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Short title: Learning novel complex words

The effect of constituent frequency and distractor type on learning novel  
complex words

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**Abstract**

The present study explored the role of constituent frequency and distractor type in complex word learning. Skilled readers were trained to associate novel letter strings with one out of two pictures, with one picture serving as the target, and the other as a distractor. A facilitatory effect of first-constituent frequency was found only in trials where distractors promoted first-constituent learning, and a facilitatory effect of second-constituent frequency only in trials where distractors promoted second-constituent learning, but not vice versa. Learning occurred in the absence of any pre-existing knowledge about the constituent morphemes and any explicit reference to the constituents during learning. The results point to the important role of constituent frequency and distractor type in novel word learning and provide insights into the mechanisms involved in the implicit acquisition of morphological knowledge in adult learners, that we suspect to be a key aspect of language learning in general.

**Keywords:** novel word learning, constituent frequency, distractor type, morphological knowledge

When describing languages, morphology refers to the minimal units of form in a given language that can be associated with a specific meaning. These minimal units of meaning-bearing orthographic or phonological forms are called morphemes. For example, the morphologically complex word “farmhouses” is composed of the constituent morphemes “farm” and “house” plus the plural suffix morpheme “s”. Much research has demonstrated that skilled readers automatically segment morphologically complex words into their constituent morphemes during reading comprehension (e.g., Beyersmann et al., 2016; Diependaele et al., 2009; Rastle et al., 2004; Taft & Nguyen-Hoan, 2010). Morphological representations therefore play a key role in language comprehension and are particularly important for understanding new (or unknown) words formed by combining known morphemes, a process referred to as word formation. In the present study, we used a novel word learning paradigm to examine the learning of novel constituent morphemes and their combination to form novel complex words. Contrary to prior work using known morphemes (e.g., Beyersmann et al., 2021; Merks et al., 2011; Tamminen et al., 2012; Tamminen et al., 2015), here, prior knowledge of constituent morphemes cannot be used to guide morphological decomposition, and learners must infer morphological structure uniquely on the basis of their exposure to different complex words.

Novel word learning experiments provide a powerful tool to test factors influencing vocabulary acquisition and offer a flexible and easily controllable testing environment, allowing systematic examination of variables without being restricted to a fixed set of known words (e.g., Rastle et al., 2011). In particular, novel word learning studies offer an important window on what is now commonly referred to as “statistical learning” and its role in the overall process of language learning. It is a well-established fact that human learners are sensitive to the probabilistic structure of language (for a review, see Erickson & Thiessen, 2015), from a very young age. Even infants show sensitivity to basic statistical information, suggesting that the ability to extract statistical regularities from a linguistic input is a fundamental prerequisite for language acquisition (Romberg & Saffran, 2010; Saffran, 2003; Saffran et al., 1996; Saffran

& Wilson, 2003). Novel word learning experiments with very small sets of words (e.g., St. Clair et al., 2009) have shown that it is possible to learn about language structure from limited input (e.g., Reali & Christiansen, 2005). Novel word learning experiments have been used with adults to study mechanisms underlying orthographic learning (e.g., Laine et al., 2014; Rastle et al., 2011; Taylor et al., 2011). Numerous studies have reported positive effects of word exposure frequency on word acquisition (e.g., Horst, Cobb and Meara 1998; Pigada and Schmitt 2006; Rott 2007; Teng, 2019; 2020). Repeated encounters with target items during learning create more opportunities for individuals to acquire a novel vocabulary.

Very few studies have used novel word training to study the learning of morphological knowledge in adults (e.g., Hupp et al., 2009; St. Clair et al., 2009). However, over the past few years, progress in this research area has been made, particularly due to the work of Merx, Rastle and Davis (2011) and Tamminen and colleagues (Tamminen et al., 2012; Tamminen et al., 2015). For instance, in the study by Merx et al. (2011) adult participants were asked to learn words comprising existing stems and novel affixes (e.g., *sleepnept*) showing that adults lexicalize affixes (e.g. *-nept*) when presented in the context of a real stem (e.g., *sleep*). The learning effect generalized to items with untrained stems and trained affixes (Tamminen et al., 2012) and has been shown to apply to novel affixes conveying a consistent meaning (e.g., *buildnule* and *sleepnule*, where the novel affix *nule* consistently refers to the meaning of ‘cost’) and inconsistent meaning (e.g., *creepesh*, where *esh* refers to the meaning of ‘place’, and *grabesh*, where *esh* refers to the meaning of ‘cost’) (Tamminen et al., 2015).

The goal of the present research was to build on these prior studies to examine the influence of constituent frequency and distractor type on the learning of morphological structure in adults. Word exposure frequency generally has a facilitatory effect on word learning (e.g., Horst et al., 1998; Pigada & Schmitt, 2006; Rott, 2007; Teng, 2016). However, it is less clear how constituent frequency affects novel word learning. While constituent frequency is known to have a robust facilitatory effect on complex word reading (e.g.,

Duñabeitia et al., 2007; Giraudo & Grainger, 2000; Taft, 2004; Vannest et al., 2011; Xu & Taft, 2015), the question of how constituent frequency influences the learning process itself has received comparatively little attention. Evidence from computational modelling suggests that morphological knowledge can be learned based on probabilistic information concerning letter sequences and their association with meaning (e.g., Baayen et al., 2011; McClelland & Patterson, 2002; Mirković et al., 2011; Ramscar, 2002; Ramscar & Dye, 2011). However, little psycholinguistic evidence exists to date supporting this view, and it thus remains uncertain if and how statistical cues of a given language input are relevant to the acquisition of morphological knowledge.

In the present work, we developed a new training paradigm to examine the learning of novel complex words consisting of two novel morphological constituents. In two online experiments, we trained our participants with a set of novel words composed of two novel constituents (e.g., *ansuda*, consisting of *ansu* + *da*), allowing the exploration of morphological learning without any influences from pre-existing lexical or morphological knowledge. Participants were not given any cues regarding the location of the morpheme boundary between the two constituents. This aspect represents a key difference between the present experimental design and prior studies (e.g., Beyersmann et al., 2021; Merx et al., 2011; Tamminen et al., 2012; Tamminen et al., 2015) where novel words consisted of one existing and one novel constituent, such that knowledge of the existing constituent could be used to isolate the to-be-learned constituent (e.g., learning the meaning of *nept* in *sleepnept* after being informed that *sleepnept* is “the hourly rate for taking a nap in an airport bed”). In the present study, the novel constituents were orthographically legal and pronounceable letter sequences but did not form any existing words (see also Havas et al., 2015). The goal of the learning task was to acquire the novel whole words and did not require participants to learn the embedded constituents. However, the task was designed in a way that the nature of the trials allowed participants to acquire information regarding the embedded constituents, without this being a task necessity.

One possibility is that novel complex words are initially learned holistically rather than via decomposition, especially under circumstances where no prior lexical knowledge exists. The complementary learning systems account of word learning (McClelland et al., 1995) proposes that holistic (or “context-dependent”) novel word learning allows for a faster integration of novel words into the set of known words and is less prone to interference from other items with overlapping morphemic constituents (Tamminen et al., 2012). If novel word learning indeed occurs holistically, constituent frequency would not be expected to exert an effect on the acquisition of novel complex words. An alternative possibility is that the novel complex words are processed via decomposition, in which case a facilitatory effect of constituent frequency was predicted. The complementary learning systems account proposes that “context-independent” learning facilitates generalization from one learning experience to another (McClelland et al., 1995), thereby allowing the memory system to discover overlapping structures and regularities amongst novel word units (Raviv et al., 2022). As such, we would expect participants to be faster and less error prone in responding to items with high frequency first constituents compared to low frequency first constituents, and faster and less error prone in responding to items including high frequency second constituents compared to low frequency second constituents.

In addition, to further explore the dynamics between the target items and the other to-be-learned novel word units, the modulating role of distractor type on constituent frequency was explored. Participants were asked to associate each target word with one out of two pictures, where one of the pictures corresponded to the target word, while the second picture served as a distractor. Distractor pictures and target pictures corresponded to words that either shared the first but not the second constituent (e.g., *ansuda* vs. *ansuban*; promoting second constituent learning) or shared the second but not the first constituent (e.g., *ansuda* vs. *fatida*; promoting first constituent learning). Frequency was represented as a three-level factor, including a high frequency first constituent + high frequency second constituent condition (HF

+ HF), a low frequency first constituent + high frequency second constituent condition (LF + HF), and a high frequency first constituent + low frequency second constituent condition (HF + LF). The HF + HF condition acted as a baseline condition. The effect of first constituent frequency was assessed by comparing the LF + HF condition against the HF + HF condition, which we predicted should be evidenced by faster and more accurate responses in the HF + HF than the LF + HF condition. The effect of second constituent frequency was assessed by comparing the HF + LF condition against the HF + HF condition, which we predicted should be evidenced by faster and more accurate responses in the HF + HF than the HF + LF condition. We further hypothesized that trials promoting first constituent learning should give more opportunities for first constituent frequency effects to arise, and trials promoting second constituent learning should give more opportunities for second constituent frequency effects to arise. Such a prediction would be supported by the presence of a significant frequency by distractor type interaction, which was explored for both dependent variables, including response times (RTs) and error rates (ERs).

In Experiment 1, distractor type was manipulated as a between-participants variable. That is, one group of participants (n = 50) was assigned to trials promoting first constituent learning, and a second group of participants (n = 50) was assigned to trials promoting second constituent learning. In Experiment 2, distractor type was manipulated as a within-participants variable, where all participants (n = 100) received exposure to both types of trials. The materials, hypotheses, and data analyses plan were pre-registered for both experiments (Experiment 1: [https://aspredicted.org/blind.php?x=DH5\\_X4Y](https://aspredicted.org/blind.php?x=DH5_X4Y); Experiment 2: [https://aspredicted.org/blind.php?x=GVJ\\_KDM](https://aspredicted.org/blind.php?x=GVJ_KDM)).



## Experiment 1

### Method

#### *Participants*

One hundred volunteers from Prolific (<https://www.prolific.co>) participated in this study for monetary reimbursement (10£ per hour). All participants were university students, had normal or corrected-to-normal vision and were monolingual native French speakers ( $M = 29.97$  years;  $SD = 8.05$ , 60 males). No participants reported a reading impairment. Participants provided informed, written consent prior to participating in the study. These experiments were carried out in accordance with relevant guidelines and regulations and the experimental protocol was approved by the National Ethics Committee (CPP SUD-EST IV, No. 17/051).

#### *Materials*

A total of 36 novel words were created for the training. The novel words (e.g., *ansuda* [red fish]) consisted of two constituents (*ansu* [fish] + *da* [red]). The items included 12 first constituents, which were 3-4 letters long, and 4 second constituents, which were 2-3 letters long. The first constituents represented nouns (e.g., fish, car, sofa) and second constituents represented adjectives (e.g., blue, red, big, small). For further item examples, see Appendix A. To test for the effect of first and second constituent frequency, the items were split into three conditions, where the high frequency first and second constituents appeared twice as often as the low frequency first and second constituents. This allowed us to manipulate constituent frequency while keeping whole-word surface frequency constant across conditions. The three conditions included a HF + HF, LF + HF, and HF + LF condition. All novel words were orthographically legal and pronounceable but did not form any existing words in French. While the length of the constituents was indeed typical of French morphology, the constituents were not orthographically similar to real morphemes. The purpose of this was to ensure that participants were not familiar with the novel constituents. The comparison of the HF + HF vs. LF + HF conditions served as a test for the role of first constituent frequency, whereas the

comparison between the HF + HF vs. HF + LF conditions served as a test for the role of second constituent frequency in novel word acquisition. All conditions were matched on string frequency, bigram frequency, trigram frequency and length. In addition, we used the French translation of all first constituents to match the high and low first constituent frequency conditions on length, frequency, syllable number, number of phones, orthographic neighbourhood, and phonological neighbourhood.

The pictures were line drawings (see Appendix B) selected from the Snodgrass and Vanderwart database (Snodgrass & Vanderwart, 1980) and the French normative measures were taken from Alario and Ferrand (1999). Pictures in the high and low first constituent frequency conditions were matched on name agreement, image agreement, familiarity, complexity, variability, age of acquisition, and frequency. We vectorised all line drawings and modified the size and colour of the drawings using the open-source software Inkscape (e.g., Bah, 2007). The small-sized pictures were four times smaller than the large-sized pictures.

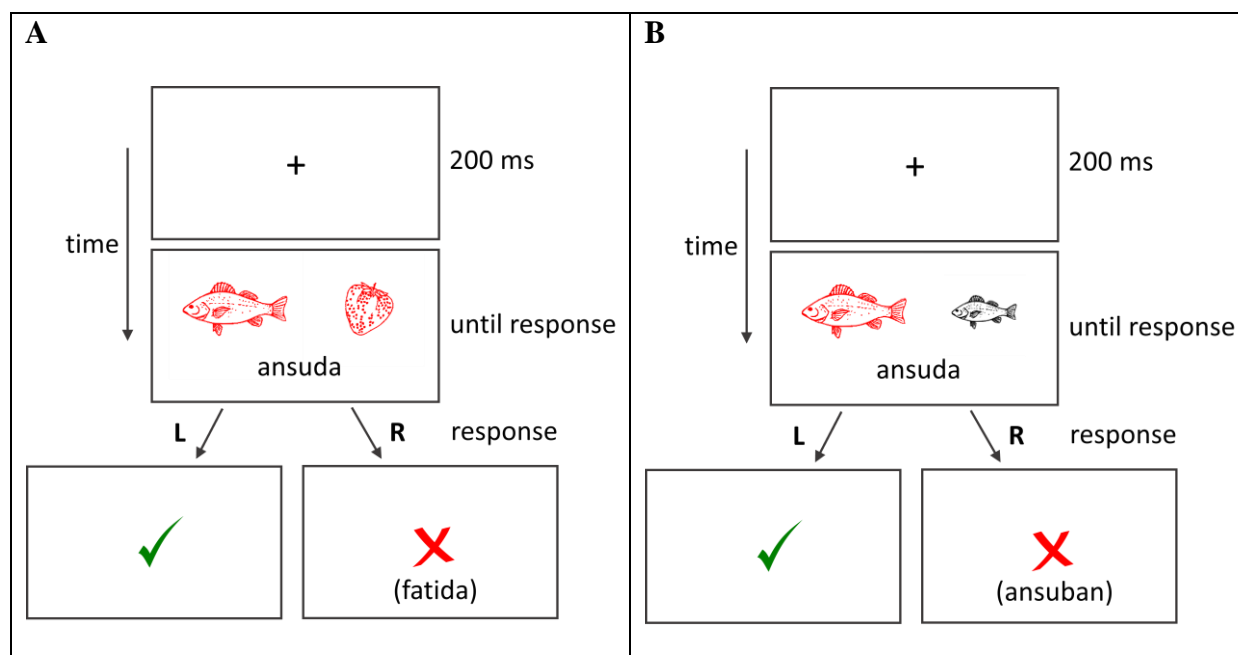
Finally, to counterbalance item specific characteristics across conditions, two sets of novel words were created (Set 1 and Set 2; see Appendix A), where the high frequency first constituents were swapped with the low frequency first constituents and the high frequency second constituents with the low frequency second constituents. That way, it was further ensured that the associations between the novel constituents and their meanings were counterbalanced between experimental item sets. In both experiments, 50 participants were assigned to each item set. The materials, including a full list of target-distractor pairs, have been made available under the following link:

[https://osf.io/r3cdf/?view\\_only=ef2fbb216734455082651bcfec644ed5](https://osf.io/r3cdf/?view_only=ef2fbb216734455082651bcfec644ed5).

### ***Procedure***

Two pictures and one word were presented simultaneously on the computer screen, using the experimental software Labvanced (Scicoverly GmbH, Paderborn, Germany). The pictures appeared on the top left and top right corner of the screen. Novel words were presented

as letter strings in the bottom-centre of the screen (Figure 1). While one of the pictures corresponded to the target word, the second picture served as a distractor. Distractor pictures and target pictures either represented the same first, but a different second constituent (promoting second constituent learning) or the same second, but a different first constituent (promoting first constituent learning). On each trial, a fixation cross was presented on the centre of the screen for 200 ms, immediately followed by the presentation of the two pictures and the target word, which remained on the screen until a response was made. Pictures and words were presented against a white background. Participants were instructed to associate each target word with one of the two pictures by using two different key-button responses, as quickly and accurately as possible. No other instructions were given to the participants in order to encourage non-intentional learning of morphological knowledge. Upon response, feedback was provided to each participant informing them whether the selected word-picture association was correct or incorrect. Negative feedback would be presented in the form of a red cross, and positive feedback in the form of a green tick, both printed in the centre of the screen. The trials were presented in randomised order.



*Figure 1.* Procedure of the word-picture matching task. Panel A provides an example for trials promoting first constituent learning, where the target (ansuda = “red fish”) and the distractor (fatida = “red strawberry”) share the same second constituent (da = “red”). Panel B provides an

example for trials promoting second constituent learning, where the target (ansuda = “red fish”) and the distractor (ansuban = “small fish”) share the same first constituent (ansu = “fish”).

At the beginning of the experiment, participants were instructed that a minimum average accuracy of 90% was required to complete the experiment. Moreover, at the end of each training run, a reminder of the 90% requirement was displayed along with the average score (%) achieved in that run. Each run took about two minutes to complete. If performance was below 90% accuracy, participants were asked to do another run. Once participants reached 90% accuracy or above, the experiment was stopped.

## Results

Participants required 1 to 15 runs (average 3.01) to achieve 90% accuracy. Two participants reached the 90% threshold within one single training run (i.e., within 36 trials). However, the majority of participants required 2-4 runs to complete the training (see Figure 2). One participant had to complete 11 and one participant as many as 15 training runs to reach the cut-off.

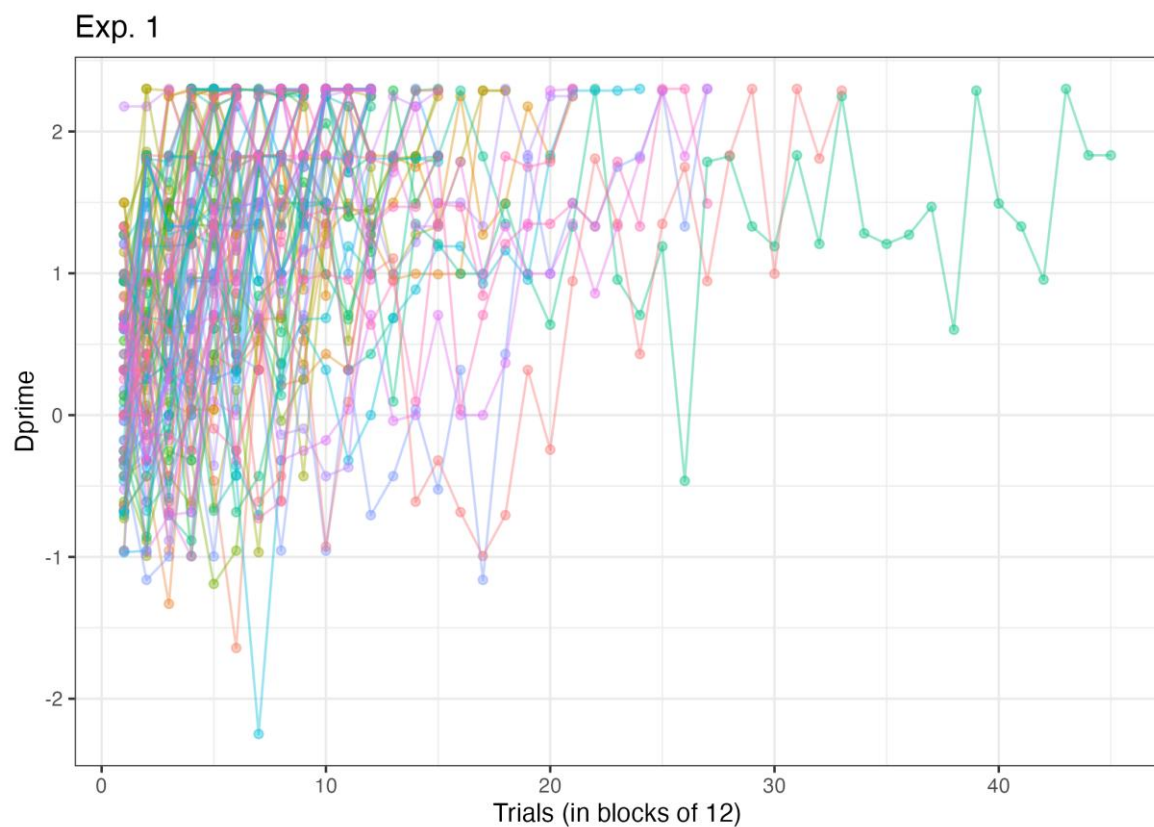


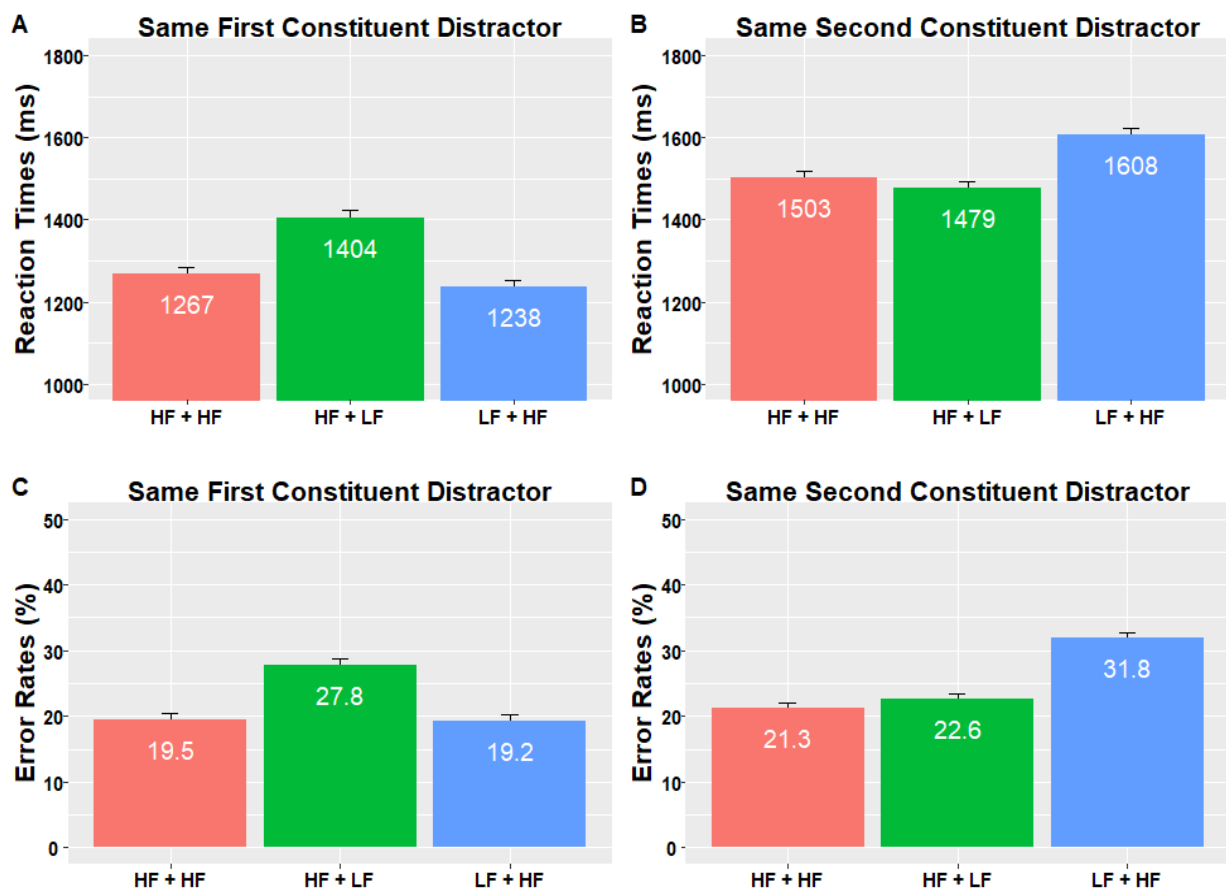
Figure 2. Dprime ( $d'$ ) as a function of training runs. For each series of 12 trials (i.e., with 36 trials representing one full training run), standard measures from Signal Detection Theory (number of hits and false-alarms) were used to compute  $d'$  with a loglinear correction to account for hit and false-alarm rates of zero or one, using the Psycho R library (version 0.6.1).

Incorrect responses were removed from the RT analysis (24.02% of the data). Based on the visual inspection of the data, RTs above 7 seconds and below 200 ms were trimmed (1.1% of the data). In addition, residual outlier trimming was applied (Baayen, 2008) which led to the removal of 2.1% of the data. RTs and ERs were analysed for each subject and are presented in Figure 3. Raw data and analyses scripts have been made available under the following link: [https://osf.io/r3cdf/?view\\_only=ef2fbb216734455082651bcfec644ed5](https://osf.io/r3cdf/?view_only=ef2fbb216734455082651bcfec644ed5).

Analyses were performed using generalized linear mixed-effects models (Baayen et al., 2008) as implemented in the *lme4* package (Version 1.1.27.1; Bates et al., 2015) in the statistical software R (Version 4.2.2, 2022-10-31, “Innocent and Trusting”, RCoreTeam, 2022). The significance of the fixed effects was determined with type III model comparisons using the *Anova* function in the *car* package (Version 3.0.12; Fox & Weisberg, 2019). Response times were logarithmically transformed. The model included two effect-coded independent variables (frequency [HF + HF, HF + LF, LF + HF] and distractor type [same 1<sup>st</sup> constituent distractor, same 2<sup>nd</sup> constituent distractor]), their interaction, and random slopes and random intercepts for items and participants. We included trial order and number of training runs to control for longitudinal task effects. As per Barr and colleagues (2013), models were computed with the maximal random effects structure (Baayen et al., 2008). Next, the random intercepts model was computed and random slopes were added incrementally. The highest converging nonsingular models are reported.

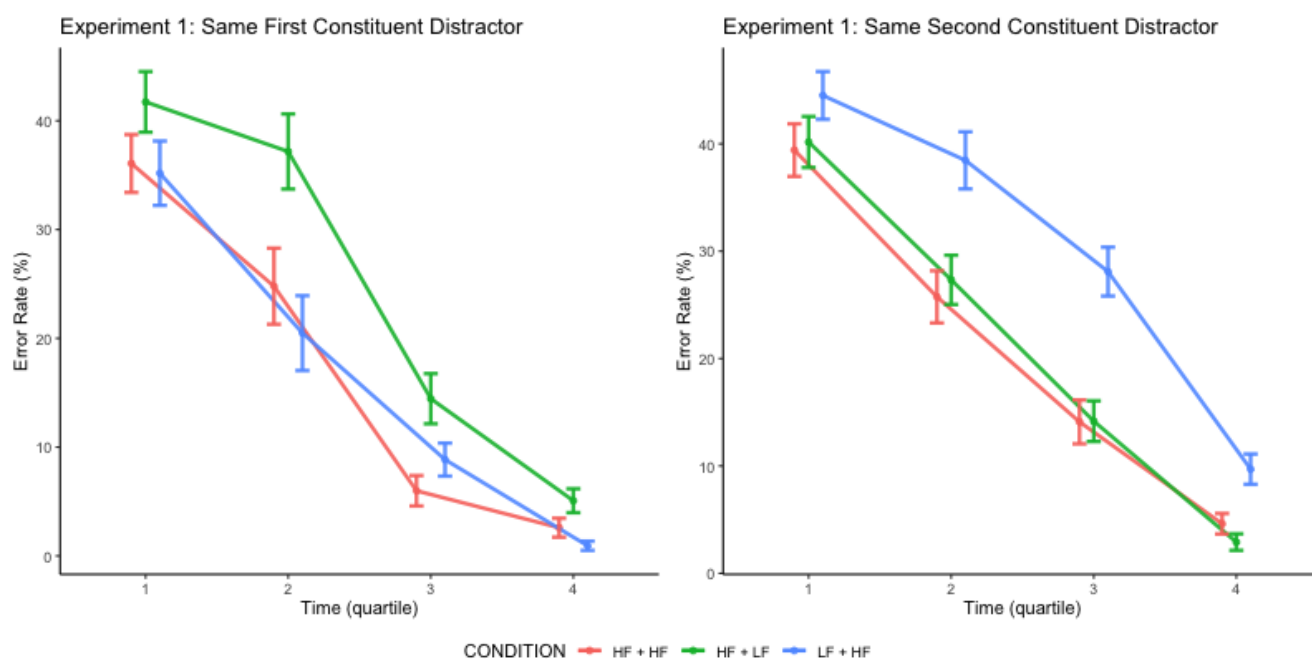
The RT analyses revealed a significant interaction between frequency and distractor type ( $\chi^2(2) = 168.25, p < .001$ ). The main effects of frequency and distractor type were significant ( $\chi^2(2) = 17.50, p < .001$ ;  $\chi^2(1) = 31.63, p < .001$ ). There was also a main effect of trial order ( $\chi^2(1) = 22.56, p < .001$ ) and training run ( $\chi^2(1) = 51.92, p < .001$ ), showing that RTs

gradually decreased the further participants progressed through the experiment. To further explore the significant two-way interaction, we analysed the effect of frequency for each distractor type. In trials promoting first constituent learning (Figure 3, panel B), there was a significant facilitatory effect of first constituent frequency: participants were faster to respond to items in the HF + HF than in the LF + HF condition ( $z = 4.87, p < .001$ ). No effect of 2<sup>nd</sup> constituent frequency was observed. In the trials promoting second constituent learning (Figure 3, panel A), there was a significant facilitatory effect of second constituent frequency: participants were faster to respond to items in the HF + HF than in the HF + LF condition ( $z = 7.54, p < .001$ ). No effect of first constituent frequency was observed.



*Figure 3.* Experiment 1. Mean reaction times (panels A and B) and error rates (panels C and D) with standard error bars, for trials including distractors that shared the same 1<sup>st</sup> but different 2<sup>nd</sup> constituent, thus promoting 2<sup>nd</sup> constituent learning (panels A and C), and trials including distractors that shared the same 1<sup>st</sup> but a different 2<sup>nd</sup> constituent, thus promoting 1<sup>st</sup> constituent learning (panels B and D). The blue and orange bars highlight the critical contrasts providing evidence for the effects of constituent frequency in novel word learning as a function of distractor type.

The error analyses were performed following the same principles as in the RT analyses. We applied a binomial variance assumption to the trial-level binary data using the function `glmer` as part of the R-package `lme4`. There was a significant interaction between frequency and distractor type ( $\chi^2(2) = 58.93, p < .001$ ), and a significant effect of distractor type ( $\chi^2(1) = 15.67, p < .001$ ), showing that participants made overall more errors in trials promoting first constituent learning (i.e., in trials where the distractor shared the same second constituent). There was also a significant main effect of frequency ( $\chi^2(2) = 12.93, p = .002$ ). The effects of trial order ( $\chi^2(1) = 57.91, p < .001$ ) and training run ( $\chi^2(1) = 713.33, p < .001$ ) were significant, showing that error rates gradually decreased the further participants progressed through the experiment. To further explore the significant two-way interaction, we analysed the effect of frequency for each distractor type. In trials promoting first constituent learning (Figure 3, panel D), there was a significant facilitatory effect of first constituent frequency: participants made less errors in the HF + HF than in the LF + HF condition ( $z = 4.93, p < .001$ ). No effect of 2<sup>nd</sup> constituent frequency was observed. In the trials promoting second constituent learning (Figure 3, panel C), there was a significant facilitatory effect of second constituent frequency: participants made less errors in the HF + HF than in the HF + LF condition ( $z = 4.47, p < .001$ ). No effect of first constituent frequency was observed. Figure 4 shows that the effect of constituent frequency was stable across training runs, although slightly smaller in the first and final training quartiles.



*Figure 4.* The effect of constituent frequency on error rates as a function of training runs. Training runs were split into quartiles for each participant, by subdividing the whole series of trials into 4 equal-length sub-series of consecutive trials.

## Discussion

The results of the RT and error rate analyses revealed that constituent frequency effects were significantly modulated by distractor type. In trials promoting first constituent learning, a significant facilitatory effect of first constituent frequency was observed. In trials promoting second constituent learning, a significant facilitatory effect of second constituent frequency was observed. The findings of Experiment 1 therefore suggest that novel word learning was influenced by the morphemic constituents of the to-be-learned words. However, it is possible that the distractor type effect in Experiment 1 was amplified by the nature of the between-participant design. While one participant group was assigned to trials promoting first constituent learning only, the second participant group was assigned to trials promoting second constituent learning only. Although this between-participant design provided a clear divide between the two learning conditions and thus served as a direct test of our hypothesis that constituent learning may be modulated by the type of learning opportunity presented by



distractor types, we designed a second experiment to test the role of distractor type in a mixed learning design where distractor type was manipulated as a within-participant factor.

## **Experiment 2**

### **Method**

#### ***Participants***

One hundred volunteers from Prolific (<https://www.prolific.co>) participated in this study for monetary reimbursement (10£ per hour). All participants were university students, had normal or corrected-to-normal vision and were monolingual native French speakers ( $M = 30.83$  years;  $SD = 10.55$ , 54 males). No participants reported a reading impairment.

#### ***Materials***

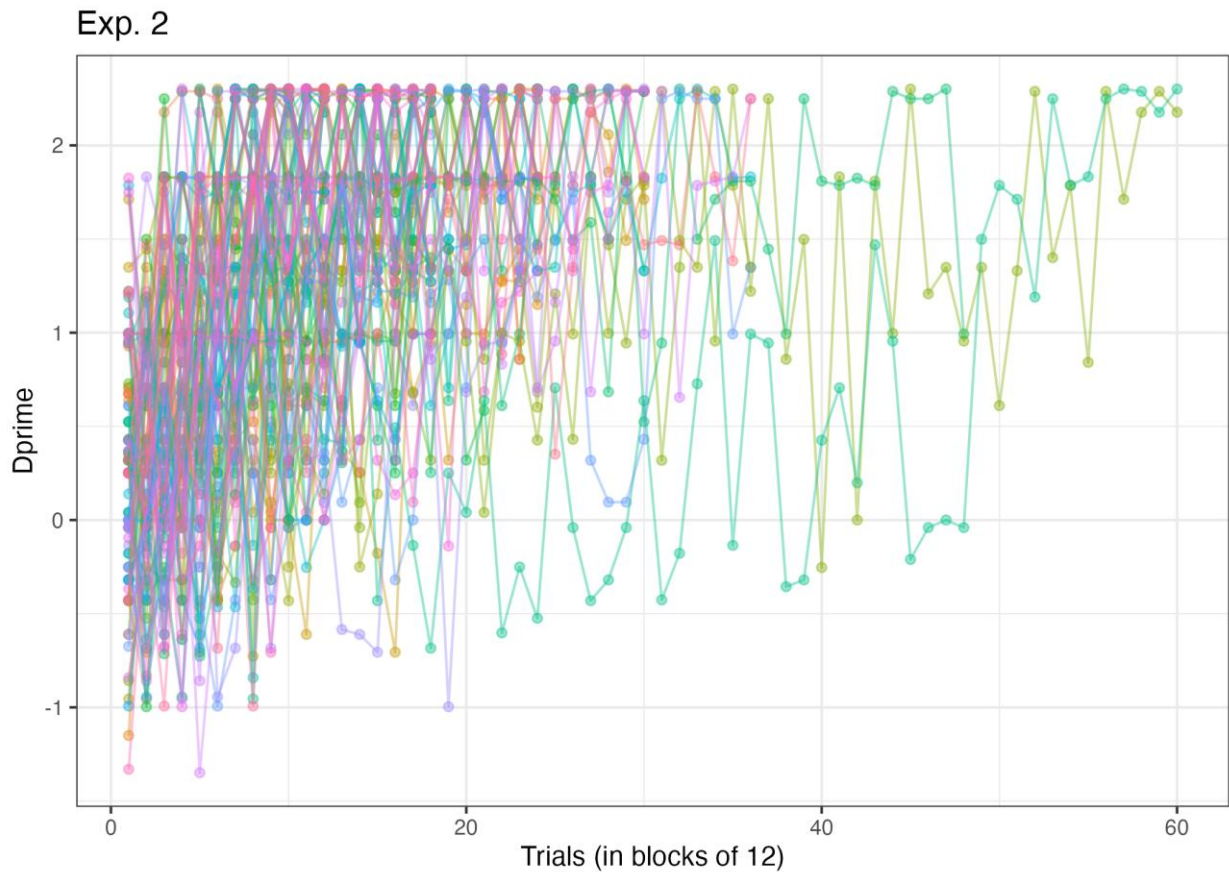
The same materials as in Experiment 1 were used.

#### ***Procedure***

The same procedure as in Experiment 1 was used, except that each participant was exposed to both learning conditions, including 50% of trials promoting first constituent learning, and 50% of trials promoting second constituent learning.

### **Results**

One participant required 23 training runs to reach 90% accuracy and was removed. The remaining participants required 2 to 10 runs (average 2.57) to achieve 90% accuracy. As can be seen in Figure 5, two participants required 10 training runs to reach the 90% threshold.

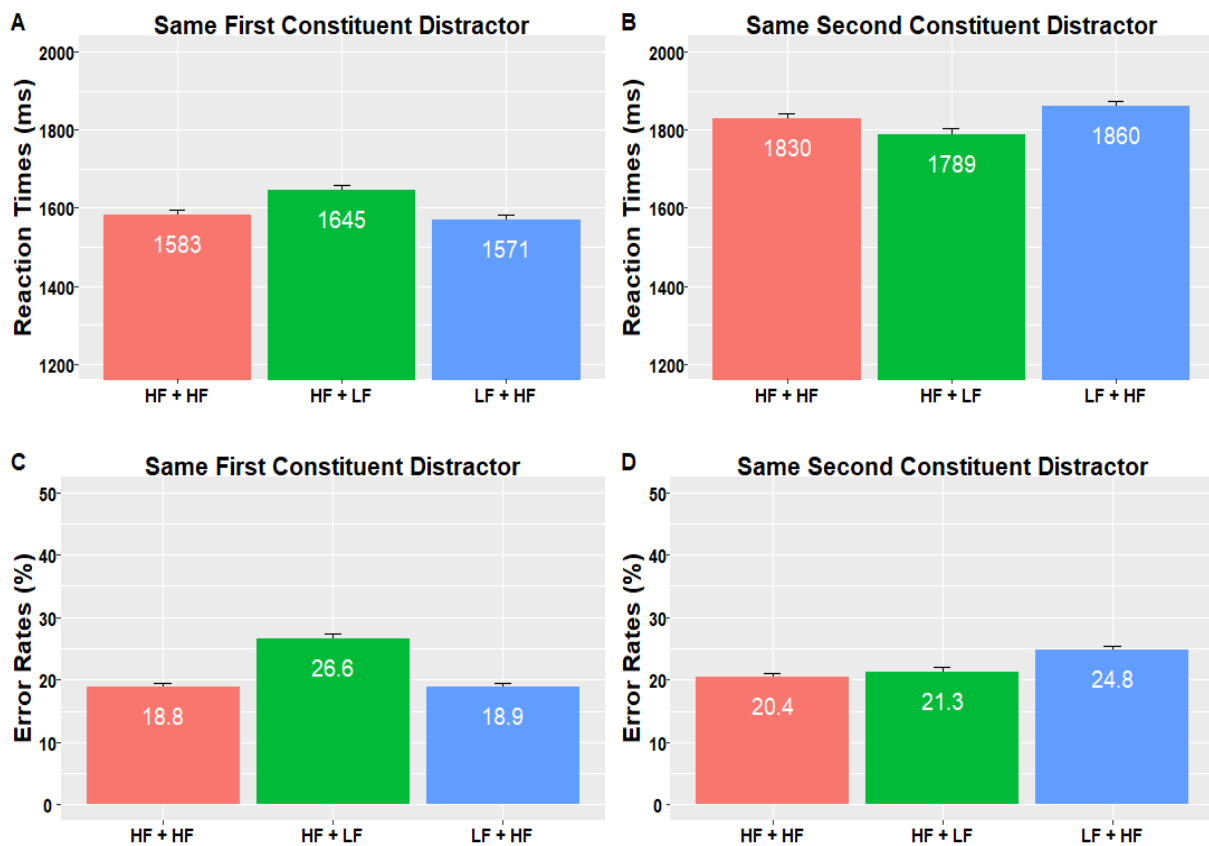


*Figure 5.* Dprime ( $d'$ ) as a function of training runs. For each series of 12 trials (i.e., with 36 trials representing one full training run), standard measures from Signal Detection Theory (number of hits and false-alarms) were used to compute  $d'$  with a loglinear correction to account for hit and false-alarm rates of zero or one, using the Psycho R library (version 0.6.1).

Incorrect responses were removed from the RT analysis (21.80% of the data). Based on the visual inspection of the data, RTs above 7 seconds and below 200 ms were trimmed (1.7% of the data). In addition, residual outlier trimming was applied (Baayen, 2008) which led to the removal of 3.0% of the data. RTs and ERs were analysed for each subject (see Figure 6).

Analyses were performed based on the same principles as in Experiment 1, using generalized linear mixed-effects models (Baayen et al., 2008). The RT analyses revealed a significant interaction between frequency and distractor type ( $\chi^2(2) = 61.92, p < .001$ ). The main effect of distractor type was also significant ( $\chi^2(2) = 623.75, p < .001$ ). There was also a main effect of training run ( $\chi^2(1) = 197.22, p < .001$ ), showing that RTs gradually decreased the further participants progressed through the experiment. To further explore the significant two-way interaction, we analysed the effect of frequency for each distractor type. In trials

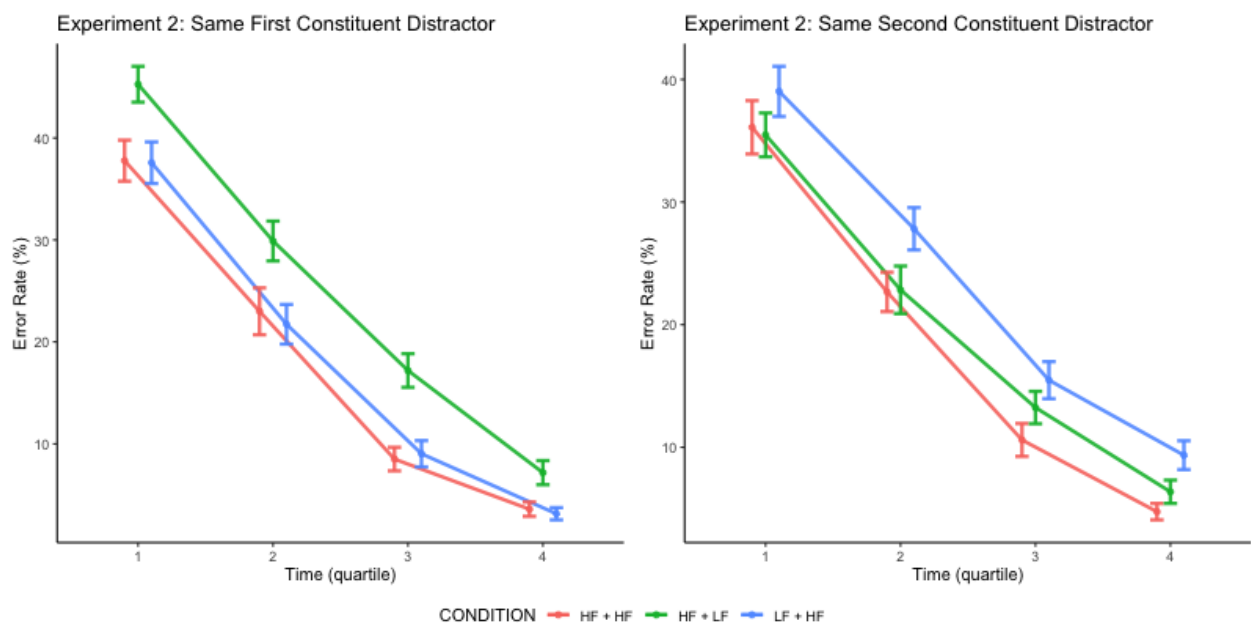
promoting first constituent learning (Figure 6, panel B), the effect of first constituent frequency was not significant (HF + HF vs. LF + HF:  $z = 0.76$ ,  $p = .446$ ), but there was a significant inhibitory effect of second constituent frequency: participants were slower to respond to items in the HF + HF than in the HF + LF condition ( $z = 2.68$ ,  $p = .007$ ). In trials promoting second constituent learning (Figure 6, panel A), there was a significant facilitatory effect of second constituent frequency: participants were faster to respond to items in the HF + HF than in the HF + LF condition ( $z = 3.43$ ,  $p < .001$ ). No effect of first constituent frequency was observed.



*Figure 5.* Experiment 2. Mean reaction times (panels A and B) and error rates (panels C and D) with standard error bars, for trials including distractors that shared the same 1<sup>st</sup> but different 2<sup>nd</sup> constituent, thus promoting 2<sup>nd</sup> constituent learning (panels A and C), and trials including distractors that shared the same 1<sup>st</sup> but a different 2<sup>nd</sup> constituent, thus promoting 1<sup>st</sup> constituent learning (panels B and D). The blue and orange bars highlight the critical contrasts providing evidence for the effects of constituent frequency in novel word learning as a function of distractor type.

In the error analyses, there was a significant interaction between frequency and distractor type ( $\chi^2(2) = 82.64$ ,  $p < .001$ ), and a significant main effect of frequency ( $\chi^2(2) =$

17.14,  $p < .001$ ). The effects of trial order ( $\chi^2(1) = 122.93$ ,  $p < .001$ ) and training run ( $\chi^2(1) = 1412.48$ ,  $p < .001$ ) were significant, showing that error rates gradually decreased the further participants progressed through the experiment. To further explore the significant two-way interaction, we analysed the effect of frequency for each distractor type. In trials promoting first constituent learning (Figure 6, panel D), there was a significant effect of first constituent frequency: participants made less errors in the HF + HF than in the LF + HF condition ( $z = 4.74$ ,  $p < .001$ ). No effect of second constituent frequency was observed. In the trials promoting second constituent learning (Figure 6, panel C), there was a significant facilitatory effect of second constituent frequency: participants made less errors in the HF + HF than in the HF + LF condition ( $z = 7.28$ ,  $p < .001$ ). No effect of first constituent frequency was observed. Figure 7 shows that the effect of constituent frequency was stable across training runs.



*Figure 7.* The effect of constituent frequency on error rates as a function of training runs. Training runs were split into quartiles for each participant, by subdividing the whole series of trials into 4 equal-length sub-series of consecutive trials.

## Discussion

The results of the RT and error rate analyses revealed that constituent frequency effects were significantly modulated by distractor type. In trials promoting first constituent learning, a significant facilitatory effect of first constituent frequency was found in the error rates, as well

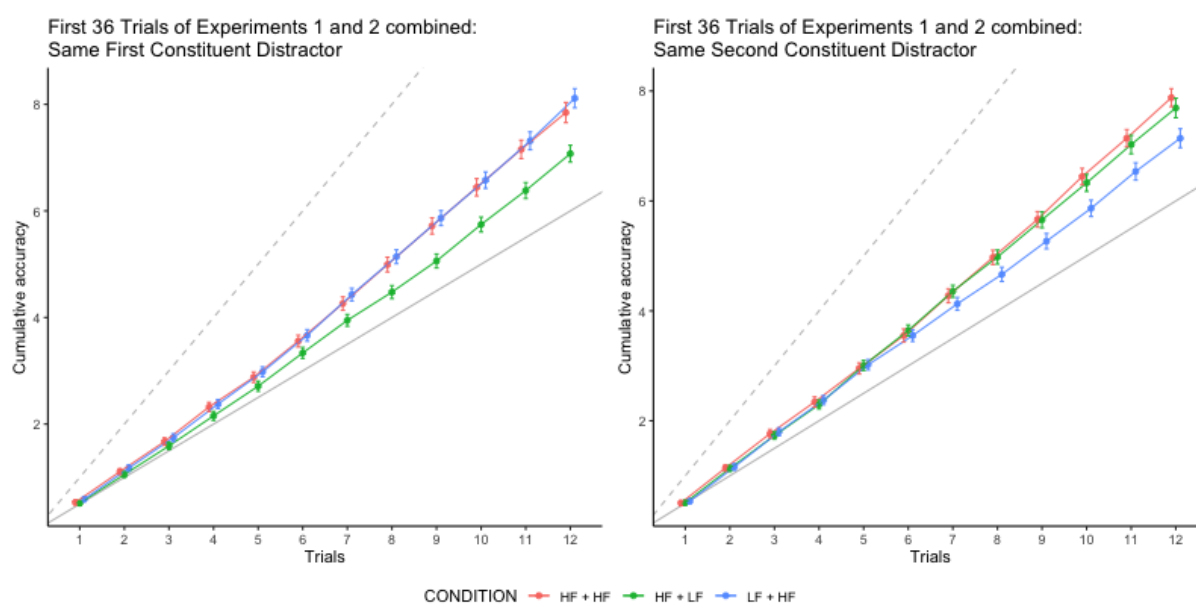
as an inhibitory effect of second constituent frequency in RTs. In trials promoting second constituent learning, a significant facilitatory effect of second constituent frequency was observed in both RTs and error rates, accompanied by no effect of first constituent frequency.

### **General Discussion**

The aim of the present study was to test the role of constituent frequency and distractor type in the learning of novel morphologically complex words. In a series of two experiments, with 100 participants per sample, participants were asked to learn 36 novel complex words by associating novel letter strings with one out of two pictures. One of the pictures represented the target word, whereas the second picture served as a distractor. In Experiment 1, distractor type was manipulated as a between-participant factor, such that each participant was only exposed to one type of distractor, but never both. In Experiment 2, distractor type was manipulated as a within-participant factor as a further test of the robustness of the distractor type manipulation. Novel words were presented as wholes, hence morphemes were never encountered in isolation. Yet, we found that the frequency of occurrence of the morphemic components and the nature of the distractor items had a significant impact on learning.

These findings obtained with a novel paradigm open-up a new avenue for research on novel word learning. More specifically, our data provide new insights into the acquisition of morphological knowledge in adult learners. Today, there is a general consensus that skilled readers rapidly and automatically segment morphologically complex words into morphemic constituents (e.g., Beyersmann et al., 2011; Beyersmann et al., 2016; Grainger & Ziegler, 2011; Rastle & Davis, 2008; Rastle et al., 2004; Taft, 2003). However, little is known regarding the mechanisms that are at play during the learning process itself, especially in a context where no prior morphemic knowledge exists to guide the morphological segmentation process. The current data provide evidence for a robust first and second constituent frequency effect on novel complex word learning. These findings suggest that participants did not simply acquire the novel words as whole units, but instead were able to process the novel words

decompositionally. Participants were faster and less error prone in responding to items with high frequency constituents compared to low frequency constituents, showing that constituent frequency had a strong facilitatory effect on word learning. Crucially, the results of both experiments revealed a significant interaction between constituent frequency and distractor type, showing that first constituent frequency effects were more likely to arise in a context that promoted the learning of first constituents, whereas second constituent frequency effects were more likely to arise in a context that promoted the learning of second constituents. These effects were stable across training runs, as witnessed across both experiments (see Figures 4 and 7). The data of the first training run alone, which included 36 trials with 12 trials per condition, show that the effects of constituent frequency quickly emerged during the initial stages of the training session and were already clearly visible towards the end of the very first training run (see Figure 8).



*Figure 8.* Mean cumulative accuracy (0 for errors, 1 for correct) for the first training run including 36 trials (12 per condition) as a function of constituent frequency, computed over the combined participants of Experiments 1 and 2. Panels represent trials including the same first constituent distractor (left panel) and those including the same second constituent distractor (right panel). The dashed straight line represents the correct response slope (slope of 1).

The RT analyses of Experiment 2 revealed an additional finding pointing to a more complex interplay between first and second constituent frequency. In trials promoting first constituent learning, a significant facilitatory effect of first constituent frequency was observed

alongside an inhibitory effect of second constituent frequency. This result was not found in Experiment 1, presumably because the between-participants design of Experiment 1 encouraged a stronger bias towards first or second constituent learning. These data are in line with an increasing body of evidence suggesting that language learning in humans is just another example of the more general principle of statistical learning (e.g., Baayen et al., 2011; McClelland & Patterson, 2002; Mirković et al., 2011; Ramscar, 2002; Ramscar & Dye, 2011). The present word-learning paradigm has the sensitivity to reveal how the frequency of the co-learned word-components can influence learning, which is consistent with predictions made by computational learning networks such as the naïve discriminative learner (e.g., Baayen et al., 2011; Pham & Baayen, 2015). The frequency with which a given input occurs determines both positive learning, when the appropriate output is present, but also determines negative learning or *unlearning* (Ramscar et al., 2013; Rescorla, 1988; Shanks, 1995) whenever the same input is paired with different outputs. Such negative learning, in the context of the within-participant design of Experiment 2, provides a potential explanation for the inhibitory effect of second constituent frequency observed in that experiment.

Several points can be made regarding the ecological validity of the word-picture association paradigm used in the current study. On the one hand, word-picture associations are employed in various educational contexts to facilitate language learning, such as in early childhood education or second language learning, where picture books, flashcards, or other visual aids may be used to help individuals associate new words with their meanings. This method is commonly used in classrooms as well as online learning apps to enhance vocabulary acquisition, an aspect that we attempted to mimic in our study. On the other hand, the current study presented pairs of pictures instead of simple one-on-one picture-word mappings. While this clearly represents a deviation from the more classical classroom setup, the picture pairs were essential in conveying morphological relationships between the to-be-learned novel words. Although it is possible that the presentation of simple word-picture associations would

have involved a lengthier acquisition period, because participants would have had to infer relationships between related words by relying on their memory from preceding trials, it would likely have resulted in a similar outcome. By presenting pairs of pictures, we were able to directly test the acquisition of novel words within the context of another morphologically related distractor item. In this regard, this learning paradigm captures an essential aspect of the fundamental processes involved in building initial word-meaning connections, and thereby has the potential to inform future investigations into the cognitive mechanisms underlying language learning.

The reported effects of frequency and distractor type on novel word learning point to the importance of morphemic knowledge in vocabulary acquisition. For the purpose of the novel word learning paradigm, the current study used constituent meanings that are easy to visualize. The first constituents represented objects, whereas the second constituents represented size or color. One promising future extension of the current study would be the examination of more abstract constituent meanings, as is typically the case with affixation, to test the robustness and generalizability of constituent acquisition effects. Indeed, the second constituents in this study were shorter than the first constituents. Moreover, one of the second constituents in our study represented the meaning of ‘small’ which is grammaticalized as a diminutive affix in some languages, including French. This did not apply, however, to any of the other constituents, which makes it difficult to clearly attribute any of the here observed findings to affix type in particular. As such, the present novel words are seen as having a more compound-like status, providing an important baseline for future more fine-tuned investigations into differences between stem and affix type features, such as differences in constituent length, during complex word acquisition.

In sum, the present study provides evidence for the rapid learning of morphological knowledge in adult learners without any pre-existing vocabulary knowledge. The different pattern of frequency effects seen for first and second constituents holds great potential for



shedding light on the nature of the mechanisms involved in associating orthographic information with meaning during word learning. More generally, we suggest that morphologically structured artificial vocabularies are a promising tool for uncovering basic principles in the acquisition of morphological knowledge and its use in language learning.

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### **Disclosure of Interest**

The authors report no conflict of interest.

### **Data Availability Statement**

Materials, data and analyses scripts have been made available under the following link:

[https://osf.io/r3cdf/?view\\_only=ef2fbb216734455082651bcfec644ed5](https://osf.io/r3cdf/?view_only=ef2fbb216734455082651bcfec644ed5).

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## Appendix A

Novel words assigned to participants in Set 1 and Set 2.

1 <sup>st</sup> constituent meaning	1 <sup>st</sup> constituent	target words			1 <sup>st</sup> constituent	target words	
	Set 1				Set 2		
HF + HF							
butterfly	<i>aldo</i>	<i>aldoda</i>	<i>aldoban</i>	<i>ansu</i>	<i>ansulo</i>	<i>ansusmi</i>	
sofa	<i>edi</i>	<i>edida</i>	<i>ediban</i>	<i>ulu</i>	<i>ululo</i>	<i>ulusmi</i>	
shirt	<i>kadi</i>	<i>kadida</i>	<i>kadiban</i>	<i>glu</i>	<i>glulo</i>	<i>glusmi</i>	
apple	<i>fla</i>	<i>flada</i>	<i>flaban</i>	<i>fati</i>	<i>fatilo</i>	<i>fatismi</i>	
car	<i>gon</i>	<i>gonda</i>	<i>gonban</i>	<i>iton</i>	<i>itonlo</i>	<i>itonsmi</i>	
tree	<i>miso</i>	<i>misoda</i>	<i>misoban</i>	<i>dri</i>	<i>drilo</i>	<i>drismi</i>	
LF + HF							
fish	<i>ansu</i>	<i>ansuda</i>	<i>ansuban</i>	<i>aldo</i>	<i>aldolo</i>	<i>aldosmi</i>	
chair	<i>ulu</i>	<i>uluda</i>	<i>uluban</i>	<i>edi</i>	<i>edilo</i>	<i>edismi</i>	
hat	<i>glu</i>	<i>gluda</i>	<i>gluban</i>	<i>kadi</i>	<i>kadilo</i>	<i>kadismi</i>	
strawberry	<i>fati</i>	<i>fatida</i>	<i>fatiban</i>	<i>fla</i>	<i>flalo</i>	<i>flasmi</i>	
bike	<i>iton</i>	<i>itonda</i>	<i>itonban</i>	<i>gon</i>	<i>gonlo</i>	<i>gonsmi</i>	
flower	<i>dri</i>	<i>drida</i>	<i>driban</i>	<i>miso</i>	<i>misolo</i>	<i>misosmi</i>	
HF + LF							
butterfly	<i>aldo</i>	<i>aldolo</i>	<i>aldosmi</i>	<i>ansu</i>	<i>ansuda</i>	<i>ansuban</i>	
sofa	<i>edi</i>	<i>edilo</i>	<i>edismi</i>	<i>ulu</i>	<i>uluda</i>	<i>uluban</i>	
shirt	<i>kadi</i>	<i>kadilo</i>	<i>kadismi</i>	<i>glu</i>	<i>gluda</i>	<i>gluban</i>	
apple	<i>fla</i>	<i>flalo</i>	<i>flasmi</i>	<i>fati</i>	<i>fatida</i>	<i>fatiban</i>	
car	<i>gon</i>	<i>gonlo</i>	<i>gonsmi</i>	<i>iton</i>	<i>itonda</i>	<i>itonban</i>	
tree	<i>miso</i>	<i>misolo</i>	<i>misosmi</i>	<i>dri</i>	<i>drida</i>	<i>driban</i>	

**Appendix B**

Line drawings selected from the standardised Snodgrass and Vanderwart picture database

(Snodgrass & Vanderwart, 1980).

