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Producing and processing word combinations in an L2: An eye-tracking study exploring the individual learner experience

RESEARCH

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ABSTRACT

Integration between production data and processing data has generally been based on the combination between corpus-based measures and psycholinguistic experiments. The main limitation of this approach is that the sample of participants providing these two kinds of data will be different, thus entailing the impossibility of investigating how production and processing are related at the level of the individual. This is particularly true when it comes to a key component in second language development such as word combinations, which has attracted attention in both corpus linguistics and psycholinguistics, without ever addressing the individual learner experience. To tap into this area, we conducted a preliminary study by eliciting written texts from a group of learners of Italian as a second language (L2), identified a set of correct verb + noun (object) combinations in each text, performed lexical and grammatical manipulations and built individualised eye-tracking experiments for each of the same participants. We found that originally produced verb + noun (object) combinations are processed faster than manipulated combinations, that lexical manipulation affects processing more than grammatical manipulation and that a higher strength of association between the components of the combination determines a processing advantage in learners with an advanced level of proficiency. Theoretical and methodological implications for the analysis of production and processing in an L2 are discussed.

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1. INTRODUCTION

The integration of corpus data and psycholinguistic data is increasingly recognised as a guiding way forward for second language acquisition research (Durrant & Siyanova, 2015; Gilquin, 2021; Deshors & Gries, 2022). One major shortcoming that runs across the several studies integrating corpus and psycholinguistic data is that they each usually derive from different, though comparable, participant samples. If the learners contributing data that will form a corpus are different from those who take part in a psycholinguistic experiment, we will never really know what the relationship between production and processing of a linguistic structure is with reference to the individual learner.

As stated in Gilquin (2021, p.137), if "the objective is to investigate the same linguistic phenomenon in the two types of data (e.g., the use of collocations in corpus and experimental data), then, ideally, the subjects who contribute data to the learner corpus should be the same as those who take part in the experiment." Nevertheless, one immediate consequence of such an integration would be the dramatic reduction in the total number of participants involved, hence challenging "one of the key advantages of learner corpora, namely that they can give access to vast quantities of data produced by large samples of a learner population" (Gilquin 2021, p.137). To try to preserve this aspect would mean devoting adequate time to the compilation of a size-adequate corpus, and then, at a much later stage, attempting to contact the same learners who contributed to the corpus. This would mean, however, potentially finding the learner in a different development stage compared to the one they found themselves in when producing the data for the corpus, which would potentially defeat the purpose of the whole enterprise. Gilquin (2021, p.137) finally concludes that "[h]aving access to corpus and experimental data from the same subjects at the same stage of development implies that the researchers know right from the start what their objective is and what data they will need, and that they collect all the data at the same time for this very specific purpose".

The present study goes in this very direction. By accepting the limitation of not possessing vast quantities of production data, as would be the case when using corpora, we integrate written production data with eye-tracking data. We specifically focus on the area of word combinations, a key area in second language development, which has been extensively studied both with corpus-based and psycholinguistic methods, as well as with an integration of the two, but never with a focus on the individual learner experience. Our study investigates the relationship between the production and processing of verb + noun (object) combinations[1] in a group of Italian second-language (L2) speakers. More specifically, we intend to ascertain which properties are more likely to affect the processing of such combinations in each individual learner. Properties include their grammatical and lexical components, as well as strength of association, which typically identifies phraseological elements and is widely reported as key in second language competence development (Granger, 2021).

Theoretically, linking L2 production and processing is motivated by usage-based accounts (Bybee, 2006), which emphasise the role of frequency and entrenchment in language learning and suggest that linguistic representations emerge from repeated exposure and usage. In our study, this perspective is particularly relevant because it provides theoretical foundations for expecting a relationship between learners' production and processing. Specifically, if learners are more likely to produce certain combinations, this repeated usage may strengthen their mental representations, leading to faster processing. Our results are interpreted in light of the usage-based framework.

2. BACKGROUND

The integration of corpus and psycholinguistic data has frequently been promoted as a fruitful way to investigate linguistic phenomena, both in first language (L1) and L2 domains (Durrant & Siyanova-Chanturia, 2015; Gilquin & Gries, 2009). In line with the focus of the current study, we trace its background by focusing solely on eye-tracking studies that involve L2 speakers, multiword units of some kind, consider association strength and that are based on the extraction of stimuli from production data, i.e., corpora. As far as we know, no eye-tracking

1 With the term *combination*, we refer to any verb + noun (object) syntactic dependency, irrespective of the nature of the association between its elements.

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study has derived stimuli from the production data of a sample of participants (i.e., production data that was not part of a pre-collected corpus) who then took part in an individualised eye-tracking experiment.

To the best of our knowledge, Schilk (2020, 2021) are the only reports on a study that uses L2 corpus data to explore the production and processing of collocations (including those with a verb + noun [object] structure) by advanced learners of English. The eye-tracking experiment uses two types of stimuli: native-like collocations (i.e., those produced by L1 speakers, e.g., *to lose virginity*) derived from the British National Corpus (BNC), and interference-based collocations displaying L1 influence (e.g., *to find a family*) derived from two learner corpora (ICLE-GER and LINDSEI-GER). The study seeks to establish whether there are processing advantages for either the native-like or interference-based collocations, whether these differ from incongruous collocations (e.g., *to drink a question*) and whether differing performance can be observed when comparing intermediate and advanced learners. The study finds that the total fixation time for native-like collocations is significantly shorter than for the other two groups of stimuli (i.e., incongruous and interference-based collocations). Furthermore, Schilk (2021, p. 218) notes that learners, despite frequently producing native-like combinations, do not necessarily prefer interference-based collocations, as they process typical English collocations significantly faster. Their knowledge of similar combinations in their L1 may aid in decoding interference collocations, distinguishing them from incongruous collocations. Although Schilk's experiment did not include stimuli based on native-like collocations produced by learners – since they were selected from a native corpus – the observation that learners frequently generate such combinations highlights the need to assess their psycholinguistic dimension, a focus of the present study.

In a rare eye-tracking study involving a language other than English, Yi et al. (2017) analysed the processing of 80 Chinese adverbial sequences by a group of L1 and a group of L2 speakers of Chinese. The study examined the combined role of frequency and contingency, which was operationalised as "the probabilistic/predictive relationship between the constituent words in a sequence, which can be measured by a variety of probabilistic measures" (Yi et al., 2017, p. 522) and measured through Mutual Information (MI).[2] To do so, the authors divided the list of 80 adverbial sequences into the following four categories: 1) high frequency – high MI (e.g., *still did not*); 2) high frequency – low MI (e.g., *only did not*); 3) low frequency – high MI (e.g., *still very much*); 4) low frequency – low MI (e.g., *still had not*) (Yi et al., 2017, p. 532). The study found that both frequency and association strength influence the processing of adverbial sequences in both L1 and L2 speakers and across the vast majority of eye-movement measures considered. Association strength, in particular, appeared relevant for both L1 and L2 speakers when analysing fixation count, but only in L2 speakers when analysing first-pass reading time.

In a follow up to a previous eye-tracking study focused solely on L1 speakers, Li et al. (2022) examined the processing of adjective + noun collocations in a group of 38 L2 intermediate learners of English with an L1 Chinese background. The participants read 80 sentences, where each one included either a strongly associated or weakly associated adjective-noun collocation (e.g., *black coffee* and *bitter coffee*, respectively). The list of collocations was extracted from the BNC and was the same one used in Li et al. (2021). The study also considered the possible processing effect of predictability by inserting the collocations in either predictable or neutral context sentences (e.g., predictive context: *To wake up, Julie went to the cafeteria and ordered a black coffee / bitter coffee and a sandwich*; neutral context: *My friend and I decided to make some black coffee / bitter coffee this weekend*). The study found that the eye movement behaviour of the participants was influenced by both association strength as well as by contextual predictability. More specifically, participants' reading times, in terms of both first-pass reading time and regression back to the collocation, were faster when presented with strongly associated collocations. Furthermore, the predictive contexts determined a processing advantage over the neutral contexts, facilitating the recognition of the collocations.

Finally, Fioravanti et al. (2023) focused on verb + noun (object) collocations derived from an L1 corpus in order to explore how modifications of their typical form affect processing in L1 and L2 speakers (intermediate and advanced) of Italian. Modified collocations were developed

2 MI is a widely used association measure that shows how strongly associated two words are, based on their probability to occur together (Evert, 2008). It is able to inform us on how exclusive and rare the co-occurrence between two words is, and is, thus, one of the measures used most frequently to identify phraseological combinations, on the basis of a threshold value of 3 (Gablasova et al., 2017).

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by manipulating grammatical components (i.e., by inserting an agreement error) and lexical components (i.e., by substituting the verb with a synonym). Results showed that both types of modifications disrupt both L1 and L2 collocation processing, with lexical modification being more problematic than grammatical modification in terms of processing cost. Further, a significant effect of proficiency was found: Intermediate learners processed lexically manipulated collocations differently from L1 speakers and advanced learners, while advanced learners showed a processing pattern similar to L1 speakers.

In the reviewed studies, the relationship between proficiency level and processing is considered only in the studies conducted by Schilk (2020, 2021), while the others consider a more or less homogeneous level of proficiency (e.g., Yi et al., 2017, Li et al., 2022). This leads to a research gap in this area, as proficiency level, which can be considered as an indicator of the level of exposure that the participant has had to the language, is increasingly seen as a key variable to examine, especially in usage-based accounts of language learning (Bybee, 2006). As proficiency increases, learners accumulate more exposure to the L2, reinforcing the associative links between collocational elements and strengthening their mental representation. If collocations are represented in the L2 mental lexicon, they are likely to be produced by learners and their use could lead to faster processing. Another gap is represented by the fact that Schilk (2020, 2021) uses learner corpus data to retrieve erroneous, L1-influenced occurrences to build the eye-tracking experiment and assess the influence of this variable on processing by learners. However, learners are known to produce many good instances of the target language, though there is little evidence in relation to the psycholinguistic dimension of such instances, so we do not have a measure of how entrenched they might be (Schmid, 2000). Another aspect we know little about is the extent to which association strength might influence processing (see Yi et al., 2017; Li et al., 2022), and no evidence seems to be available in relation to how association strength might influence processing at different levels of proficiency. In our study, we seek to address these gaps, while also building up on Gilquin's (2021) and other scholars' considerations about the need to delve deeper into the relationship between product and process at the level of the single speaker.

3. CURRENT STUDY

3.1. DESIGN

The present study stems from a larger project seeking to explore the relationship between production and processing of phraseology in L2 Italian (see Fioravanti et al., 2023). It is based on individually tailored eye-tracking experiments containing stimuli derived from the written texts produced by a group of 24 learners, evenly divided into intermediate and advanced levels of proficiency. Tailoring the eye-tracking experiments on the specific combinations produced by each learner involved allows us to investigate more accurately the psycholinguistic underpinnings that a produced combination has in the mind of a single learner. This way, each learner is exposed to their own produced combinations. Additionally, each combination is manipulated lexically and grammatically to assess whether altering the lexical or the grammatical structure of learners' produced combinations disrupts their processing.

The specific research questions addressed by the study are:

1. How do L2 speakers of Italian process the typical verb + noun (object) combinations they produced in their own writing?
2. How does the lexical and grammatical manipulation of the verb + noun (object) combinations produced in their own writing by L2 speakers of Italian affect their processing?
3. Is the processing advantage (if observed) of typical verb + noun (object) combinations influenced by strength of association?

In the first research question we aim to explore the extent to which the correct use of Italian verb + noun (object) combinations by learners is connected with an actual competence related to those combinations. Our hypothesis is that, just as typical combinations produced by L1 speakers lead to a processing advantage in L2 speakers (Schilk, 2020, 2021), so will the typical combinations produced by L2 speakers themselves, possibly to an even greater

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extent. The second research question tackles the effect of two different manipulations (i.e., lexical and grammatical) on the processing of correct combinations. In line with our previous study (Fioravanti et al., 2023), we expect lexical manipulation to play a considerable role, with respect to grammatical manipulation. Finally, the third and last research question addresses the possible influence of strength of association in the verb + noun (object) combinations considered. We hypothesise the presence of an influence, specifically that a higher level of association will lead to lower processing costs, especially in the advanced learner group. Proficiency level is considered among the predictors across all three research questions. Specifically, we hypothesise that both intermediate and advanced learners will process typical collocations faster than manipulated collocations. Further, considering that association strength reflects speakers' linguistic experience (Carrol & Conklin, 2020), we expect advanced (but not intermediate) learners to be affected by the strength of association, as they may have more experience with the L2 than intermediate learners.

3.2. PARTICIPANTS

The present analyses are based on an analysis of 24 L2 speakers of Italian (mean age: 25.25) who were presented with a customised list of stimuli derived from their own written productions (see Section 3.3 for details). In addition to data on age, sex, and either normal or corrected-to-normal vision, participants also provided the following information about their linguistic background: L1, starting age of learning Italian, expected stay in Italy (in months), as well as their perceived proficiency in Italian (based on the CEFR levels) and a self-rated evaluation of their writing, reading, listening and speaking skills in Italian on a five-point Likert scale (1 = *very poor* to 5 = *excellent*). They were further screened on a Yes/No checklist for vocabulary assessment (LexITA, Amenta et al., 2021) and then divided into two main groups: intermediate learners, who scored a mean of at least 38/60 points on the LexITA and self-identified as B1-level learners, and advanced learners, who scored a mean of at least 51/60 on the LexITA and a self-reported C1 level.

Since our participants declared a self-related proficiency level, we assessed whether the two groups of learners differed in terms of proficiency skills. We derived the mean of self-rated proficiency skills for each learner and observed that the two proficiency groups significantly differed in the mean of the four proficiency skills ($p < .001$). Spearman's rank correlation was also computed in order to assess the relationship between the LexITA score and learners' proficiency level and a positive correlation was found between the two variables ($r = .7$, $p < .001$). While variations in their first contact with Italian were nuanced, the difference between the two groups was statistically significant ($p < .001$) in terms of the mean value of time spent in Italy (intermediate: 2.6 months; advanced: 92.3 months). Learners' metadata are shown in Table 1.

Table 1 Participant metadata.

Note. °Based on a 5-point scale (1 = *very poor*, 2 = *weak*, 3 = *OK*, 4 = *very good*, 5 = *excellent*).

INTERMEDIATE LEARNERS			
VARIABLES	***MEAN***	***SD***	***RANGE***
First contact with Italian (in years)	21.2	1.8	19–25
Time spent in Italy (in months)	2.6	0.9	2–5
Speaking°	2.8	0.5	2–4
Writing°	2.6	0.7	1–4
Listening°	3.3	0.6	2–4
Reading°	3.6	0.5	3–4
ADVANCED LEARNERS			
First contact with Italian (in years)	19.1	6.1	3–26
Time spent in Italy (in months)	92.3	112.9	1–360
Speaking°	4	0.7	3–5
Writing°	3.2	0.6	2–4
Listening°	4.2	0.6	3–5
Reading°	4.1	0.7	3–5

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3.3. IDENTIFICATION AND MANIPULATION OF STIMULI

The 24 participants were asked to produce a short essay (800–1000 words) on the topic "Describe the activities you enjoy doing in your free time". The texts were written on the online platform Exam.net. The platform did not allow for any other browser activity and participants were supervised for the duration of the task. The 24 texts were randomly divided into two groups of 12, each of which was assigned to a group of three annotators. Each text was then annotated with respect to the identification of correct and incorrect or non-typical verb + noun (object) combinations. To this end, an error annotation scheme, building on Spina (2019), was developed. The scheme contained three broad categories: correct combinations, incorrect combinations due to lexical errors and incorrect combinations due to grammatical errors. For the purposes of the present study, only combinations judged as correct by all three annotators of a given combination were considered. The relatively short length of the essays made it challenging to find an equal number of verb + noun (object) combinations across all texts. In the end, 12 combinations from each of the 24 written texts produced were selected, creating a total of 288 combinations.

Each set of 12 combinations was then listed in random order. The first six items from each list were manipulated lexically, while the second group of six items was manipulated grammatically. Lexical manipulation was conducted by substituting the verb with a synonym, producing a lexically non-typical combination.[3] Possible differences in length between the original verb and its synonym were limited to a range of +/− 3 characters. For example, the combination *condividere* + *emozione* [to share + emotion], was modified into *spartire* + *emozione* [to divide + emotion]. The non-typicality of the resulting combination was checked against a reference corpus of Italian (Perugia corpus; Spina, 2014) in order to ensure absence of usage. Grammatical manipulation was conducted by inserting an agreement error into the combination. For example, the combination *parlare la*$_{[singular]}$ *lingua*$_{[singular]}$ [to speak the language] was modified into *parlare le*$_{*[plural]}$ *lingua*$_{[singular]}$. Both the grammatical and lexical manipulations reflected the trends observed in the error analysis performed on the basis of the aforementioned error annotation scheme.

Further, as our third research question aimed to address a possible effect of strength of association on the processing of typical combinations, we operationalised strength of association in terms of MI. Although MI overestimates the importance of rare collocations compared to other association measures (e.g., LogDice; Gablasova et al., 2017), we employed MI as it has been found to be a stronger predictor of phraseological processing advantage compared to phrase frequency (Carrol & Conklin, 2020). We then derived the information about MI as well as phrase frequency from the Perugia Corpus (Spina, 2014) for each set of 12 combinations. Combinations produced by learners were placed on a continuum of MI. Table 2 presents descriptive data on MI and phrase frequency for all combinations, as well as for those produced by intermediate and advanced learners separately. On average, intermediate learners produced more frequent combinations than advanced learners. In contrast, advanced learners produced more highly associated combinations compared to intermediate learners.

Table 2 Descriptive data on MI and phrase frequency of combinations.

ALL COMBINATIONS			
VARIABLES	***MEDIAN***	***SD***	***RANGE***
Phrase frequency	94.8	182.5	1–953
MI	3.6	2.5	0.001– 10.4
COMBINATIONS PRODUCED BY INTERMEDIATE LEARNERS			
Phrase frequency	108.6	211.4	1–953
MI	3.41	2.55	0.001–10.4
COMBINATIONS PRODUCED BY ADVANCED LEARNERS			
Phrase frequency	81.2	147.4	1–871
MI	3.75	2.54	0.001–9.46

3 Synonyms were identified using the Treccani dictionary (https://www.treccani.it/vocabolario). For each verb we retrieved its synonyms from the reference dictionary and sorted them according to usage. The first verb in the list was chosen and its length and frequency were checked against the original one.

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Overall, 24 stimuli were identified for each of the 24 eye-tracking experiments constructed, creating a total of 576 experimental items (i.e., 288 intact combinations and 288 manipulated combinations). Each participant was thus exposed to 12 of the correct combinations that they produced in their own writing, with six of these being manipulated lexically and the other six being manipulated grammatically, for a total of 24 stimuli in each eye-tracking experiment (12 intact and 12 manipulated). Intact and manipulated stimuli were then embedded into 24 context sentences for each of the 24 experiments. Sample combinations in intact and manipulated versions can be found in Table 3.

Table 3 Sample intact and manipulated combinations used in the eye-tracking experiments.

INTACT COMBINATION	MANIPULATED COMBINATION
*Di solito preferisco **visitare una città** da sola scrivendo su un diario tutto ciò che vedo.*	*Di solito preferisco **esaminare una città** da sola scrivendo su un diario tutto ciò che vedo.*
[Usually, I prefer to visit a city on my own writing everything I see on a diary.]	[Usually, I prefer to examine a city on my own writing everything I see on a diary.]
	[lexical manipulation]
*Per me è importante **ascoltare musica** perché mi aiuta a rilassarmi quando sono stressata.*	*Per me è importante **ascoltare le musica** perché mi aiuta a rilassarmi quando sono stressata.*
[To me it is important to listen to music because it helps me to relax when I get stressed.]	[To me it is important to listen to the$_{[plural]}$ music$_{[singular]}$ because it helps me to relax when I get stressed.]
	[grammatical manipulation]

3.4. PROCEDURE

The individual eye-tracking sessions were scheduled for a minimum of three weeks after the written production (see Section 3.3). Participants were instructed to read sentences for comprehension. Experimental sentences contained the stimuli described in Section 3.3 and were integrated with 24 filler sentences (i.e., sentences unrelated to the experiment, added in order to prevent participants from identifying the aim of the experiment). The elements of the selected collocations were not used in the filler sentences. Each filler sentence was followed by a Yes/No question (for a total of 24 comprehension questions). The questions were included to ensure that participants read with focus. Experimental and filler sentences were displayed randomly. The trial was not timed, meaning that it was up to the subject when to move on to the next sentence, by clicking on the mouse button once they felt they were ready. For the reading experiment, we used Tobii Pro Lab (v.1.118) on a 24-inch screen monitor and provided participants with a chin rest. Data analyses were run on an area of interest (AOI) drawn over the verb + noun (object) region of each sentence. We considered the total duration of fixations (TDFs, total reading time) and the number of fixations (NFs, otherwise known as fixation count), as late measures are usually more sensitive to readers' recovery from processing difficulties (Clifton et al., 2007).

3.5. DATA ANALYSIS

Three different aspects were under investigation:

1. how L2 speakers of Italian process the typical verb + noun (object) combinations they produced in their own writing,
2. how lexical and grammatical manipulation of the verb + noun (object) combinations produced by learners affect their processing,
3. whether the processing advantage (if observed) of typical verb + noun (object) combinations is influenced by strength of association.

Eye movement data were cleaned and all zero values were removed as they occurred if readers skipped the AOI or if the tracking was lost. Data loss accounted for 1.4% of the total data. Participants had no difficulty in answering the comprehension questions. We carried out linear mixed-effects models (Cunnings & Finlayson, 2015; Gries, 2015; Linck & Cunnings, 2015; Murakami, 2016) to investigate processing of typical and atypical word combinations. Models were run for two eye-tracking measures: TDFs and NFs. Since in this last case the dependent

variable is discrete, we used a generalised linear mixed-effect model with a Poisson distribution when fitting the model. The numeric dependent variable (TDF) was logarithmically transformed. Descriptive statistics for the two dependent variables can be found in Table 4.

VARIABLE	*MEAN*	*SD*	*RANGE*
Total duration of fixations (ms)	1107	603.8	263–4384
Number of fixations	5	2.98	1–20

Table 4 Mean fixation durations (in milliseconds) and mean fixation count with standard deviation (SD).

To address the first two aspects, the following predictors were included in the two models: proficiency (two-level categorical variable: intermediate and advanced), manipulation (three-level categorical variable: original, lexical, and grammatical) and length of the AOI in number of letters (continuous variable; mean = 15.5; *SD* = 3.3; range = 7–24), and phrase frequency (the raw frequency of word combinations derived from the reference corpus). The intermediate learners and the original manipulation were set as the reference level in all the analyses. Proficiency, manipulation and their two-way interaction were included as core predictors. Length and phrase frequency were selected as control predictors, as previous research has demonstrated that they affect the online processing of both single words and multi-word expressions (Kliegl et al., 2004; Ellis, Simpson-Vlach, & Maynard, 2008; Rayner, 2009). Phrase frequency was logarithmically transformed.

To investigate whether the processing of typical verb + noun (object) word combinations was influenced by strength of association (i.e., MI), we considered only the typical word combinations produced by learners in their own writing. We carried out two models – one for each eye-tracking measure (i.e., TDF and NF) – including the following predictors: proficiency, MI (numeric variable), length, and phrase frequency. Proficiency and MI and their two-way interaction were included as core predictors. MI was included as a continuous variable as our aim was to observe whether increasing the strength of association led to faster reading of word combinations. In all the analyses, participants were included in the models as a random effect by fitting a by-subject random intercept for each of them.

Models were carried out using R (Version 4.4.1; R Core Team, 2024) and the R package lme4 (Version 1.1–28; Bates et al., 2015). We built models starting with all core predictors and control predictors and specifying a maximally random structure (by-subject and by-item slopes and intercepts) and we removed random slopes in case of convergence issues (Barr et al., 2013). Assumptions of the final models (linearity, normality of residuals, normality of random effects, and homogeneity of variance) were checked by producing validation graphs. Finally, multicollinearity was checked using Variance Inflation Factors (VIF): All scores were smaller than five. For each significant effect, the estimated coefficient (β), standard error (SE), *t*, effect size (*d*), and *p* values are reported.

4. RESULTS

We start by reporting the results of the first models – TDF model(a) and NF model(a) – with the interaction between proficiency and manipulation, which assessed how learners produced typical and manipulated verb + noun (object) combinations and a possible influence of L2 proficiency. The TDF model(a), the main effects and their *p* values can be found in Table 5. The model's explanatory power is moderate (R^2 = .24), and the part related to the fixed effects alone (marginal R^2) is .13, indicating that the variability is due more to the individual behavior of learners than to the influence of the selected predictors. However, for language-related phenomena, such explanatory power can be considered relevant (Ellis and Larsen Freeman 2006). Length (*b* = 0.01, *t* = 5.81, *p* <.001) and lexical manipulation ((*b* = 0.13, *t* = 4.72, *p* <.001) significantly affected the duration of fixations on the AOIs. The interaction between proficiency and manipulation was not significant: Learners' proficiency did not affect the processing of the original and the manipulated combinations.

	b	STD. ERROR	95% CI	*T*	*P*
(Intercept)	2.6934	0.0559	[2.58–2.80]	48.171	**<.001**
Length	0.0158	0.0027	[0.01–0.02]	5.811	**<.001**
Phrase frequency	–0.005	0.0110	[–0.03–0.02]	–0.469	0.639
Proficiency (advanced)	0.0474	0.0379	[–0–03 – 0.13]	1.249	0.221
Manipulation(grammatical)	–0.006	0.0281	[–0.06–0.05]	–0.212	0.832
Manipulation(lexical)	0.1329	0.0281	[0.08–0.19]	4.716	**<.001**
Proficiency (advanced): Manipulation (grammatical)	0.0287	0.0395	[–0.05–0.11]	0.728	0.467
Proficiency (advanced): Manipulation (lexical)	–0.0282	0.0397	[–0.11–0.05]	–0.711	0.477
RANDOM EFFECTS	**VARIANCE**	***SD***			
Subject	0.0054	0.0740			
Residual	0.0371	0.1926			
R^2 conditional/marginal	0.24/0.13				

Table 5 Summary of the TDF model(a).

The positive effect of length suggests that longer combinations (in terms of number of letters) are processed more slowly than shorter combinations, thus confirming similar findings from previous research (e.g., Kliegl et al., 2004; Rayner 2009). Learners' reading times were significantly affected by lexical manipulation. Its positive estimate suggests that learners took more time to process lexically manipulated combinations compared to typical combinations. Although the value of grammatical manipulation is not significant, it is noteworthy that learners read grammatically manipulated combinations slightly more slowly than typical combinations (Figure 1).

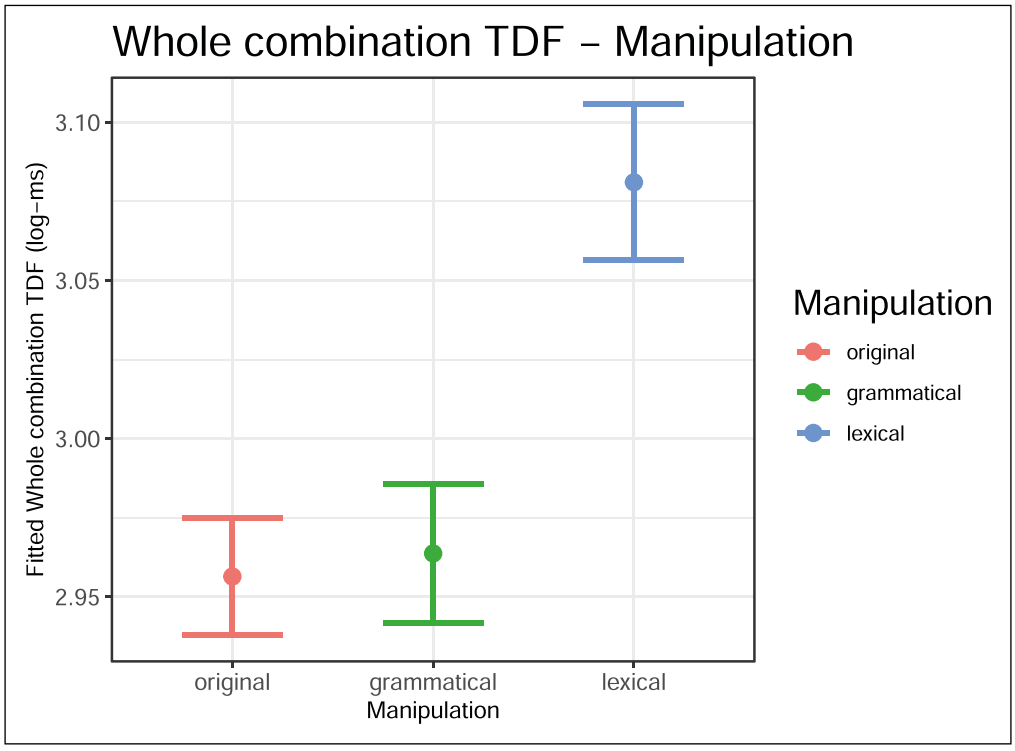

Figure 1 TDF predicted by Manipulation.

The NF model(a) indicates similar results. Table 6 shows the model, its main effects, and their *p* values. The model's total explanatory power is substantial (R^2 = 0.28), and the part related to the fixed effects alone (marginal R^2) is 0.14. Length (b = 0.98, t = 7.67, p < .001) and Lexical Manipulation (b = 0.29, t = 4.82, p < .001) significantly affected the number of fixations. Again, we did not find any effect of proficiency.

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	b	STD. ERROR	95% CI	*Z*	*P*
(Intercept)	0.9833	0.1283	[0.73–1.23]	7.661	**<.001**
Length	0.0393	0.0060	[0.03–0.05]	6.534	**<.001**
Phrase frequency	–0.0351	0.0249	[–0.08–0.01]	–1.409	0.159
Proficiency (advanced)	0.1021	0.0927	[–0.08–0.28]	1.101	0.271
Manipulation(grammatical)	0.0532	0.0653	[–0.07–0.18]	0.815	0.415
Manipulation(lexical)	0.2943	0.0601	[0.17–0.41]	4.828	**<.001**
Proficiency (advanced): Manipulation (grammatical)	0.0121	0.0894	[–0.16–0.19]	–1.135	0.892
Proficiency (advanced): Manipulation (lexical)	–0.1389	0.0848	[–0.30–0.03]	–1.638	0.101
RANDOM EFFECTS	**VARIANCE**	***SD***			
Subject	0.0345	0.1859			
R^2 conditional/marginal	0.28/0.14				

Table 6 Summary of the NF model(a).

Learners fixated on longer combinations more frequently than shorter combinations. Further, only lexical manipulation affected learners' number of fixations, suggesting that L2 speakers fixated lexically manipulated combinations more frequently than typical combinations. Although the grammatical manipulation is not significant, its positive estimate indicates that learners fixated typical combinations less frequently than grammatically manipulated ones (Figure 2). Comparing the results for TDF and NF, it is noteworthy that learners fixated more frequently combinations with grammatical manipulation with respect to typical combinations. However, they were likely to read grammatically manipulated combinations in a similar way to typical combinations in terms of reading times. This tendency suggests that learners were able to recover quickly from grammatical errors.

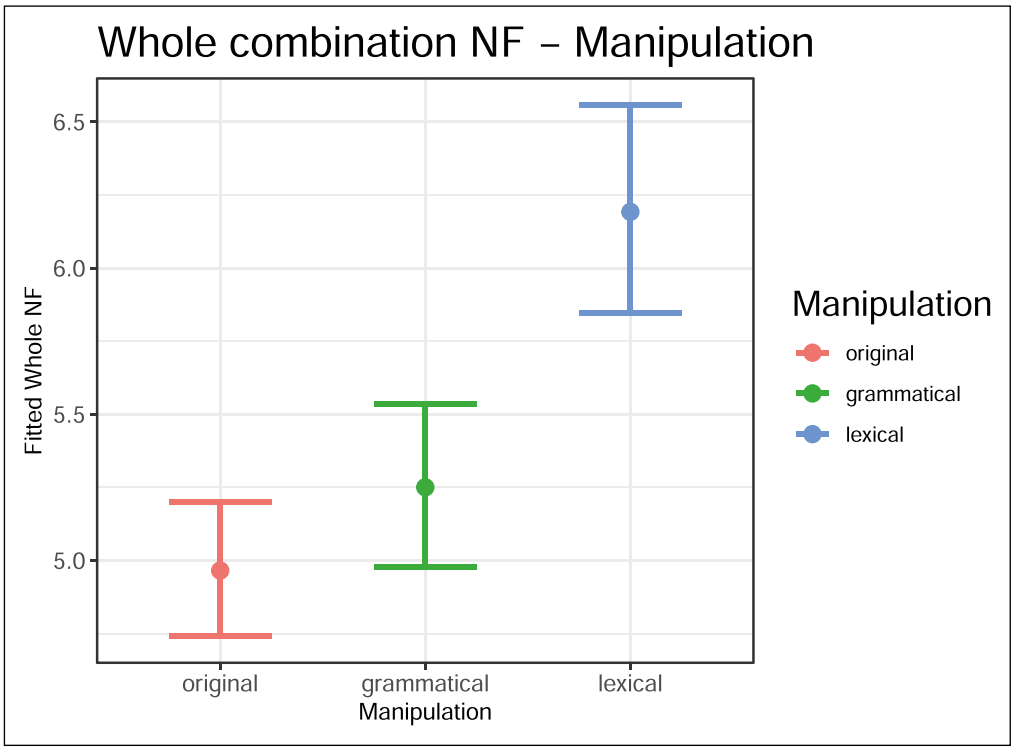

Figure 2 NF predicted by Manipulation.

We now turn to the results of the second group of models – i.e., TDF model(b) and NF model(b) – which assess the influence of strength of association (measured in terms of MI) on the typical verb + noun (object) combinations. To this aim, we considered only typical combinations and investigated the effects of the two-way interaction between proficiency and MI along with the control predictors (i.e., length, and phrase frequency).

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The TDF model(b), the main effects and their *p* values can be found in Table 7. The model's explanatory power is moderate (R^2 = .24), and the part related to the fixed effects alone (marginal R^2) is .11.

	b	STD. ERROR	95% CI	*T*	*P*
(Intercept)	2.6407	0.0723	[2.49–2.78]	36.523	**<.001**
Length	0.0171	0.0036	[0.01–0.02]	4.704	**<.001**
Phrase frequency	−0.0081	0.0178	[−0.04–0.03]	−0.453	0.17
Proficiency (advanced)	0.1209	0.0488	[0.02–0.22]	2.473	**0.016**
MI	0.0109	0.0068	[−0.01–0.02]	1.614	0.11
Proficiency (advanced): MI	−0.0206	0.0087	[−0.04– −0.01]	−2.362	**0.019**
RANDOM EFFECTS	**VARIANCE**	***SD***			
Subject	0.0055	0.0742			
Residual	0.0326	0.1808			
R^2 conditional/marginal	0.24/0.11				

Table 7 Summary of the TDF model(b).

Length (*b* = 2.64, *t* = 36.52, *p* < .001) and the interaction between proficiency (advanced) and MI (*b* = −0.02, *t* = −2.36, *p* = 0.019) were significant. Again, learners took more time reading longer typical combinations compared to the shorter ones. Interestingly, the interaction between proficiency and MI showed a significant effect of strength of association modulated by proficiency. Specifically, advanced learners took less time in reading highly associated combinations than less associated combinations compared to intermediate learners. Indeed, the results show an inverse trend between intermediate and advanced learners. While intermediate learners read low-MI combinations faster than high-MI combinations, the opposite occurs in advanced learners: Highly associated combinations are processed faster than weakly associated ones (Figure 3).

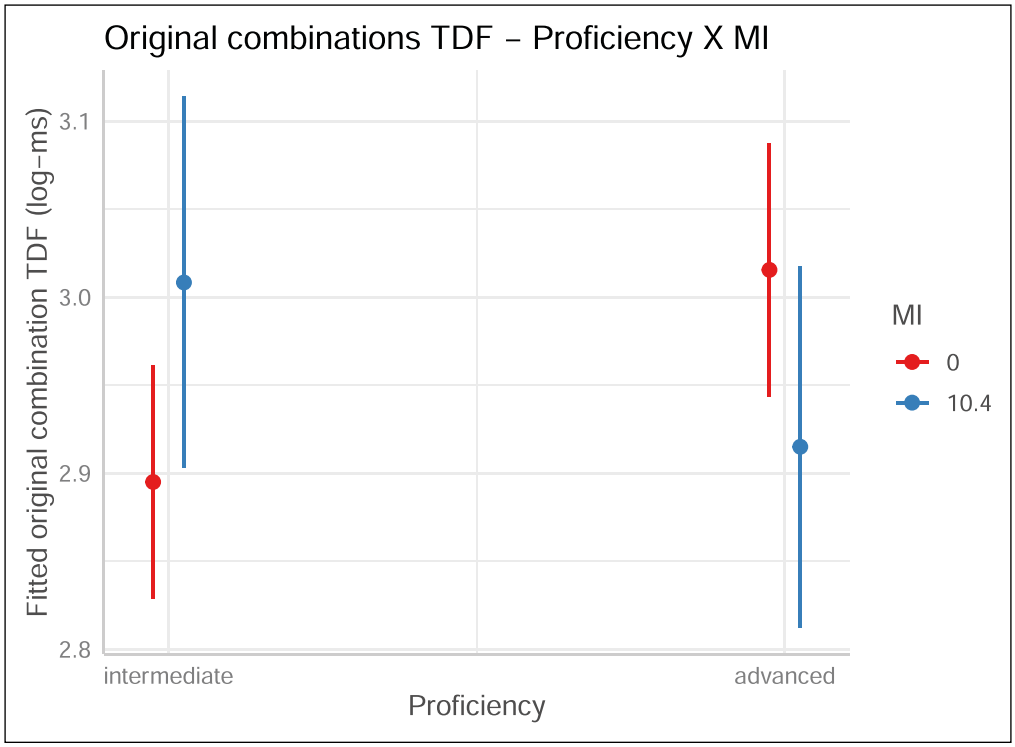

Figure 3 TDF predicted by the interaction between Proficiency and MI.

Again, the NF model(b) indicates similar results. Table 8 shows the model, its main effects, and their *p* values. The model's total explanatory power is substantial (R^2 = 0.28), and the part related to the fixed effects alone (marginal R^2) is 0.14. Length (*b* = 0.04, *t* = 4.58, *p* < .001) and the interaction Proficiency (advanced) x MI (*b* = −0.05, *t* = −2.67, *p* = .007) significantly affected the number of fixations.

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	b	STD. ERROR	95% CI	*Z*	*P*
(Intercept)	0.8239	0.1799	[0.47–1.77]	4.578	**<.001**
Length	0.0434	0.0088	[0.03–0.06]	4.925	**<.001**
Phrase frequency	–0.0568	0.0451	[–0.14–0.03]	–1.259	0.21
Proficiency (advanced)	0.3003	0.1181	[0.07–0.53]	2.538	**0.01**
MI	0.0353	0.0164	[0.003–0.07]	2.169	**0.03**
Proficiency (advanced): MI	–0.0566	0.0211	[–0.09– –0.01]	–2.674	**0.007**
RANDOM EFFECTS	**VARIANCE**	***SD***			
Subject	0.0317	0.1781			
R^2 conditional/marginal	0.27/0.14				

Table 8 Summary of the NF model(b).

Unsurprisingly, learners fixated more frequently on longer combinations with respect to shorter ones. The interaction between Proficiency and MI confirmed the opposite trend between intermediate and advanced learners, with advanced learners fixating less frequently on highly associated combinations compared to weakly associated ones. In contrast, high-MI combinations elicited more fixations from intermediate learners compared to low-MI combinations (Figure 4).

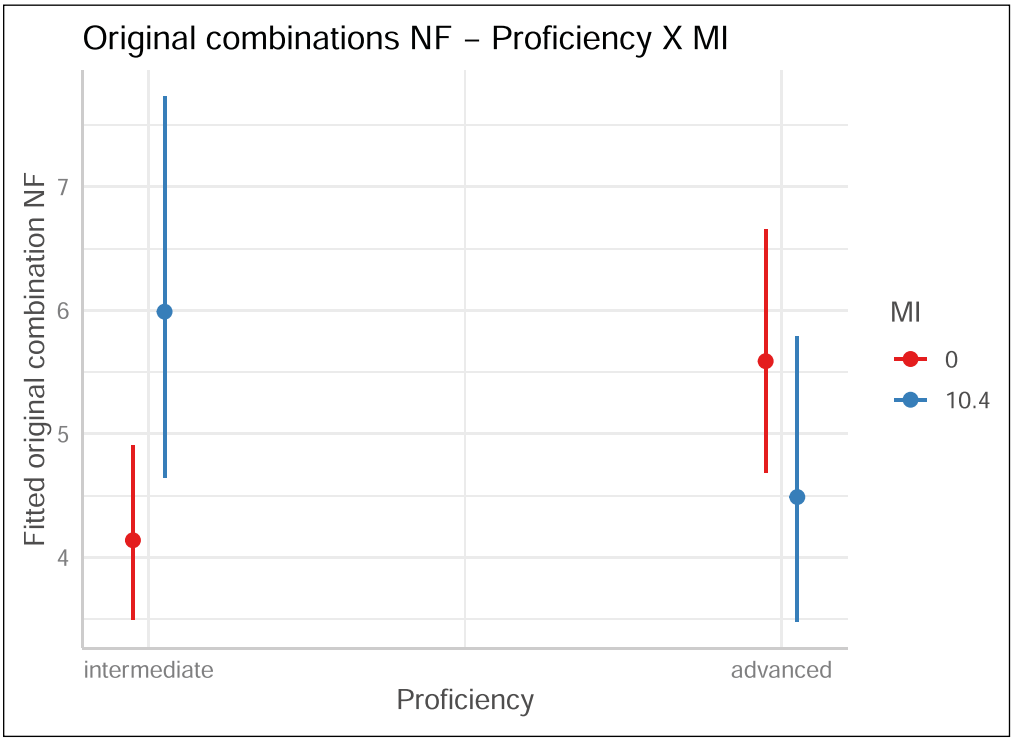

Figure 4 NF predicted by the interaction between Proficiency and MI.

5. DISCUSSION

5.1. HOW DO L2 SPEAKERS OF ITALIAN PROCESS THE TYPICAL VERB + NOUN (OBJECT) COMBINATIONS THEY PRODUCED IN THEIR OWN WRITING?

In our first research question we looked into the overall relationship between typical verb + noun (object) combinations and the way they are processed. Overall, learners exhibited a tendency to process the typical, target-like combinations they produced in their own writing faster than the manipulated counterparts, with no differences between the two proficiency levels considered. Some interesting links can be established between our findings and those reported by Schilk (2020, 2021). In Schilk's eye-tracking experiment, the typical native-like collocations were extracted from L1 corpora and compared with erroneous L1-informed collocations extracted from two learner corpora. The advanced learners in the study processed the typical collocations faster than the atypical ones, even though these contained elements that would be familiar to them because they were derived from an interference with their mother tongue. Our findings can also be related to a previous study conducted involving the same group of participants

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(Fioravanti et al., 2023). In the latter, we selected a set of verb + noun (object) combinations from an L1 corpus in order to ascertain whether any processing differences between the intermediate and the advanced learners could be observed in comparison to a sample of L1 speakers. Overall, L1 speakers' processing times were faster than those of the learners. More specifically, a significant difference was found between intermediate and L1 speakers, but not between advanced and L1 speakers, nor between the two groups of learners. If we compare these findings with our present study, we may hypothesise that depending on the source of the eye-tracking stimuli (i.e., either L1- or L2-derived), learners may exhibit different degrees of processing advantages. On the one hand, typical combinations produced frequently by L1 speakers may require, in learners, an advanced level of proficiency, in order to obtain a comparable processing advantage. On the other hand, typical combinations produced even only once by L2 speakers may not require an advanced level of proficiency to be processed with ease.

We find this result particularly interesting as it sheds light on how proficiency may play a role in L2 processing. Building eye-tracking experiments with stimuli derived from L1 corpora, used as an approximation of target language input as a whole, and then combining them with different levels of proficiency, used as an approximation of exposure and interaction with target language input, gives us a measure of how learners at different levels of proficiency deal with the overall target language input. In this scenario, it is expected that greater proficiency will correspond to great processing advantages (e.g., Fioravanti et al., 2023). However, if we use stimuli derived from individual L2 production, finding no differences across proficiency levels means that irrespective of the learners' exposure to and interaction with the target language, if a combination is produced in writing, then it is likely to represent a solid degree of entrenchment, as a result of a particular, specific experience with the language. This consideration is in line with usage-based theories (Bybee, 2006), which are based on the entrenchment of connections due to exposure to the language and not strictly on proficiency.

5.2. HOW DOES LEXICAL AND GRAMMATICAL MANIPULATION OF THE VERB + NOUN (OBJECT) COMBINATIONS PRODUCED IN THEIR OWN WRITING BY L2 SPEAKERS OF ITALIAN AFFECT THEIR PROCESSING?

Our second research question specifically addresses the effect of lexical and grammatical manipulation on the processing of combinations produced by learners. We would expect manipulations to disrupt verb + noun (object) combinations, with lexical manipulation playing a considerable role, based on the results in Fioravanti et al. (2023). Our results on verb + noun (object) combinations show that not only do learners tend to prefer typical combinations over manipulated ones, but their processing is also sensitive to the different kinds of manipulation. No differences were observed between the two proficiency levels considered. The substitution of the verb component significantly affects both total duration of fixations and number of fixations, while grammatical manipulations do not go unnoticed but do not reach significance either. This is in line with Fioravanti et al. (2023), where learners like L1 speakers processed slowly and fixated frequently lexically manipulated combinations. In both studies, lexical manipulation was found to have a greater impact on combination processing compared to grammatical manipulation. The fact that manipulating the form of a combination disrupts processing is also supported by the studies reviewed in our literature.

In Schilk (2020, 2021), both interference collocations and incongruent collocations require learners to spend more processing time compared to correct collocations. Moreover, interference collocations are processed more quickly than incongruent ones, as learners can draw on their L1 knowledge to easily decode them during processing and overcome any potential comprehension difficulties. Similarly, Yi et al. (2017) and Li et al. (2022) observed that replacing an element of a collocation with a weakly associated collocate results in longer reading times. We now wish to propose a hypothesis as to why lexical manipulation proves more problematic than grammatical manipulation: Lexically altering a combination produced by the learner disrupts the recognition mechanisms for that combination during processing. Indeed, learners are not able to recognise the already-known combination when they encounter it with a modified verb. In contrast, in the case of grammatical manipulation the form of the combination remains unaltered, which does not compromise its recognition during processing. However, even though grammatical manipulation did not reach the threshold of statistical significance, it did not go unnoticed – especially in terms of the number of fixations – suggesting that learners, while aware of the grammatical error, were able to recover quickly.

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5.3. IS PROCESSING ADVANTAGE (IF OBSERVED) OF TYPICAL VERB + NOUN (OBJECT) COMBINATIONS INFLUENCED BY STRENGTH OF ASSOCIATION?

We now turn to our last research question, which addresses the issue of whether the processing advantage of combinations can be explained in terms of strength of association, which was operationalised in terms of MI. The combinations were positioned along a continuum of association strength.

Interestingly, the results demonstrate that the effect of association strength is modulated by proficiency: Advanced learners processed more strongly associated combinations faster than less associated ones. In contrast, intermediate learners processed low-MI combinations faster than high-MI combinations. The findings related to this research question link back to the first one. While, overall, the individually produced verb + noun (object) combinations are processed similarly at both levels of proficiency, the more strongly associated ones are distinctive of the higher proficiency level. Furthermore, our results are in line with Yi et al. (2017) and Li et al. (2022), who found a significant effect of association strength on reading times of advanced L2 learners. This difference in the effect of MI between intermediate and advanced learners can be explained by the fact that they are characterised by varying levels of exposure and experience with the L2. As noted by Carrol and Conklin (2020), MI more accurately reflects a speaker's linguistic experience than generic phrase frequency. It is likely that advanced learners, compared to intermediate learners, have been more exposed to and have more experience with the L2. Indeed, it is well established that exposure to the L2 plays a key role in strengthening associative links between elements of a combination (Ellis, 2002; Hoey, 2005). With greater exposure to the L2, learners not only reinforce the associative links of a combination in their mental lexicon but also become more sensitive to the distributional properties of words. In contrast, with less exposure learners may not perceive the association between two elements and may not be sensitive to the strength of association during processing.

6. CONCLUSION

This study sought to explore the relationship between production and processing in a second language. We constructed 24 individualised eye-tracking experiments for each of the learners involved in the study, so as to expose them to the specific combinations they produced in their own writing. We found that (a) both intermediate and advanced learners tend to process the typical target-like combinations faster than manipulated ones; (b) both intermediate and advanced learners are significantly more sensitive to lexical manipulation; and (c) more strongly associated combinations are processed more quickly by advanced learners.

The study is not without limitations. First, the sample size of the participants is limited and our analysis should thus be qualified as preliminary with respect to the theoretical and methodological issue it addresses, namely the relationship between production and processing at the level of the single learner. Second, though the writing task was administered so as to potentially enhance the production of verb + noun (object) combinations, these were limited in number and varied in terms of association strength. Nevertheless, we argue that the present study has the potential to widen the debate on L2 phraseological processing research by contributing some methodological and theoretical considerations.

So far, L2 processing has been implicitly connected to the processing of L1 language, rather than L2 language. Schilk (2020, 2021) is, to the best of our knowledge, the first study to use learner data to construct an eye-tracking experiment tailored to L2 learners with a specific L1 background. Yet even in this case, the learner data used are deviant data, since the aim of the study was to analyse the possible impact that deviant collocations produced as a result of L1 influence have on L2 processing. In no case do correct, target-like combinations successfully produced by learners seem to be taken into consideration.

When deriving eye-tracking stimuli from an L1 corpus, we investigate how learners would process a linguistic element that they might hear or read in an L1 environment. The findings of any such investigation would clearly be influenced by the degree of exposure to the language and, consequently, to the chance of increased degree entrenchment, with subsequent implications for successful language use. When deriving eye-tracking stimuli from an L2 corpus, or as in our case from learner texts, the focus shifts slightly: we seek to discover to what

extent a linguistic element produced by a learner, even only once, is entrenched in the learner's mind. We believe that this aspect of L2 processing deserves more attention in psycholinguistic studies, as it carries a number of theoretical and methodological implications.

SUPPLEMENTARY MATERIAL

The full dataset and R script used for the analyses contained in this paper is accessible via the following link: https://osf.io/xfzms/?view_only=873f86eb69fd4d5a9970711270ae013d.

ETHICS AND CONSENT

Informed consent was obtained for anonymised participant information to be published in this article.

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AUTHOR CONTRIBUTIONS

L.F.: conceptualisation, writing – original draft preparation (§§ 1, 2, 3.1, 5.1, 6), writing – review editing.

I.F.: conceptualisation, writing – original draft preparation (§§ 3.3, 3.5, 4, 5.3, 5.4), writing – review editing, methodology, data analysis, data curation.

V.D.: writing – original draft (§§ 3.2, 3.4, 5.2), methodology, data collection, data curation.

M.R.: funding acquisition, methodology, data collection, data curation.

S.S.: project supervision and administration, funding acquisition, data analysis, data curation.

All authors have read and agreed to the published version of the manuscript.

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