initially build sensitivity to the preferred word order (*wires and pipes* vs. *pipes and wires*). This seems to support Durrant and Schmitt's (2010) finding that non-natives are able to extract co-occurrence restrictions from input, refuting traditional claims (e.g., Wray, 2000), and backing up usage-based models of language processing (Bybee, 2006; Ellis, 2002). However, as noted earlier, binomials may be different from other forms of lexical patterns in that they involve co-occurrence and configuration restrictions. In a study on the processing of lexical bundles, Ellis et al.

(2008) found that non-native speakers are sensitive just to the frequency in the language, but native speakers seem to extract the nuance of the bundle's association strength (i.e., how often two words tend to co-occur above chance). Similarly, one might claim that the non-native participants in the present study were able to exhibit sensitivity to mere frequency but were not sensitive to higher-level restrictions on word order, at least not after one encounter as Analysis 1 seems to suggest.

The second research question (Analysis 2) examined the possible modulating effect of frequency of encounters (two vs. four) on the development of a sensitivity to the canonical order of binomials. Conklin and Carrol (2021) found that their native speakers processed the forward forms of novel binomials faster than their reversed forms, similar to existing binomials, after four to five exposures.<sup>10</sup> Crucially, exposure to the subsequent reversed form led to a cost (a marked rise in processing time) compared to the most recent encounter, despite this being faster than the first exposure. However, results of Analysis 2 failed to report similar effects for our non-native participants even after four exposures. In line with the findings of Analysis 1, non-natives in the present study processed the last reversed form (*pipes and wires*) significantly more quickly (with a small/medium effect) than the experimentally defined forward form (*wires and pipes*) regardless of how many times it was encountered. This finding is further supported by the raw RTs in Table 1, showing similar processing times for the third encounter in the 2-repetition category (backward) and the third encounter in the 4-repetition category (forward). Thus, it seems to be the case that whilst non-natives did register co-occurrence restrictions in terms of which words go together, they did not also register the configuration / order of the words. This lack of a configuration effect stands in contrast with findings of Alotaibi et al. (2022) who found that non-native Arab learners of English were able to

develop sensitivity to the preferred order of binomials (similar to existing phrases) after six exposures. It should be noted, however, that unlike the present study, Alotaibi et al. (2022) included higher frequency levels (up to six occurrences) than the present study (with a maximum of four encounters) and employed declarative post-treatment measures. Sonbul and Schmitt (2013) found a dissociation between gains in declarative (paper-and-pencil) tests and those reflecting on-line performance. In the present study, we did not employ any post-treatment declarative measure of sensitivity to target binomials' word order. Future research can benefit from combining both on-line (eye-movement) measures and off-line (paper-and-pencil) tasks in order to compare findings at both processing levels. Moreover, more encounters can be included to allow participants to develop sensitivity to configuration restrictions. A relevant point, relating to Arabic speakers of English, may be that Arabic seems to be less fixed than English regarding the order of binomials' components (see *Materials*). Thus, it can be speculated that, given the flexibility in their L1, Arabic speakers of L2 English might not develop sensitivity to binomial restrictions in context. Since research on the structure of binomials in Arabic is extremely limited (but see Kaye, 2009), this possibility can only be viewed as a hypothesis that needs to be explored by future research comparing L2 English speakers from a variety of L1 backgrounds. Another related issue is that, in contrast to English, the Arabic script is read from right to left. As the focus of the present study is on binomials' word order in L2 English, Arabic native speakers might be disadvantaged (in comparison to L2 English speakers whose native language is read from left to right). This would be an interesting question to explore in future research.

The fact that non-natives in the present study developed a sensitivity to one aspect of binomials (i.e., co-occurrence restrictions) but not another (i.e.,

configuration restrictions) is in line with eye-tracking evidence for the incidental acquisition of single words from context. As indicated earlier, the limited available research in this area (Pellicer-Sánchez, 2016) seems to suggest that non-native learners tend to develop different word knowledge aspects at different rates: while the form is acquired quickly, knowledge of meaning fails to develop even after repeated exposure. Along the same lines, it can be claimed that not all aspects of binomial knowledge are learned at the same pace. On-line sensitivity to the co-occurrence restrictions of binomials can develop quickly from exposure, but sensitivity to the canonical order does not develop even after several exposures. Further eye-tracking research on the processing of novel binomials can include more encounters to arrive at an estimated frequency after which non-natives develop a sensitivity to binomials' preferred order.

Another parallel in eye-movement patterns between individual words and binomials is the effect of multiple encounters on processing. In their study on individual words, Godfroid et al. (2018) found a tendency for RTs of novel words to initially decrease but then increase around the seventh encounter, reflecting "increased cognitive effort and attempts on their [participants'] part to integrate the words into the sentence contexts and make form-meaning connections." (p. 575). Similarly, our findings showed a slight increasing trend at the fourth encounter for the 4-repetition novel binomials (see Table 1) which disappeared with the presentation of the reversed form. Thus, although we did not intend to examine the gradual effect of exposure on the processing of novel binomials in the present study, a tendency seems to emerge at the fourth encounter, similar to the effect reported by Godfroid et al. (2018) for single words. Building on predictions of the type of processing resource allocation (TOPRA) Model (Barcroft, 2002), one might argue that in the first few encounters with a given

binomial, the cognitive demands are high as language users are encoding co-occurrence restrictions (i.e., learning that 'wires' and 'pipes' occur together). Then, around the fourth encounter, more cognitive resources are freed and can thus be devoted to the specific configuration and the overall meaning that is denoted by the phrase. With more exposure, the forward form of novel binomials might show further decrease in RTs. However, given the limited number of encounters in the present study (maximum four), this interpretation is speculative. Future eye-tracking research on the on-line processing of novel binomials would do well to include more encounters with novel binomials, in line with Godfroid et al.'s (2018) design, to fully explore the possible S-shaped processing of novel lexical patterns in context.

## **Conclusion**

The present study was intended to extend Conklin and Carroll's (2021) findings for the native processing of novel binomials to a population of non-native English speakers (L1 Arabic). Results showed that non-natives had limited sensitivity to the preferred order of existing binomials; they did not develop sensitivity to the experimentally defined configuration of novel binomials even after four encounters. These results seem to suggest that the non-native participants were simply recording co-occurrence restrictions, disregarding direction preference, which may be a feature of language that is less salient and therefore requires more input to emerge. The study is limited, however, in that it did not include a balanced number of congruent/incongruent binomials to fully examine the congruency effect. Additionally, the study only included two frequency conditions (two vs. four) and did not include a post-exposure measure of declarative knowledge. Future research should explore the effect of

increased frequency and L1-L2 congruency on the acquisition process (both on-line processing and off-line, post-exposure, gains). Despite the limitations, the present study can be viewed as an initial attempt to examine non-natives' processing of novel binomials in context. This line of research can further our understanding of the conditions that might help non-natives develop sensitivity to lexical patterns like *bread and butter* (over *butter and bread*), enabling new and broader explanations of input-driven language development.

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## Notes

- 1- It should be noted that congruency is not a main factor in the present study but, due to its central role in processing lexical patterns, it will be considered in item development and data analysis.
- 2- Another option would have been to follow Conklin and Carrol's (2021) design with five frequency levels, but just increase the number of items at each level. Doing this would have increased item power but would have also resulted in passages becoming saturated with binomials, making the repetition manipulation clearly marked.
- 3- We should note that the native group in Conklin and Carrol (2021) was reasonably large, and we expect less variation in a group of native speakers than in a group of non-natives, especially when the native group is drawn from

a similar pool (native speaker undergraduates at a British university). Thus, their pattern of results should be robust. However, researchers may wish to replicate their novel research.

- 4- Four of the 39 participants reported learning a language other than Arabic (English or French) at an early age. They can thus be considered balanced bilinguals. We conducted the analyses excluding them, and the pattern of results remained the same.
- 5- Only one difference was found in Analysis 1 for the total RT word 1 measure where the Type x Direction interaction was not significant ( $p = .56$ ).
- 6- To check comparability between the two groups, we gave the participants who completed the familiarity rating task the same V\_YesNo Vocabulary test. Their scores ( $M = 6568.96$ ,  $SD = 1127.03$ ) were similar to those of the main group (see *Participants*) and the difference was not significant: ( $t(60) = -0.43$ , 95% CI [-803.27, 517.08],  $p = .67$ ,  $d = 0.12$ ).
- 7- For the first-pass RT measure for word 1 we did not include word 3 length or word 3 Zipf frequency as word 3 had not been encountered in reading yet at this point.
- 8- The study employed a within-subject design (i.e., all participants saw items under all conditions: existing binomials, 2-repetition novel binomials, and 4-repetition novel binomials). Thus, we only included by-participant random slopes (no by-item slopes) to account for the random variation in repeated measures (see Linck & Cunnings, 2015).
- 9- This model also included all possible two-way interactions to control for their effect: Direction x Vocabulary Score and Type x Vocabulary Score. This was



also the case in Analysis 2 which included Category x Vocabulary Score and Iteration x Vocabulary Score.

10- While Conklin and Carrol (2021) found a processing cost for reversing a novel binomial after four to five exposures, it is the only study to investigate the development of a sensitivity to word order for novel binomials in native speakers from natural reading. More research is needed to firmly establish the emergence of such a sensitivity.

## Supplementary Materials

**Appendix S1: A full list of the existing and novel binomials used in the experiment, with raw frequencies and ratio of forward to backward occurrences**

Phrase	Forward Freq	Forward Zipf	Backward Freq	Backward Zipf	Ratio	Forward Association	Backward Association	Repetitions (in text)	Existence in Arabic	Direction in Arabic	Familiarity rating
<b>Existing binomials</b>											
aches and pains	71.00	2.86	1.00	1.30	71.00	0.62	0.04	1.00	Existing	Forward	4.39
black and white	1119.00	4.05	57.00	2.76	19.63	0.58	0.55	1.00	Existing	<b>Both</b>	7.00
boys and girls	383.00	3.58	93.00	2.97	4.12	0.81	0.50	1.00	Existing	<b>Both</b>	6.96
brother and sister	473.00	3.68	27.00	2.45	17.52	0.57	0.63	1.00	Existing	Forward	6.91
food and drink	210.00	3.32	8.00	1.95	26.25	0.14	0.01	1.00	Existing	Forward	6.96
knife and fork	150.00	3.18	4.00	1.70	37.50	0.45	0.65	1.00	Existing	<b>Reverse</b>	6.70
mum and dad	516.00	3.71	11.00	2.08	46.91	0.70	0.56	1.00	Existing	<b>Both</b>	7.00
name and address	657.00	3.82	2.00	1.48	328.50	0.10	0.13	1.00	Existing	Forward	6.96
son and daughter	133.00	3.13	11.00	2.08	12.09	0.49	0.63	1.00	Existing	<b>Reverse</b>	6.70
tea and coffee	133.00	3.13	19.00	2.30	7.00	0.18	0.39	1.00	Existing	<b>Both</b>	6.78
time and money	271.00	3.43	29.00	2.48	9.34	0.00	0.00	1.00	Existing	Forward	6.22
wind and rain	103.00	3.02	17.00	2.26	6.06	0.10	0.00	1.00	Existing	Forward	5.57

<b>Phrase</b>	<b>Forward Freq</b>	<b>Forward Zipf</b>	<b>Backward Freq</b>	<b>Backward Zipf</b>	<b>Ratio</b>	<b>Forward Association</b>	<b>Backward Association</b>	<b>Repetitions (in text)</b>	<b>Existence in Arabic</b>	<b>Direction in Arabic</b>	<b>Familiarity rating</b>
<b>Novel binomials</b>											
bags and coats	9.00	2.00	2.00	1.48	4.50	0.00	0.00	4.00	Novel	---	4.83
boat and train	3.00	1.60	4.00	1.70	0.75	0.02	0.03	2.00	Novel	---	4.13
bottles and tins	5.00	1.78	3.00	1.60	1.67	0.00	0.00	2.00	Novel	---	3.61
cards and gifts	3.00	1.60	1.00	1.30	3.00	0.01	0.00	2.00	Novel	---	5.70
chickens and rabbits	3.00	1.60	2.00	1.48	1.50	0.00	0.00	2.00	Novel	---	3.70
eggs and milk	8.00	1.95	11.00	2.08	0.73	0.01	0.01	4.00	<b>Existing</b>	<b>Reverse</b>	6.30
farms and houses	4.00	1.70	9.00	2.00	0.44	0.12	0.00	4.00	Novel	---	5.43
games and music	2.00	1.48	1.00	1.30	2.00	0.00	0.00	4.00	Novel	---	4.30
goats and pigs	1.00	1.30	0.00	1.00	0.00	0.02	0.00	2.00	Novel	---	3.09
grass and leaves	4.00	1.70	6.00	1.85	0.67	0.00	0.00	2.00	Novel	---	5.48
kitchen and bedrooms	6.00	1.85	3.00	1.60	2.00	0.01	0.00	2.00	Novel	---	5.00
paint and glue	2.00	1.48	2.00	1.48	1.00	0.00	0.02	2.00	Novel	---	4.26
plates and glasses	5.00	1.78	1.00	1.30	5.00	0.06	0.00	4.00	<b>Existing</b>	<b>Reverse</b>	5.52
shelves and drawers	2.00	1.48	1.00	1.30	2.00	0.01	0.00	4.00	Novel	---	5.96
spoons and bowls	1.00	1.30	1.00	1.30	1.00	0.00	0.03	4.00	Novel	---	4.87

<b>Phrase</b>	<b>Forward Freq</b>	<b>Forward Zipf</b>	<b>Backward Freq</b>	<b>Backward Zipf</b>	<b>Ratio</b>	<b>Forward Association</b>	<b>Backward Association</b>	<b>Repetitions (in text)</b>	<b>Existence in Arabic</b>	<b>Direction in Arabic</b>	<b>Familiarity rating</b>
stone and wood	3.00	1.60	7.00	1.90	0.43	0.01	0.02	2.00	Novel	---	5.00
stories and jokes	2.00	1.48	3.00	1.60	0.67	0.00	0.00	4.00	Novel	---	5.61
tennis and football	1.00	1.30	2.00	1.48	0.50	0.00	0.01	4.00	Novel	---	5.26
walls and fences	11.00	2.08	5.00	1.78	2.20	0.04	0.02	4.00	Novel	---	4.65
wires and pipes	3.00	1.60	3.00	1.60	1.00	0.00	0.00	2.00	Novel	---	4.39

Zipf frequencies (scale from 1 to 7 with 7 being highest frequency), association strength (from 0.00 to 1.00), and familiarity rating (scale from 1 to 7 with 7 being highest familiarity).

## Appendix S2: Item characteristics for all existing and novel binomials

Binomial Type	Zipf forward form	Zipf reversed form	Association strength (Forward)	Association strength (Backward)	Word 1 Length	Word 1 Zipf	Word 3 Length	Word 3 Zipf
Existing binomials ( <i>n</i> = 12)	3.41 (0.36)	2.15 (0.50)	0.40 (0.28)	0.34 (0.28)	4.25 (1.14)	5.10 (0.55)	5.25 (1.36)	4.93 (0.40)
	2.86 - 4.05	1.30 - 2.97	0.00 - 0.81	0.00 - 0.65	3.00 - 7.00	4.00 - 6.24	3.00 - 8.00	4.00 - 5.56
Novel binomials ( <i>n</i> = 20)	1.63 (0.23)	1.56 (0.27)	0.02 (0.03)	0.01 (0.01)	5.50 (1.10)	4.75 (0.36)	5.45 (1.23)	4.69 (0.40)
	1.30 - 2.08	1.00 - 2.08	0.00 - 0.12	0.00 - 0.03	4.00 - 8.00	4.02 - 5.30	4.00 - 8.00	4.03 - 5.79

Mean values are provided with standard deviation in parentheses and range underneath. Frequency is expressed on the Zipf scale (Van Heuven et al., 2014) from 1 to 7; association strength

(Edinburgh Associative Thesaurus, Kiss et al., 1973) is measured on a scale from 0.00 to 1.00; word length is measured in characters.

### **Appendix S3: Procedures of operationalizing congruency**

Operationalizing congruency was done in two steps. In the first step, we presented the 32 target items to five proficient Arabic-English speakers and asked them to decide if each English target existed in Arabic, that is, whether the direct translation of the English binomial yielded a common expression in Arabic. Only items with an 'existence' decision that was shared by at least three of the five judges were classified as 'existing in both languages' or 'existing only in one language', respectively. All 'existing' binomials were also 'existing' in Arabic. However, for the 'novel' category, there was a mismatch whereby two English novel binomials were common in Arabic.

The second step for defining congruency evaluated the direction of the 'existing' binomials (forward vs. reverse). Initially, we asked the five Arabic-English bilinguals to decide on the most common direction in Arabic, but there was considerable variation in judgements. Then, we used the [Arabic Corpus Tool \(https://arabiccorpus.byu.edu/\)](https://arabiccorpus.byu.edu/), but it did not include occurrences of all binomials. Eventually, we decided to use Google as a corpus and searched for the literal Arabic translation of the 12 'existing' binomials in both directions such as 'boys and girls' (forward) vs. 'girls and boys' (reverse). An arbitrary, threshold of 3/1 was set for a conventionalized direction of a given binomial. It should be noted that this is a low threshold in comparison to the original threshold set by Conklin and Carrol (2021). The small difference between the 'forward' and 'reverse' direction for the translated binomials in Arabic seems to suggest that, unlike English, Arabic is more tolerant when it comes to binomial configurations. While the average 'forward-reverse' ratio for the six binomials that existed in both languages was 76:1 ( $SD = 125.71$ ) for the English version according to the BNC frequency, it was only 10:1 ( $SD = 13.88$ ) for their Arabic equivalents based on Google frequency. At the end, we found that of the 12 existing binomials, six had the same direction in both Arabic and English while the other six either had no preferred order or had the opposite order.

**Appendix S4: Pairwise comparisons between forward and reversed forms for existing and novel binomials for whole phrase RTs, word 1 and word 3**

				<i>Estimate</i>	<i>SE</i>	<i>t</i>	<i>lower</i>	<i>upper</i>	<i>p</i>		<i>Cohen's d</i>
<b>First-pass RT</b>	Whole phrase	Existing binomials	Forward - reversed	-0.01	0.04	-0.24	-0.08	0.06	.81		-0.01
		Novel binomials	Forward - reversed	0.15	0.03	5.11	0.09	0.21	< .001	***	0.25
	Word 1	Existing binomials	Forward - reversed	0.03	0.03	0.99	-0.03	0.08	.32		0.06
		Novel binomials*	Forward - reversed	0.09	0.02	4.31	0.05	0.14	< .001	***	0.21
	Word 3	Existing binomials	Forward - reversed	-0.02	0.03	-0.84	-0.07	0.03	.40		-0.05
		Novel binomials	Forward - reversed	0.16	0.02	8.03	0.12	0.20	< .001	***	0.40
<b>Total RT</b>	Whole phrase	Existing binomials	Forward - reversed	-0.01	0.03	-0.39	-0.06	0.04	.69		-0.02
		Novel binomials	Forward - reversed	0.28	0.02	13.95	0.24	0.31	< .001	***	0.62
	Word 1	Existing binomials	Forward - reversed	0.02	0.03	0.50	-0.05	0.08	.62		0.03
		Novel binomials	Forward - reversed	0.16	0.02	6.44	0.11	0.20	< .001	***	0.32
	Word 3	Existing binomials	Forward - reversed	-0.03	0.03	-1.08	-0.09	0.03	.28		-0.07
		Novel binomials	Forward - reversed	0.25	0.02	10.69	0.20	0.30	< .001	***	0.52

\* The model for first-pass RT - word 1 (Table 2) shows no main or interacting effect of direction or phrase type. Thus, the significant 'forward-reversed' difference for novel binomials should be interpreted cautiously.

\*\*\* $p < .001$

**Appendix S5: Pairwise comparisons between first, last, and reversed iterations of novel binomials for whole phrase RTs, word 1 and word 3**

			<i>Estimate</i>	<i>SE</i>	<i>t</i>	<i>lower</i>	<i>upper</i>	<i>P</i>		<i>Cohen's d</i>
<b>First-pass RT</b>	Whole phrase	Iteration (first) - Iteration (last)	0.06	0.03	1.87	0.00	0.11	.06		0.09
		Iteration (first) - Iteration (reversed)	0.15	0.03	4.97	0.09	0.21	< .001	***	0.24
		Iteration (last) - Iteration (reversed)	0.09	0.03	3.10	0.03	0.152	.002	**	0.15
	Word 1	Iteration (first) - Iteration (last)	0.04	0.02	1.91	0.00	0.08	.06		0.09
		Iteration (first) - Iteration (reversed)	0.10	0.02	4.40	0.05	0.137	< .001	***	0.22
		Iteration (last) - Iteration (reversed)	0.05	0.02	2.48	0.01	0.10	.01	*	0.13
	Word 3	Iteration (first) - Iteration (last)	0.10	0.02	5.06	0.06	0.14	< .001	***	0.25
		Iteration (first) - Iteration (reversed)	0.16	0.02	7.94	0.12	0.20	< .001	***	0.39
		Iteration (last) - Iteration (reversed)	0.06	0.02	2.93	0.02	0.10	.003	**	0.14
<b>Total RT</b>	Whole phrase	Iteration (first) - Iteration (last)	0.16	0.02	7.98	0.12	0.19	< .001	***	0.34
		Iteration (first) - Iteration (reversed)	0.28	0.02	14.08	0.24	0.31	< .001	***	0.60
		Iteration (last) - Iteration (reversed)	0.12	0.02	6.10	0.08	0.16	< .001	***	0.26
	Word 1	Iteration (first) - Iteration (last)	0.07	0.02	3.10	0.03	0.120	.002	**	0.15
		Iteration (first) - Iteration (reversed)	0.16	0.02	6.55	0.11	0.20	< .001	***	0.31
		Iteration (last) - Iteration (reversed)	0.08	0.02	3.44	0.04	0.131	< .001	***	0.17
	Word 3	Iteration (first) - Iteration (last)	0.17	0.02	7.38	0.12	0.21	< .001	***	0.35
		Iteration (first) - Iteration (reversed)	0.25	0.02	10.73	0.20	0.30	< .001	***	0.52
		Iteration (last) - Iteration (reversed)	0.08	0.02	3.43	0.03	0.13	< .001	***	0.17

\*  $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$



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