Do cues compete? The role of multiple cues in learning a novel grammar.

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Abstract

When acquiring a language learners are expected to extract multiple regularities present in that language and apply them when interpreting or producing fluent speech. However, there are various instances in previous literature where participants have been able to acquire some regularities but not others (Hickey, 2022; Mirković et al., 2021; Vujović et al. 2021). Models of learning (Bates & MacWhinney, 1989; Culbertson et al., 2017) have posited that when there are multiple cues available in a language, they compete with each other for relevance based on their availability and relevance to the learner. The first four experiments in this thesis address whether grammatical cues embedded in semantics compete with and subsequently block less relevant cues when participants attempt to learn a novel grammar. This was examined by training participants on an artificial language which contained both semantic and phonological-distributional cues of word class and testing whether they could generalize associations between different cues to novel words after training. The influence of semantic cues was addressed by manipulating their availability during training. The third and fourth experiments examine whether the presence of semantics as individual word meanings unrelated to grammar, influences word learning and cue acquisition. Finally, the fifth and sixth experiments examine whether phonological-distributional cues compete amongst themselves and whether presenting cues sequentially can support learning of cues which would otherwise be blocked out as irrelevant. Across six experiments this thesis demonstrates that the presence of semantic cues does not interfere with learning of phonological-distributional cues. Contrary to this, phonological-distributional cues may instead compete with each other to be associated with semantic cues.

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Author's Declaration

This thesis is a presentation of original work completed solely by the author, under the supervision of Dr Emma Hayiou-Thomas and Dr Jelena Mirković. This work has not been previously presented for an award at this or any other university. All sources are acknowledged as references. Some of the data collected were by undergraduate students under the author's co-supervision (Chapter 3, Experiment 1).

Chapter 1. Introduction

When acquiring a language learners must contend with numerous regularities in order to learn how to produce and interpret fluent speech. Corpus analyses conducted in English have demonstrated that there are various phonological and distributional cues in the English language that can be used to distinguish between different classes of words (Christiansen & Monaghan, 2006; Monaghan et al., 2005), a critical step in interpreting fluent speech. Phonological cues refer to features of a word, syllable or phoneme that learners can hear in the language. Drawing on a corpus of the 1000 most frequent words in child-directed speech from the English CHILDES database (MacWhinney, 2000) Christiansen and Monoghan (2006) identified 16 phonological cues in infant directed speech which they believed could be used to identify syntactic categories. Distributional cues refer to contextual information available from co-occurrences between words. They operationalized distributional cues as adjacent dependencies between the most frequent words in the corpus and words immediately succeeding them. Based on their analyses they concluded that phonological and distributional cues could be used to classify a variety of word types, phonological cues being especially suited to identifying verbs and distributional cues to identifying nouns. These findings demonstrate that there are regularities present in English speech which, while not perfectly reliable as predictors of word type, can be used together to discriminate between verbs and nouns.

Computational models have demonstrated that in principle learners can acquire and integrate multiple cues together when trained on an artificial language (Monaghan & Christiansen, 2006,

2008). When applied to human learners, artificial language studies have found that humans are able to learn and make use of regularities present in a language from a very young age (Gomez & Gerken, 1999; Lew-Williams & Saffran, 2012; Saffran et al., 1996). In a seminal study on statistical learning, Saffran et al. (1996) tested whether 8-month-old infants could segment words in fluent speech using only the transitional probabilities between adjacent syllables. The infants were exposed to a speech stream of four three-syllable pseudowords with the pseudowords being played in a random order during the speech stream. As such participants were guaranteed to hear two syllables from the same word one after the other, but when listening to the last syllable in a pseudoword there was a one in three chance of hearing any given syllable from the start of the next word. During testing infants listened to one of four three-syllable strings: two of these strings were pseudowords from training, while the other two were nonwords. Nonwords contained syllables from the training set but were heard in an order that violated the transitional probabilities established during training. Infants listened for significantly longer when hearing nonwords compared to words from the training set, suggesting that they detected the difference and thus were able to learn the transitional probabilities between syllables in the training language.

On the basis of these findings, Saffran argued that infants were able to learn transitional probabilities through an experience-dependent mechanism which she termed statistical learning. While initially only used to explain infants' ability to learn the statistical regularities needed to observe transitional probabilities, statistical learning has since expanded to a much broader construct which can be applied to a variety of environmental inputs. Many studies have continued to investigate infants' ability to use transitional probabilities replicating Saffran's finding that infants are able to observe transitional probabilities (Gomez & Gerken, 1999; Lew-Williams & Saffran, 2012). Extending this approach to adults, multiple studies have demonstrated that they are also able to learn word boundaries through statistical learning, a finding which has been interpreted as evidence that statistical learning is age-invariant (Arciuli et al., 2014; Batterink & Paller, 2017; Siegelman & Frost, 2015; Siegelman et al., 2016, 2017; Stärk et al., 2022).

In a study investigating the extent to which pre-existing knowledge of the phonotactic regularities in one's language influence statistical learning, Stark et al. (2022) expanded these findings to German speaking adults. Similar to previous studies, participants were able to learn transitional probabilities, repeating words over part-words with greater accuracy. This demonstrates that statistical learning is a universal mechanism not tied to any one language. To test whether prior language experience affected statistical learning, the study also compared accuracy between naturalistic and non-naturalistic sequences. Naturalistic sequences paired syllables which regularly co-occurred in

German, while non-naturalistic sequences paired syllables which never co-occurred in German. Participants were more accurate when repeating back naturalistic sequences suggesting that when learning associations which align with their previous experience learners acquire associations more easily.

The finding that both infants and adults can learn transitional probabilities is well replicated. However, studying only transitional probabilities limits our understanding of statistical learning to a mechanism which enables learning of adjacencies in language. Gomez (2002) expanded the scope of statistical learning by demonstrating that adults and infants can also learn non-adjacent dependencies in language. Non-adjacent dependencies refer to associations between linguistic units which have variable material in between. A commonly cited example of a non-adjacent dependency In English is the relationship between auxiliaries and inflectional morphemes (e.g. is walking, has walked).

Gomez (2002) investigated learning of non-adjacent dependencies by training adults and infants on an artificial language. The language was presented as auditory strings composed of three word types (aXb, cXd and eXf). The nonadjacent-dependency in the artificial language was an association between the first (a, c and e) and last syllable (b, d and f) in each word, with each pair of syllables corresponding to a different word type. The stem between the first and last syllables, denoted as X because it varied, drew from a pool of 2, 6, 12 or 24 pairs of syllables. After exposure to the training set, learning of non-adjacent dependencies was measured as participants' ability to discriminate between strings from the training set and novel strings with inconsistent pairings between the first and last syllables in each word. While participants' learning of non-adjacent dependencies was low when trained on a pool of 2, 6 or 12 words, participants trained on 24 words were able to learn them. These findings were replicated in infants who showed significantly greater fixation times for inconsistent first and last syllable pairings after training on a pool of 24 words, indicating that they had detected when the last syllables did not match the first in each word. Thus, when there is sufficient variability in the stems that learners are exposed to, they are able to learn the invariance reflected in the non-adjacent dependency. Gomez's findings clearly demonstrate the potential of statistical learning as a mechanism available to both adults and infants to learn a variety of associations in linguistic input beyond transitional probabilities. As such statistical learning is likely to be involved in multiple aspects of language acquisition beyond simply identifying word boundaries.

One limitation of Gomez's findings is that while they demonstrated that participants learned non-adjacent dependencies, they did not investigate whether participants could generalize them to unfamiliar words. In language acquisition, participants need to be able to apply associations beyond

the context in which they are learned; the ability to generalise is a marker of true language proficiency. Later studies have addressed this by testing word segmentation and generalisation separately (Frost & Monaghan, 2016; Frost et al., 2019). Frost et al. (2019) trained participants on non-adjacent dependencies using a language consisting of trisyllabic words. Each word began with one of three syllables, each of which was paired with a specific syllable that came at the end of the word. As in the Gomez paradigm, the intervening syllable in each word varied and was not systematically related to the non-adjacent dependency. Word segmentation was measured by testing participants' ability to discriminate between full words from training and part-words consisting of the end of one word and the start of another. Generalisation of non-adjacent dependencies was measured by testing participants' ability to discriminate between full words and part-words when the variable syllable in each word was replaced with an unfamiliar one. They found that participants were able to discriminate between full words and part-words regardless of whether the variable syllable was substituted for an unfamiliar syllable. These findings replicated their previous study with adults (Frost & Monaghan, 2016) and have since also been replicated in infants using looking time measures (Frost et al., 2020). These findings suggest that in addition to learning non-adjacent dependencies using statistical learning, adults and infants can generalise these learned associations to novel contexts.

Most studies investigating statistical learning have largely focused on phonological-distributional cues, testing learners ability to observe the placement of phonemes or syllables within words. In these studies, semantics have been omitted entirely or have been included as arbitrary labels completely unrelated to the phonological and distributional properties of each word. However, in natural languages the relationship between a word and its meaning are not arbitrary. As outlined in Monaghan's studies the phonological and distributional properties of words are often associated with their meaning (Christiansen & Monaghan, 2006; Monaghan et al., 2005). One such example is the way in which nouns are commonly preceded by articles (e.g. a, the). As much of the literature has either employed semantics as arbitrary labels or omitted semantics entirely, this raises the question of how semantics as a cue interacts with phonological-distributional cues during language acquisition.

1.1 Competition model of language learning

One framework for how semantic and phonological-distributional cues might interact comes from the competition model (Bates & MacWhinney, 1989). The competition model is derived from a functionalist approach, which argues that the form a system takes exists in service to its purpose. In

the case of multiple cues the competition model argues that they exist across different languages because they help to communicate a word's meaning. Based on this premise, the competition model asserts that learners will respond to the validity or predictive value a cue provides when interpreting meaning. If true, then this would suggest that without semantics, cues in an artificial language would be separated from their purpose.

According to the Bates and MacWhinney (1989) cue validity is the major predictive construct in the competition model. It asserts that learners respond to cues based on their validity and how informative they are during acquisition. They outlined three properties that can contribute to cue validity; availability, reliability and conflict validity. Availability refers to how often the cue is present in the language when the learner needs it. Reliability refers to how often the cue leads to correct interpretations when it is relied upon. Conflict validity occurs only when there are cases in the language where two cues lead to conflicting interpretations. When there are conflicting cues, cues which lead to the correct interpretation more often than competing cues will have higher validity than the cues they were in conflict with. Conflict validity is a key part of the competition model's explanation of how cues encountered later or infrequently during language acquisition can become more prominent in a language than cues which are available earlier or more often.

In relation to learning of phonological-distributional and semantic cues, the competition model suggests that learners may favour one cue over the others based on properties inherent to each cue. Thus, semantic cues and phonological-distributional cues in the language input may compete with each other for the learner's prioritisation. However, it does not answer which cue would be favoured in competition nor does it provide evidence for which specific properties of semantic and phonological-distributional cue would drive this preference.

In a recent empirical investigation of the competition model, Culbertson et al. (2017) addresses these questions by probing participants' weighting of phonological-distributional and semantic cues when the salience and availability of each cue were manipulated during training. In an initial experiment, cue salience was manipulated by using two phonological-distributional cue types and three semantic cue types. Phonological-distributional cues were classified as having high or low salience: high salience meant that grammatical class was marked using one of two determiner-suffix pairs, while low salience marked class using one of two suffixes. Similarly, semantic cues were classified as having high, medium or low salience. High salience meant that grammatical class was marked using animacy, medium salience marked class using shape and low salience marked class using flexibility. Participants were trained in one of six conditions, in which each condition paired a different set of semantic (animacy, shape or flexibility) and phonological-distributional cues (both

affixes or only suffixes. For example, in one condition class was marked using animacy (animals or artefacts) as the semantic cue and a set of affixes (di-X-te, ba-X-po) as the phonological-distributional cue. During training trials, pseudowords were preceded by one of two markers of grammatical class (kuh or shae) which were separate from the phonological-distributional and semantic cues in the language.

At test, participants were then presented with novel words and pictures and asked to choose the appropriate marker for each word-picture pair. Participants' acquisition of grammatical classes during training was tested by investigating whether they were able to select the correct class marker when given a consistent set of phonological-distributional and semantic cues. Participants' weighting of each cue was assessed by using conflicting test items which had contradictory phonological-distributional and semantic cues. The marker of grammatical class chosen for conflicting items was used to measure whether participants favoured phonological-distributional or semantic cues.

Participants across conditions were able to accurately select markers for non-conflicting items, suggesting that they were able to learn and generalize some cues of grammatical class. A mixed-effects logistic regression found that regardless of the phonological-distributional cue present participants would favour the semantic cue if it had high salience (animacy). Additionally, they found that participants would favour the phonological-distributional cue regardless of its salience if the semantic cue had low salience (flexibility). Finally, if the semantic cue had intermediate salience (shape), participants would favour the phonological-distributional cue, but only if it had high salience (both affixes) not if it had low salience (only suffixes). These findings suggest that participants favour semantic cues over phonological cues when both are highly salient, but that if the semantic cue becomes less salient in the language participants weighting may shift towards phonological-distributional cues. In line with the competition model, these findings demonstrate learners will favour cues based on their properties, in this case their relative salience when the cues are in conflict.

In a series of follow-up experiments, Culbertson et al. (2017) investigated whether the timing of cue availability influenced learning. To do this, they manipulated the availability of phonological-distributional and semantic cues during training, predicting that participants would favour cues which were available earlier during training when assigning grammatical class. They found that when learning a language in which both cues had high salience - both affixes for the phonological-distributional cue and animacy for the semantic cue - participants favoured whichever cue they were trained on first. An additional experiment supported this, finding that even when trained on low-

salience phonological-distributional cues (only suffixes), these were still favoured over high-salience semantic cues (animacy) as long as they were presented first during the learning phase.

Taken together these findings suggest that when learning a language with phonological-distributional and semantic cues, salience and the timing of availability influenced which cues participants favoured when they were in conflict with each other. However, Culbertson et al. (2017) leave some unanswered questions regarding cue competition; while participants favoured specific cues when they were in conflict, they did not measure whether participants could select markers using only semantic or only phonological-distributional cues. As such it is not clear based on their findings whether participants only learned one cue or learned both cues while still favouring one of them. This prevents us from confirming whether competition between cues led to one cue being learned to the exclusion of the other. Additionally, when comparing how availability influences cue competition the number of exposures were confounded with the timing of availability: cues that were presented earlier were also presented more often than cues that were presented later. Thus, it remains unclear whether the early availability of the cues is actually the driver of cue preference in these experiments.

As a construct the competition model frames availability, reliability and conflict validity as ways in which cues derive validity from being used to make predictions about the language. Cues which are regularly available and lead to correct interpretations gain validity with learners while cues which are not available or which are contradicted during language learning lose validity. However, studies of statistical learning often do not provide participants feedback which can be used to confirm or deny their predictions. In some cases this is due to a lack of decision making tasks during training and in others, decision making tasks are present but participants are not told whether their responses are correct. As such it is unclear how participants in statistical learning studies would evaluate a cue in terms of reliability and conflict validity.

1.2 Discriminative learning

While statistical learning studies do not always provide participants with feedback which they can use to evaluate cues, one explanation for how participants could still evaluate cue validity comes from discriminative learning. Discriminative learning conceptualises language acquisition as a process driven by learners forming expectations while listening to speech and then comparing their expectations against subsequent speech (Ramscar et al., 2010; Ramscar & Port 2016). Ramscar and colleagues developed their discriminative learning approach from the error-driven process of language learning predicted by formal learning theories and blocking.

Looking at formal learning theories and blocking individually can provide insight into how learners may evaluate semantic and phonological-distributional cues when they are encountered together. Formal learning theories posit that learners form expectations based on past experience and then confirm their expectations when encountering additional input (Rescorla, 1988). In addition to drawing feedback from successful and unsuccessful predictions, formal learning theories argue that previously learned knowledge can block acquisition of additional information (Kamin, 1969).

In relation to competition between cues Arnon and Ramscar (2012) suggest that when learning an artificial language, learners form expectations for subsequent word sounds after observing semantics or hearing sounds from the beginning of a word. Once a learner can predict an outcome using a set of cues, further cues predicting the same outcome become unnecessary. Based on this, as uncertainty regarding prediction decreases learners will have less reason to acquire additional cues. When learning grammatical classes, Arnon argues that learners favour semantic cues because they are available before phonological-distributional cues and can be used to anticipate upcoming words. In natural languages, semantic cues can be derived from visual information or prior context which are available before learners encounter any sounds in the word itself. After semantic cues are acquired, phonological-distributional cues are then blocked out as they can only be used to narrow down the number of candidate words that learners may hear, rendering them less informative than semantic cues already available to the learner. An example of this cited by Arnon is the way in which non-native Spanish speakers are unable to use gendered articles to anticipate upcoming words or recognise gender mismatches between articles and words (Guillelemon & Grosjean, 2001; Lew-Williams & Fernald, 2010; Scherag et al., 2004).

Arnon and Ramscar (2012) demonstrated discriminative learning, offering evidence of cue blocking by manipulating the presence of carrier sentences and determiners in a pseudoword language. There were two item types during training; noun-label and full sentences. Noun-label stimuli presented participants with a picture representing meaning and then played the word stem aloud without any phonological-distributional cues present. Full sentence stimuli presented participants with a picture representing meaning alongside the figure of a person gesturing to the artefact, they then played a sequence composed of a carrier sentence, one of two determiners and the word stem. Participants were assigned to one of two conditions. In the sequence-first condition participants were trained on the full sentence stimuli first. In the noun-first condition participants were trained on the noun-label stimuli first. They anticipated that participants trained on full sequences first would be more successful in associating determiners with stems because they would begin by treating the carrier phrase, the picture of a person gesturing, the artefact and the determiner as

equally viable cues which will be reinforced or contradicted with each new word. In contrast, they predicted that participants trained on noun-label stimuli first would develop a strong association between the artefact and word stem which would lead to them blocking out redundant cues when they are introduced in the full sentence stimuli.

During testing, participants trained in the sequence-first condition showed a significant advantage in their learning of determiner-stem associations when compared to participants in the noun-first condition. Participants in the sequence-first condition also showed above chance performance when discriminating against sentences with inconsistent determiners and sentences with inconsistent word stems. Participants in the noun-first condition showed above chance performance when discriminating against sentences with inconsistent stems but were unable to discriminate against sentences with inconsistent determiners. These findings have been replicated with both adults and children (Havron & Arnon, 2021).

Taken together Arnon's studies demonstrate that even within trials, cue availability can affect which associations participants learn when acquiring a novel grammar. Participants who learned associations between the most informative cue and word stems first blocked out other less informative cues present in the language. Additionally these findings demonstrate that when learning competing cues participants may evaluate those cues based on their ability to predict stems. In artificial language learning studies which contain both phonological-distributional and semantic cues, this would lead to participants learning associations with semantic cues while blocking out other associations which do not compete with semantics as a predictor for the stems.

1.3 Semantic and phonological-distributional cues in grammatical gender

A useful example of how phonological-distributional and semantic cues interact in natural languages is grammatical gender. Grammatical gender is a system found in many languages which assigns words to grammatical classes marked by the affixes preceding and following the word. In French, nouns begin with the determiner la or le based on the class they are assigned to and end with suffixes common to each class. Grammatical gender classes are present in multiple languages including French, Dutch, German and Spanish.

Corbett (1991) argued that semantics are at the core of grammatical gender systems with the use of additional phonological-distributional cues varying between languages. In support of this Corbett drew on multiple examples of semantics cuing grammatical gender in natural languages. One example cited by Corbett was that languages, such as Ojibwa and other Algonquian languages

replace the feminine-masculine gender system used in Indo-European languages with an animate-inanimate distinction. Corbett also cited a corpus analysis from Zubin and Köpcke (1981, 1986) that showed groups of same-gendered nouns in German can be clustered based on semantic properties. In German, nouns for apes, mammals and birds tended to be masculine while nouns denoting reptiles and lower animals tended to be feminine. This positions grammatical gender as a construct well suited to investigating how learners learn and use both phonological-distributional and semantic cues in language (Mirković et al., 2005).

Lew-Williams and Fernald (2010) provides a useful example of how phonological-distributional and semantic cues of grammatical gender interact to enable identification of learned artefacts. In their first experiment participants were presented with 8 familiar Spanish words, 4 for each grammatical gender. The feminine words chosen as stimuli were preceded by the determiner la and ended in the suffix -a, masculine words were preceded by el and ended in -o. During training a picture for each word appeared for 2 seconds before the word was played, each picture was associated with a specific word stem. During testing, participants' were shown two pictures which had both been encountered during training. Participants then heard a familiar word associated with one of the two pictures and eye tracking was used to measure how quickly they oriented to the correct picture. There were two types of test trials, same-gender trials which had two pictures from the same grammatical gender and different-gender trials which presented a picture from each grammatical gender.

If participants' reaction times for different-gender trials were significantly faster than for same-gender trials this would indicate that participants were using the determiners to predict which word stem would be played. In Experiment 1 they found that while native Spanish speaking children (d= .62) and adults (d = .59) reacted faster during the different-gender trials, non-native Spanish speaking adults did not (d= .09). Follow up experiments showed that when the familiar words were replaced with unfamiliar words and pictures, non-native Spanish speaking adults were able to use the determiners to predict the pseudoword's stems (d= .49). However, when trying to generalize between different affixes for the same class (e.g. una and la are both feminine affixes) native Spanish speakers were able to use determiners to predict stems (d= .69) while non-native Spanish speakers were not (d= .11). Other studies conducted with participants whose native language contains natural gender classes, have similarly found that learners used gendered determiners to predict stems or suffixes (Lew-Williams & Fernald, 2007; Mills, 1985; Rodina & Westergaard, 2012; Vuong et al., 2016).

These findings demonstrate that learners whose native language contains gender classes are able to predict word meanings by associating phonological-distributional and semantic cues. This aligns with the competition model and its functionalist approach showing that the presence of multiple cues helps learners process linguistic input. Non-native speakers' less consistent use of determiners to predict upcoming words supports the competition model, suggesting that as grammatical gender was not available in their native language they may be less likely to rely on its associated cues. These findings do however raise the question of whether participants whose native language does not include grammatical gender are able to learn and make use of phonological-distributional and semantic cues to predict upcoming words.

In Lew-Williams and Fernald (2010) non-native speakers showed greater difficulty using gender markers, but non-native speakers' ability to use gender markers during second experiment and evidence from artificial language learning studies (Arnon & Ramscar, 2012; Frigo & McDonald, 1998; Gomez, 2002; Havron & Arnon, 2021) suggests that learners whose first language does not have grammatical gender are still capable of using gender markers to predict upcoming nouns.

Frigo and McDonald (1998) provide a clear example of learners whose native language - English - lacks grammatical gender successfully using phonological-distributional cues to produce fluent speech. Frigo and McDonald tested English speakers' ability to generalize between different gender-like articles in a pseudoword language. Participants were taught different greetings which acted as class markers for various words. Each word stem was assigned to one of two grammatical classes, for each class there were two possible greetings meant for mornings and evenings. Grammatical class for each word stem was cued by phonological-distributional markers; over three experiments, class was cued by determiners, suffixes, or both affixes. Participants' ability to provide the correct greeting for each word was tested after training as a measure of their ability to acquire gender-like classes. Their ability to provide greetings for unstudied stem-time combinations was used to test whether they could generalize between different gender-like articles.

Frigo and McDonald found that native English speakers were able to learn greetings for each stem during training and could provide the greetings for different times when prompted with the determiners, suffixes or both affixes. Learners were most successful when the language used both determiners and suffixes as markers. Additionally, participants whose greetings were only cued with determiners performed better than participants whose greetings were only cued with suffixes. These findings demonstrate that learners whose native language does not have gender classes are able to learn and generalize phonological-distributional cues of grammatical gender. Additionally, it demonstrates that participants are able to benefit from multiple phonological-distributional cues as

participants performance was greater when provided with both a determiner and suffix for each word.

Studies investigating statistical learning of grammatical gender have largely focused on participants' ability to use phonological-distributional cues to predict individual word sounds and meanings. While knowledge of semantics was a prerequisite for the associations shown in these studies, they did little to distinguish between knowledge of phonological-distributional cues and knowledge of semantic cues.

1.4 Artificial language learning paradigms

Artificial language learning paradigms offer an effective way to assess a learner's knowledge of both phonological-distributional and semantic cues. In these paradigms participants are trained on individual pseudowords in a novel language. All of the words in the artificial language have specific meanings and the grammatical class of each word is marked by phonological-distributional and semantic cues. This paradigm enables researchers to test participants' ability to recall and generalize multiple facets of the language after training without explicitly communicating the underlying grammatical regularities to them. Artificial language learning paradigms have been employed to investigate whether learners can acquire semantic and phonological-distributional cues to gender-like grammatical classes (Brown et al., 2022; Hickey, 2022; Mirković & Gaskell, 2016; Mirković et al., 2011, 2019, 2021; Van den Bos et al., 2012; Vujović et al., 2021).

Mirković and Gaskell (2016) demonstrates that learners trained on an artificial language are able to learn semantic cues and generalize them to novel words. They trained participants on a pseudoword language with two grammatical classes, words in each grammatical class had a specific determiner, a unique stem and one of two suffixes. Each stem referred to a stereotypically gendered occupation, with stereotypically feminine occupations cuing one grammatical class and masculine occupations cuing the other. In this language the determiners and suffixes were a set of phonological-distributional cues and the gendered occupations were a semantic cue to grammatical class. Participants' acquisition of grammatical classes was tested by comparing whether they endorsed novel words with determiners and suffixes matching the gender of the words' meaning over novel words which had phonological-distributional cues inconsistent with the semantic cue.

Mirković and Gaskell (2016) found that participants endorsed consistent items over items which had determiners and suffixes inconsistent with the grammatical class of the occupation. This supports the notion that participants are able to learn semantic cues and their associations in the language.

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However, while these findings demonstrate that participants are able to learn and generalize semantic cues they do not demonstrate whether semantic cues were specifically favoured over phonological-distributional cues. As the paradigm does not allow for knowledge of each cue in isolation to be measured, this would need to be tested by comparing generalisation of semantic associations to generalisation of associations between phonological-distributional cues.

Participants did not demonstrate significant discrimination against novel words which had consistent determiner-semantic associations but suffixes inconsistent with the other cues. This suggests that participants may have only learned determiners and semantic cues while blocking out suffixes. However, as generalisation of determiner-semantic associations was not measured on its own we cannot conclude which associations drive performance when participants generalize semantics to both affixes.

Other studies have similarly found that participants were able to learn associations between semantic and phonological-distributional cues (Brown et al., 2022; Hickey, 2022; Mirković & Gaskell, 2016; Mirković et al., 2011, 2019, 2021; Van den Bos et al., 2012; Vujović et al., 2021). However, only a handful measured participants' ability to generalize associations between phonological-distributional cues without semantic cues present during testing (Hickey, 2022; Mirković et al., 2021; Vujović et al. 2021). This design feature is necessary for addressing how the presence of semantics as a cue for grammatical class interacts with learning of phonological-distributional cues.

Mirković et al. (2021) investigated whether English speaking adults and children were able to generalize associations between phonological-distributional and semantic cues. Participants were trained on a pseudoword language with two grammatical classes, each class was cued by determiners, suffixes and the animacy of the word's meaning. Participants' ability to associate multiple cues for the same grammatical class was measured after training. Participants' ability to generalize associations was measured using three generalisation tasks. Generalisation of associations between determiners and suffixes without semantics present was measured using a phonological form generalisation task. Generalisation of suffix-semantic associations was measured using a suffix generalisation task. Generalisation of associations between both affixes and semantics was measured using a determiner-suffix generalisation task. Adults and children were able to generalize the association between both affixes and semantics to novel words. Only adults were able to generalize the association between the suffix and semantics to novel words. In contrast, both adults and children were unable to generalize the association between determiners and suffixes to novel words.

The findings of Mirković et al. (2021) demonstrate that while adults and children were able to learn semantic associations in the language, they were unable to learn the associations between the phonological-distributional cues. Other papers investigating participants' ability to generalize both phonological-distributional and semantic cues have similarly found that participants were able to generalize associations between semantic and phonological-distributional cues but were unable to generalize the associations between the multiple phonological-distributional cues (Hickey, 2022; Vujović et al., 2021). This contrasts with previously discussed literature which found that participants were able to generalize associations between multiple phonological-distributional cues when learning a language without semantic cues (Frigo & McDonald, 1998; Gomez, 2002; Vuong et al., 2016). This discrepancy suggests that participants may have acquired semantic cues and associated them with other cues in the language, but that they subsequently blocked out associations between phonological-distributional cues as redundant.

This supports the competition model (Bates & MacWhinney, 1989; Culbertson et al., 2017) suggesting that the different cues competed for relevance and in line discriminative learning (Ramscar et al., 2010; Ramscar & Port, 2016) semantics were favoured over phonological-distributional cues. It is possible that participants favoured semantic cues over phonological-distributional cues because they were seen before participants have heard each word and could be used to predict both the upcoming word stem and phonological-distributional cues. As determiners and suffixes do not provide additional predictive value and are encountered after semantic cues, participants may be blocking them out during training (Kamin, 1969).

1.5 Implicit and explicit knowledge

Several studies employing the artificial language learning paradigm to investigate acquisition of semantic and phonological-distributional cues have measured explicit knowledge of cues in addition to implicit knowledge (Hickey, 2022; Mirković et al., 2021). This was done to address the ambiguous role of explicit knowledge in the artificial language learning task. Statistical learning has generally been considered an implicit learning mechanism which learners can use to make decisions regarding input but are unable to verbalise when asked (Aslin & Newport, 2012; Christiansen, 2019; Seidenberg & MacDonald, 2018). However, while the tasks teach and measure implicit knowledge, there is evidence that explicit knowledge also emerges in statistical learning tasks and is associated with participants' performance on implicit measures (Batterink et al., 2015, 2019; Mirković et al., 2021; Rebuschat & Williams, 2012).

Mirković et al. (2021) examined the presence of explicit awareness in an artificial language learning task. Across three experiments participants implicit awareness of cue associations was measured using generalisation tasks and their explicit awareness was measured using verbal reports at the end of the experiment. Participants' answers were scored for explicit awareness of the phonological forms and semantic associations of determiners and suffixes in the language. Over the course of three experiments participants showed some explicit awareness of each affix, but demonstrated significantly greater awareness of the determiners compared to the suffixes. Mixed-effects models conducted for the first and third experiments found that explicit awareness of the determiners was a significant predictor of whether participants could generalize associations between animacy of word meanings and determiner-suffix pairs after training was complete. Other literature also found evidence of explicit awareness of grammatical cues in an artificial language learning task and that explicit awareness was associated with performance on implicit measures (Brown et al., 2022; Hickey, 2022).

These results show that even if the instructions and task do not explicitly instruct learners to look for cues of grammatical class, explicit knowledge of classes can emerge during training and is associated with participants' performance on implicit measures of class knowledge.

1.6 The present study

Literature investigating statistical learning of multiple cues has largely focused on phonological-distributional cues while omitting semantic cues from language (Frigo & McDonald, 1998; Gomez, 2002; Lew-Williams & Fernald, 2010; Vuong et al., 2016). However, the associations between semantics and other cues of grammatical class are not arbitrary. In fact, semantic cues and their associations with phonological-distributional cues are at the core of grammatical gender classes (Corbett, 1991; Zubin & Köpcke, 1981, 1986). As such when investigating how multiple cues interact it is vital to measure learning of both semantic and phonological-distributional cues.

Both the competition model (Bates & MacWhinney, 1989; Culbertson et al., 2017) and discriminative learning (Arnon & Ramscar, 2012; Havron & Arnon, 2021; Ramscar et al., 2010; Ramscar & Port, 2016) argue that when semantic cues are present in a language, they outcompete phonological-distributional cues for the participants attention. Studies testing these predictions have attributed the preference for semantic cues to their greater salience (Culbertson et al., 2017), earlier availability (Arnon & Ramscar, 2012; Culbertson et al., 2017; Havron & Arnon, 2021; Ramscar et al., 2010) and greater predictive validity (Arnon & Ramscar, 2012; Havron & Arnon, 2021; Ramscar et al., 2010) when compared to phonological-distributional cues.

When applied to multiple cue learning the competition model predicts that one cue will outcompete the other for validity as a grammatical cue. Discriminative learning further specifies that learners will favour semantic cues to the exclusion of phonological-distributional ones. When trained on a language with both semantic and phonological-distributional cues to grammatical class, participants have been able to generalize associations between semantic and phonological-distributional cues but unable to generalize associations between multiple phonological-distributional cues (Hickey, 2022; Mirković et al., 2021; Vujović et al., 2021). In contrast, when trained with only phonological-distributional cues participants were able to learn the associations between those phonological-distributional cues (Frigo & McDonald, 1998; Gomez, 2002; Vuong et al., 2016).

Thus, there is evidence that the presence of semantics during artificial language learning may interfere with learning of phonological-distributional cues. However, previous literature has not examined whether manipulating the presence of semantics in an artificial language affects participants' ability to learn and generalize other cues. Additionally, the competition model and discriminative learning both attribute preference for semantic cues in part to their early availability. Across the set of six experiments presented in this thesis, I investigated firstly, whether the presence of semantics influenced participants' ability to generalize associations between phonological-distributional cues. and further, whether the timing of the availability of different cues in the training language affected participants' ability to generalize the associations of each cue.

All six experiments employed an artificial language consisting of pseudowords associated with pictures of animals and artefacts. To replicate the gender-like system employed by previous studies (Hickey, 2022; Mirković et al., 2021; Vujović et al., 2021), words belonged to one of two grammatical classes. Each grammatical class was marked with a specific determiner and suffix which acted as phonological-distributional cues. The animacy of each word's individual meaning was used as a semantic cue.

Across all six experiments participants were trained on the artificial language using a word learning task. Implicit awareness of grammatical associations in the language was measured using phonological form and semantic generalisation tasks. The phonological form generalisation tasks measured participants' ability to associate determiners with suffixes when there are no semantic cues available to base decisions on. The semantic generalisation tasks measured participants' awareness of associations between animacy and affixes. Based on the emergent explicit awareness of grammatical categories found in previous artificial language learning studies (Hickey, 2022; Mirković et al., 2021), participants' verbal reports during debriefing were used to measure explicit awareness of phonological-distributional and semantic cues of grammatical class.

Our hypothesis is that when semantic and phonological-distributional cues are presented together throughout training, participants will learn associations with semantic cues but block out associations between multiple phonological-distributional cues. If as the competition model and discriminative learning predict, participants favour semantic cues to the exclusion of phonological distributional cues, we hypothesise that manipulating the availability of semantic cues during training will enable participants to learn associations between multiple phonological-distributional cues.

In Experiments 1 and 2 we investigated whether the cues available during a participant's initial exposure to the language affected which cues were learned over the course of training. Experiments 3 and 4 investigated whether the presence of semantics as either individual word meanings or a cue to grammatical class interfered with learning of phonological-distributional cues. Experiments 5 and 6 investigated whether competition occurs between multiple phonological-distributional cues, causing some cues to block out others. Experiment 6 also investigates whether participants are able to learn multiple associations in the language by sequentially presenting cues from least favoured to most favoured.

Chapter 2. Methods

All six experiments presented in this thesis employ the same artificial language paradigm, modified in each experiment to address specific research questions. For clarity and succinctness, the structure of the language, considerations taken for online testing, the stimulus set, and the tasks used in training and testing, will be presented here. Design features specific to each experiment will be presented in the relevant empirical chapters.

2.1 Training language

We used a word-learning paradigm, in which the task presented to participants is to learn a set of words from an 'alien language'. Unbeknownst to the participants, the language incorporates grammatical regularities corresponding to grammatical gender, as described below.

Across our experiments participants learned a set of 24-32 pseudowords during training: in the first two experiments participants were trained on a set of 32 pseudowords while later experiments trained participants on a set of 24. These were all pronounceable English pseudowords taken from the ARC database (Rastle et al., 2002), each comprising a unique stem, which was preceded by one of two determiners and followed by one of two suffixes. Half of the stems were preceded by the

determiner *tib-* and were followed by the suffix *-eem* (e.g. *tib hormeem*) while the remaining stems were preceded by *ked-* and followed by *-ool* (e.g. *ked larshool*).

During training, participants were presented with an audio recording of each pseudoword alongside its corresponding referent - i.e. a picture of an animal or inanimate artefact. Each pseudoword was presented multiple times; the number of exposures during training varied across experiments.

In addition to the association between each stem and a specific referent, there was a higher-order 'grammatical' regularity in which each of the determiner-suffix pairs was associated with the animacy of the presented picture. During training pseudowords beginning with *tib-* and ending with *-eem* were presented with pictures of animals while pseudowords beginning with *ked-* and ending with *-ool* were presented with pictures of artefacts. Across our studies whenever participants were trained with both pseudowords and referents, the language was counterbalanced such that for half of the participants a given determiner-suffix pair was associated with animals, while for the other half the same determiner-suffix pair was associated with artefacts.

As illustrated in Table 1 each stem was associated with a picture of a specific animal or artefact while each determiner-suffix pairing was associated with the animacy of the word meaning.

Table 1. Example stimuli for the training set

Grammatical category	Determiner	Suffix	Full Word	Picture
Animals	tib-	-eem	tib-zeap-eem	
Artefacts	ked-	-ool	ked-cass-ool	

The training language mimicked the grammatical gender classes encountered in natural languages such as Spanish (Lew-Williams & Fernald, 2007, 2010) and Dutch (Vuong et al., 2016). As in these languages, stems were assigned one of two grammatical classes which were indicated by the determiner preceding the stem and the suffix associated with each grammatical class. Similar to the semantic cues of grammatical gender classes found in languages such as German and Serbian (Zubin

& Köpcke, 1981, 1986; Mirković et al., 2005), the animacy of word meanings was used as a semantic cue of grammatical class.

The training language incorporates multiple features that participants could in principle learn. Participants could learn specific word forms and their meanings. They could also abstract grammatical classes which could be applied to novel pseudowords by learning the determiner-suffix pairings and semantic associations in the language.

2.2 Online Testing

All six experiments were conducted online. Each experiment was constructed using the experiment builder included in the online testing platform Gorilla. Before being given access to the experiment participants were instructed to complete it using either a desktop computer or a laptop. Participants were told before taking part that the experiment would need access to their microphone and speakers. Speaker access was tested before the experiment began and participants were asked to check their microphone was working using a playback function, if they could not complete these checks participants were asked to exit the study. Before training, participants were asked to ensure that they were in a quiet setting free of any background noise or disturbances to avoid any distractions or interference with voice recordings.

As participants could not be monitored directly by a researcher, audio of participants repeating back pseudowords during the repetition tasks during training were reviewed to confirm that participants had followed instructions.

2.3 Training tasks

2.3.1 Repetition task

In Experiments 1 and 2 participants were trained on the language using repetition tasks. In each block participants were exposed to the set of training pseudowords once in a randomised order. Before the first block of training participants were informed that during each trial they would see a picture and would hear a made-up word for that picture, and were instructed to repeat back each word as they heard it. Each block began with two practice trials before progressing to the training set.

During each trial a picture of an animal or artefact appeared in the centre of the screen after 500 ms and a pseudoword began playing simultaneously. After each word was played participants had 2500 ms to repeat the pseudoword before the experiment moved on to the next trial. Between trials a

fixation cross appeared in the centre of the screen to maintain participants visual attention on the pictures when they appeared. For each trial participants were recorded repeating back the pseudoword which had been played, the recording began immediately after the stimuli finished playing and ended after 2500 ms. Participants' responses were reviewed offline by the experimenter, to assess compliance with instructions. For these checks, successful repetitions of the played stimuli were coded as correct while instances where no speech was recorded or where participants spoke words other than the target stimuli were coded as incorrect. Participants were considered to have engaged with the task if they correctly repeated back at least 80% of the stimuli played to the during training.

2.3.2 Word-picture matching task

In later experiments participants were trained using both repetition and word-picture matching. In the word-picture matching task, participants were informed that during each trial they would see a picture and hear a made-up word for that picture which they were instructed to repeat back. In addition, after each repetition they heard the pseudoword a second time and had to indicate whether they thought the word and picture went well together or not, by selecting a smiley or frowny face at the bottom of the screen.

Two practice trials were carried out at the start of each block of training. Participants had 6000 ms to select a face before the experiment moved on to the next trial. Between trials a fixation cross appeared in the middle of the screen.

2.4 Tests of word learning

Across our experiments, participants' word learning was measured using two recognition tasks, one indexing learning of the word-form, and the other word-meaning mapping.

2.4.1 Word-form: Phonological form recognition task

The phonological form recognition task was used to investigate participants' learning of word forms. Before the task, participants were told that they would be hearing familiar and unfamiliar pseudowords without any pictures present and that after hearing each pseudoword they needed to identify the word as either "old" meaning that they heard it during training or "new" meaning that this was their first time hearing it.

During the task participants were played a set of pseudowords; half of these were taken from the training set and the other half were novel pseudowords that they were hearing for the first time.

The novel pseudowords had determiner-suffix pairings consistent with the training language but stems which participants had not heard during training. As the aim of the task was to assess learning of phonological forms in the absence of semantics, pictures of animals and artefacts were not present during the task. Instead, a fixation cross in the centre of the screen was visible when each pseudoword was presented.

Of the pseudowords from the training set heard during the phonological form recognition task, half began with *tib-* and ended with *-eem* while the other half began with *ked-* and ended with *-ool*. Similarly, half of the novel words used *tib-* and *-eem* while the other half used *ked-* and *-ool*. During the task the item order was randomised for each participant and there were two practice trials before they began.

For each trial participants had 6000 ms to indicate whether a word was old or new before they were timed out and moved onto the next trial. If participants demonstrated above chance accuracy (50%) when identifying familiar words as being present during the training, it was taken as evidence that participants had learned the word-forms of the trained items. Participants results for this task were excluded from the dataset if they were timed out for more than 20% of the trials or if they selected the same option for every trial.

2.4.2 Word-meaning: 2AFC task

The 2AFC task was used to investigate participants' learning of the mapping between word-forms and their referents. Participants were instructed that they would be hearing familiar pseudowords alongside two familiar pictures and would need to select which picture which goes with the pseudoword.

During the task participants were presented with pseudowords encountered during training, for each trial participants were played one of the pseudowords from the training set and were presented with the target picture and a foil picture. The foil picture was a picture taken from a different training word which matched the animacy of the target picture. The foils were assigned such that each training word would serve as a target and foil once for each 2AFC task. During the task the order of items was randomised for each participant and there were two practice trials before they began.

For each trial participants had 4000 ms to select which picture goes with the pseudoword before they were timed out and moved onto the next trial. If participants demonstrated above chance accuracy (50%) when identifying word-picture pairings, it was taken as evidence that they had

learned the semantics associated with each pseudoword during training. Participants results for this task were excluded from the dataset if they were timed out for more than 20% of the trials or if they selected the same option for every trial.

2.5 Tests of grammar learning

2.5.1 Phonological form generalisation task

Across our experiments, phonological form generalisation tasks were used to investigate whether participants were able to generalize the determiner-suffix pairings heard during training to novel pseudoword stems.

The pseudowords used in the generalisation tasks had novel stems which participants were unfamiliar with. As with the training items, all pseudowords used in the generalisation tasks were pronounceable English pseudowords from the ARC database (Rastle et al., 2002). Half of the novel words presented in each generalisation task were consistent with the training language; of these, half paired *tib-* with *-eem* and half paired *ked-* with *-ool*. The inconsistent words paired determiners and suffixes which did not go together during training (i.e. *tib-* with *-ool* and *ked-* with *-eem*).

To ensure participants' judgements were based on their learning of the determiner-suffix pairings heard during training and not the associations with semantics, there were no pictures of animals or artefacts during this test.

Table 2. Example phonological form generalisation task items

Item type	Pseudoword
Consistent with phonological cues from training	**tib** gatch**eem**/**ked** gatch**ool**
Inconsistent with phonological cues from training	**tib** viff**ool**/**ked** viff**eem**

During each trial participants saw a fixation cross in the middle of the screen and heard a novel pseudoword, they were instructed to select a smiley or frowny face to indicate whether the word went with the training language. Participants had 6000 ms to decide before they were timed out and moved onto the next trial. Participants results for the task were excluded from the dataset if they were timed out for more than 20% of the trials or if they selected the same option for every trial. The order of items was randomised for each participant and there were two practice trials before the test.

A' scores were used as the outcome measure for the generalisation tasks (Pallier, 2002) to account for response biases. A' scores for each task were calculated using endorsements of consistent test items as hits and endorsements of inconsistent items as false alarms. A' scores ranged from 0 to 1. A' scores significantly above 0.5 were evidence that learners had generalize a regularity.

If participants demonstrated the ability to distinguish between grammatical and ungrammatical items in the phonological form generalisation task, it would demonstrate that they had abstracted the nonadjacent dependency between the determiners and suffixes allowing them to apply it to novel words.

2.5.2 Semantic generalisation tasks

The three semantic generalisation tasks used across our experiments, investigated participants' ability to generalize the association between animacy and specific phonological-distributional cues. The determiner set tested participants ability to generalize the association between determiners and animacy to novel words; the suffix set tested for generalisation of the association between suffixes and animacy; and the determiner-suffix set tested participants' ability to generalize the association between determiner-suffix pairs and animacy. Unique stems were used for each of the generalisation sets.

Within each generalisation set half of the items were consistent with grammatical classes from the training set. These consistent items had novel pseudoword stems and pictures which participants hadn't encountered before, but had semantic and phonological-distributional cues consistent with the training set. Pseudowords representing animals began with *tib-* and ended with *-eem* while pseudowords representing artefacts began with *ked-* and ended with *-ool*.
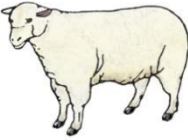
In the determiner-only set items inconsistent with grammatical classes from the training set had a suffix consistent with the animacy of the picture, but the determiner was from the other grammatical class. Pseudowords for animals began with *ked-* and ended with *-eem* while pseudowords for artefacts began with *tib-* and ended with *-ool*.

In the suffix-only set items inconsistent with grammatical classes from the training set had a determiner consistent with the animacy of the picture, but the suffix was from the opposite grammatical class. Pseudowords for animals began with *tib-* and ended with *-ool* while pseudowords for artefacts began with *ked-* and ended with *-ool*.

In the determiner-suffix set items inconsistent with grammatical classes from the training set, had a determiner and suffix from the opposite grammatical class to the animacy of the picture.

Pseudowords for animals began with *ked-* and ended with *-ool* while pseudowords for artefacts began with *tib-* and ended with *-ool*.

Table 3. Example grammar generalisation task items

Item type	Picture	Determiner Set	Suffix Set	Determiner-Suffix Set
Consistent with grammatical classes during training		**tib**-jel-eem	tib-jel-**eem**	**tib**-jel-**eem**
Inconsistent with grammatical classes during training		**ked**-hor-eem	tib-hor-**ool**	**ked**-hor-**ool**

Participants completed three grammar generalisation tasks after the phonological form generalisation task. In each trial participants were shown a novel picture of an animal or artefact and heard a novel pseudoword. Participants were instructed to choose the smiley or frowny face to indicate whether the word and picture went well together. Participants had 6000 ms to decide before they were timed out and moved onto the next trial. Participants results for the task were excluded from the dataset if they were timed out for more than 20% of the trials. The order of items was randomised for each participant and there were two practice trials before each test.

2.6 Explicit awareness questionnaire

Participants' explicit knowledge of the associations present in the language was assessed after the final set of tests. Participants' explicit knowledge was measured as multiple subtests.

Explicit awareness was measured using two questions;

1. Did you notice anything about the fictional language?
2. For the new words and pictures that you saw, what kinds of strategies or clues did you use to decide if the word and picture matched?

The responses for both questions were scored together for awareness of the determiner's phonological forms, determiner-semantic associations, suffix phonological forms, suffix-semantic associations and determiner-suffix pairings to reflect the complexity of the regularities present in the language.

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A score of two was assigned to responses which fully specified the regularities, for determiner forms this involved specifying both determiners (*tib-* and *ked-*). A score of one was assigned to responses demonstrating partial knowledge, for determiners this involved specifying one determiner but not the other. A score of zero was assigned to responses which did not reference any phonological or semantic regularities.

Awareness of determiner forms awarded a point for each determiner participants identified (e.g. *tib-* and *ked-*) while awareness of suffix forms awarded a point for each suffix identified (e.g. *-eem* and *-ool*). Awareness of phonological form co-occurrence awarded a point for each determiner-suffix pair which participants were able to identify (e.g. *tib-* goes with *-eem* and *ked-* goes with *-ool*). Awareness of determiner-semantic associations awarded a point for each association between the determiner and grammatical class that participants identified (e.g. *tib-* goes with animals and *ked-* goes with artefacts). Finally, awareness of suffix-semantic associations awarded a point for each association between the suffix and grammatical class that participants identified (e.g. *-eem* goes with animals and *-ool* goes with artefacts). During analysis these scores were indexed into explicit awareness of: i) determiner phonology (0-2), ii) determiner semantics (0-2), iii) suffix phonology (0-2), iv) suffix semantics (0-2) and v) determiner-suffix pairs (0-2).

Chapter 3. Competition between semantic and phonological-distributional cues.

3.1 Introduction

The competition model (Bates & MacWhinney, 1989; Culbertson et al., 2017) argues that learners favour cues based on their objective properties such as availability and conflict validity. Discriminative learning (Arnon & Ramscar, 2012; Havron & Arnon, 2021; Ramscar et al. 2010; Ramscar & Port, 2016) expands on this identifying early availability and predictive value as properties which lead to learners favouring semantic cues over phonological-distributional cue. When applied to adult learners' encountering a second language this leads to them learning semantic cues more successfully than phonological-distributional cues.

In addition to arguing that participants favour semantic cues over phonological-distributional cues based on their earlier availability, a component of discriminative learning, blocking (Kamin, 1969), suggests after acquiring cues which are either available earlier or are more useful for predicting upcoming speech, unlearned cues which only provide redundant information will be blocked out. As

such, after acquiring one cue, learners will only acquire alternative cues if they provide predictive value that cannot be derived from the already learned cues. In a language with semantic and phonological-distributional cues, semantic cues can be acquired from visuals or preceding context before learners encounter phonological-distributional cues immediately before and after a word. Additionally, visual information associated with a word can be used to predict a specific word whereas cues such as determiners can only be used to narrow down the words to a group of candidates which share that determiner. According to blocking, this means that learning semantic cues such as animacy may interfere with learning of phonological-distributional cues such as determiners and suffixes. This is because participants can already predict upcoming words using semantic cues and therefore do not need to use phonological-distributional cues to anticipate upcoming words.

Looking at previous artificial language learning studies, there is evidence that participants can learn and generalize associations between different phonological-distributional cues when learning languages without any semantic cues (Frigo & McDonald, 1998; Gomez, 2002; Vuong et al., 2016). In contrast, when semantics cues are present alongside phonological-distributional cues participants were able to generalize associations with the semantic cue but not the associations between the different phonological-distributional cues (Hickey, 2022; Mirković et al., 2021; Vujović et al., 2021). Taken together these findings suggest that the presence of semantic cues interferes with learning of phonological-distributional cues. However, these studies did not directly compare how the presence or absence of semantics affects learning of phonological-distributional cues between otherwise equivalent training conditions.

One study that indirectly demonstrates that semantics can interfere with learning of phonological-distributional cues is Arnon and Ramscar (2012). They investigated whether the order in which participants were trained on determiners and semantics affected which cues participants were able to associate with trained words. They found that participants trained on full sentences, with a carrier phrase, determiner and semantics available as equally viable predictors of an upcoming word were able to learn which determiners and meanings were associated with each word. In contrast, when participants were trained on word-picture pairs before being trained on full sentences with a carrier phrase and determiner they were able to learn each word's meaning but were unable to associate words with their determiners when trained on them later. In line with discriminative learning and blocking, these findings suggest that when learners acquire a word's meaning without any other contextual cues, they are less likely to learn those cues later. There are some limitations to consider when evaluating these findings. The study measured cue acquisition by testing whether participants

could associate determiners and semantics with each trained word but in natural languages cues need to be learned and generalised to novel contexts if they are to support language acquisition.

To investigate whether participants have actually learned grammatical cues as a feature distinct from previously learned words it is necessary to test whether they can use learned cues to make decisions about unfamiliar words. Culbertson et al. (2017) demonstrate that learners seem to favour semantic cues and that delaying their inclusion may enable participants to acquire phonological-distributional cues. In their initial experiment, they found that participants were able to identify the grammatical categories of novel words using the animacy of each word's meaning and determiner-suffix pairs. Following this, when asked to identify the grammatical category of novel words with conflicting semantic and phonological-distributional cues they found that participants favoured the semantic cue over the phonological-distributional cue.

In a follow up experiment they manipulated the availability of semantic cues by training participants on a language with only determiner-suffix pairings as a cue of grammatical class and then introducing animacy as a semantic cue in the second half of training. They found that while participants favoured semantic cues over phonological-distributional cues when they were in conflict in the previous experiment, training participants with only phonological-distributional cues first resulted in participants favouring phonological-distributional cues instead. Taken together these findings suggest that when both semantic and phonological-distributional cues are available in the language participants will favour semantic cues, but that early availability can shift which cues participants rely on to phonological-distributional cues.

Culbertson's study provides a useful illustration of how participants seem to value semantic cues over phonological-distributional cues and how availability can be manipulated by delaying the inclusion of a specific cue during the course of training. However, when addressing whether semantic cues interfere with learning of phonological-distributional cues there are several limitations to these methods that need to be considered. While they showed that participants favoured semantic cues when the two cues were in conflict, they did not confirm whether participants were still able to learn and generalize the less favoured phonological-distributional cue. This leaves the question of whether this preference would lead to interference in learning of the less favoured cue unresolved. Additionally, as Culbertson's manipulation of availability did not control for the number of exposures to each cue it did not differentiate between early availability and number of exposures as a property which leads to specific cues being favoured.

<u>Rationale</u>

Study 1 incorporates two experiments addressing whether semantic and phonological-distributional cues compete for relevance during learning, and based on this which cues and associations between cues participants can generalize to novel words. Further, it addresses whether manipulating the availability of cues during participants' initial exposure to the language affect which cues they are able to learn.

Participants' ability to generalize associations between different cues was measured across four different tasks, probing learning of i) the association between determiners and suffixes, ii) determiner-semantic associations, iii) suffix-semantic associations and iv) associations between semantics and determiner-suffix pairs. In contrast to previous studies which measured determiner-suffix pairs as a single phonological-distributional cue this allowed us to address whether individual cues had been acquired by testing which cues were able to be used in the generalisation tasks.

In addition to investigating the effect of semantics on learning and generalisation of cues, both experiments also measured participants' learning of the trained words' forms and meanings. Previous studies using this paradigm have consistently found that participants were able to learn individual word forms and meanings, even when they were not able to demonstrate learning of the grammatical regularities (Hickey, 2022; Mirković et al., 2021); Experiment 1 investigated participants' ability to generalize associations for semantic and phonological-distributional cues while testing whether the delaying the availibility of semantic cues during training affected participant's ability to generalize phonological-distributional cues. To do this Experiment 1, manipulated the availability of semantic cues during participants initial exposure to the language via two training conditions. In the simultaneous condition participants' first exposure to the language trained them on the phonological forms and word meanings; that is, both phonological-distributional and semantic cues were available during their initial exposure to the language. In the sequential condition, participants' first exposure to the language trained them on phonological forms but omitted word meanings; this meant that only phonological-distributional cues were available. In Experiment 1 the number of exposures to semantic cues was matched across conditions to ensure that differences in preference were driven by the timing of cues rather than number of exposures.

Experiment 2 expanded on this by investigating whether omitting semantic cues during participants' first exposure to the language had a significant effect on cue preference when subsequent training

included both semantic and phonological-distributional cues. This was done to address generally lower learning of word forms and meaning during Experiment 1 and to test whether further exposure to the training language can enable participants to learn redundant cues.

Based on previous findings, semantic cues outcompete phonological-distributional cues when both are present in a language (Hickey, 2022; Mirković et al., 2021; Vujović et al., 2021). This happens because semantic cues are available before phonological-distributional cues and they have greater value when predicting upcoming words (Arnon & Ramscar, 2012; Havron & Arnon, 2021; Ramscar et al., 2010). As phonological-distributional cues do not provide additional information when making predictions they are treated as redundant and blocked out (Arnon & Ramscar, 2012; Havron & Arnon 2021; Ramscar et al., 2010). Culbertson et al. (2017) have demonstrated that beyond which cues are available first during each word's presentation, experiments can manipulate availability by omitting more relevant cues during initial exposures to the language. In the absence of a more relevant cue, previously redundant cues in the language are no longer blocked out and become comparatively more available. While Culbertson tested cue learning using preference when cues were in conflict with each other, Experiments 1 and 2 address whether participants demonstrate different patterns of learning and generalisation when manipulating cue availability.

Experiments 1 and 2 tested whether delaying the inclusion of semantics in the training language, will result in participants learning and generalizing associations between the phonological-distributional cues available during the first phase of training. Experiment 1 tested whether early exposure to only the phonological-distributional cues affected learning when compared with a group controlling for equal exposures to semantic and phonological-distributional cues in the training language while Experiment 2 tested whether early exposure to only the phonological-distributional cues had a lasting effect on which cues were generalised after participants had undergone further exposure to the language.

3.2 Experiment 1

3.2.1 Introduction

In Experiment 1 participants were trained on a miniature artificial language, using a word-learning paradigm. Each pseudoword was presented alongside a picture representing its meaning. Determiner and suffixes heard before and after word served as the phonological-distributional cues in the language while the animacy of each associated picture served as a semantic cue. Experiment 1 manipulated the availability of the semantic cue during participants' initial exposure to the language

via two training conditions. In the simultaneous condition, participants were trained on word-picture pairs during the first phase of training; as such, both semantic and phonological-distributional cues were available during participants' first exposure to the language. In the sequential condition, participants were trained on phonological forms while omitting semantics; as such, the only cues available during the first phase of training were phonological-distributional cues. Following this in the second phase of training participants in the simultaneous condition were trained on only phonological forms while participants in the sequential condition were trained on word-picture pairs. This ensured that any differences between conditions could be attributed to which cues were available during participants' initial exposure to the language and not how many times they were exposed to semantic cues. In the third phase of training, participants in both conditions were trained on word-picture pairs for a second time to provide them with sufficient exposures to both cues in the language.

To establish whether participants were able to acquire the language in general, learning of word forms and word meanings was used to investigate whether they could recognise the words they were trained on. Learning of word forms was measured by testing whether participants could recognise words from training when they were presented alongside novel pseudowords with unfamiliar stems. Learning of word meanings was measured by prompting participants with words from the training set and testing whether participants could identify which of two familiar pictures was associated with each word. In line with findings from previous studies using this and similar paradigms, it was predicted that participants would recognise word forms and meanings in both conditions (Hickey, 2022; Mirković et al., 2021; Vujović et al., 2021).

A phonological form generalisation task was used to measure whether participants can associate the two phonological-distributional cues, in this case determiners and suffixes, in the absence of any semantic cues. A series of semantic generalisation tasks measured participants' ability to associate determiners, suffixes and determiner-suffix pairs with semantic cues. While not directly measuring learning of each cue, participants' success when forming associations for each cue can be used to determine if they have been able to generalize it. Alongside this, explicit questions are employed during debriefing to measure participants' explicit knowledge of the cues and their associations.

In Experiment 1, comparisons between training conditions were used to investigate whether exposure to only the phonological-distributional cues during the first block of training had a positive effect on participants' ability to generalize phonological-distributional associations. Comparisons between training conditions were also used to investigate whether exposure to only the

phonological-distributional cues during the first block of training would have a negative effect on generalisation of semantic associations in the language.

Based on the competition model and discriminative learning, it was predicted that participants trained on only phonological-distributional cues for the first phase of training would generalize associations between phonological-distributional cues to a greater extent than participants trained with semantics and phonological-distributional cues. In line with previous literature (Hickey, 2022; Mirković et al., 2021; Vujović et al. 2021), it was predicted that participants trained with both semantics and phonological-distributional cues for the first phase of training would be unable to generalize associations between the phonological-distributional cues.

Based on blocking, early exposure to the phonological-distributional cues would not interfere with subsequent learning of semantic cues. As such it was predicted that training participants with only phonological-distributional cues for the first phase of training would not affect generalisation of semantic cues. In line with previous findings (Hickey, 2022; Mirković et al., 2021; Vujović et al., 2021), it was predicted that participants would generalize associations between semantic and phonological-distributional cues in both training conditions.

Hypotheses

1. Based on previous studies using this paradigm, it was predicted that participants across training conditions would be able to recognise word forms and meanings.
2. Based on previous studies, it was also predicted that participants would be able to generalize associations between semantic cues and phonological-distribution cues to novel words. This meant associating the animacy of novel pictures with; i) determiners, ii) suffixes and iii) determiner-suffix pairs.
3. Based on the competition model and discriminative learning, it was predicted that participants trained on phonological forms without semantics for the first phase of training would be able to generalize associations between determiners and suffixes to novel words.
   a. In contrast it was predicted that participants trained on phonological forms and semantics for the first phase of training would be unable to generalize associations between determiners and suffixes to novel words.

3.2.2 Methods

Participants

During recruitment, fifteen participants were excluded from the study for not complying with instructions during training. The resulting sample was comprised of eighty monolingual, native English-speaking adults (26 male, 51 female, 3 nonbinary; mean age = 24.97 range = 18-40) with no known language disorders was used in Experiment 1. Participants had normal hearing and normal or corrected-to-normal vision. Forty-nine of the participants in the sample were drawn from the undergraduate and postgraduate population of the University of York, these participants were volunteers recruited by undergraduate students who aided in my data collection and used part of the data for their undergraduate project report. Thirty-one participants were recruited from Prolific with each participant being paid £7.50 for their participation. Before taking part in the study all participants gave informed consent. The study was approved by the Ethics Committee at the Department of Psychology, University of York.

Participants were randomly allocated to one of two training conditions. After recruitment was complete, there were 41 participants in the simultaneous condition and 39 participants in the sequential condition. The differing sample sizes between training conditions after recruitment was complete were caused by a combination of varying attrition rates between conditions and participants whose results were excluded when they did not follow instructions during training.

Materials

Language training set

The training set for Experiment 1 comprised 32 pseudowords, as described in Chapter 2 of this thesis. Briefly, pseudowords belonged to one of two grammatical classes, each class being associated with a specific determiner and suffix as well as being associated with either animals or artefacts.

Table 4 shows example word-picture pairs for each training condition and grammatical class. Pseudowords were composed of a determiner (*tib-* or *ked-*), a unique stem and a suffix (-*eem* or -*ool*). Each pseudoword was associated with a specific animal or artefact and the animacy of the pictures was associated with one of the two determiner-suffix pairs. The language used during training and testing was counterbalanced such that for half of participants *tib-* and -*eem* were associated with animals while *ked-* and -*ool* were associated with artefacts. The other half learned that *tib-* and -*eem* were associated with artefacts while *ked-* and -*ool* were associated with animals.

For participants in each training condition semantics were omitted from the language for one phase of training. During the phases without semantics, pictures of animals and artefacts were replaced with a fixation cross which remained in the middle of the screen to maintain visual attention. In the

sequential condition, semantics were omitted for the first phase of training and were introduced during the second.

In the simultaneous condition participants were trained with semantics present for the first phase of training. Semantics were then omitted in the second phase. During the third phase of training participants in both conditions were trained with semantics present. This ensured that participants' overall exposure to the language included both semantic and phonological-distributional cues and that this exposure was matched across training conditions.

During each phase of training participants were exposed to the full set of 32 trained pseudowords once. Alongside the trained words a set of 32 mismatched items were created which paired trained pseudowords with an incorrect trained picture to simulate statistical noise in natural language acquisition. Mismatched pictures matched the grammatical class of the pseudoword but displayed a different animal or artefact. For each of the two phases of training which included semantics, participants were exposed to 16 mismatched items alongside the 32 trained word-picture pairs. Participants encountered each of the 32 mismatch items once over the course of training.

Table 4. Example stimuli for each training condition

Length of Training	Stimuli	Simultaneous Condition		Sequential Condition	
		Animal Word	Artefact Word	Animal Word	Artefact Word
First Phase of Training	Pseudoword	zeap-eem	cass-ool	zeap-eem	cass-ool
	Picture			+	+
Second Phase of Training	Pseudoword	tib-zeap-eem	ked-cass-ool	tib-zeap-eem	ked-cass-ool
	Picture	+	+		
	Pseudoword	tib-zeap-eem	ked-cass-ool	tib-zeap-eem	ked-cass-ool

Third Phase of Training	Picture				

Generalisation sets

A total of 40 novel pseudowords were used across the generalisation tasks. Novel pseudowords used the same determiners and suffixes as the training set but replaced the stems heard during training with new English pseudowords taken from the ARC database (Rastle et al., 2002). Each novel pseudoword in the semantic generalisation tasks was presented alongside a novel picture of an animal or artefact.

The two phonological form generalisation tasks each used 8 novel pseudowords. For each task there were 4 consistent pseudowords which had determiner-suffix pairings consistent with the training set. Of these 2 words paired *tib-* with *-eem* and 2 paired *ked-* with *-ool*. Inconsistent pseudowords paired determiners with suffixes from the opposite grammatical gender. Of the 4 inconsistent pseudowords, 2 paired *tib-* with *-ool* and 2 paired *ked-* with *-eem*.

The three semantic generalisation tasks each used 8 novel pseudowords. As outlined in the general methods section consistent items in each task had determiner-suffix pairs which matched the animacy of their assigned picture, while inconsistent items varied between each test. Inconsistent items in the determiner generalisation task, had a suffix which matched the animacy of the picture but had a determiner which did not match the other two cues. Inconsistent items in the suffix generalisation task, had a determiner which matched the animacy of the picture but had a suffix which did not match the other two cues. Finally inconsistent items in the determiner-suffix generalisation task had a determiner-suffix pairing that went together but did not match the animacy of the picture.

Procedure

As illustrated in Figure 1, participants in both conditions completed three phases of training. Participants were tested after the first and third phases of training. The training and testing sessions lasted approximately 45 minutes, all training tasks and tests were presented using the platform Gorilla.

Before training participants were given an outline of what would be expected of them during the experiment. Afterward they signed a digital consent form and answered questions regarding their age, gender and whether they had a history of language disorders. Participants then completed a sound and microphone test, to confirm that they would be able to hear pseudowords during the experiment and that their repetitions would be picked up by their speaker during training. Participants were not given any information on group assignment prior to or during the experiment.

First phase of training	Second phase of training	Third phase of training

Training
Repetition Task
   1 Block of 32 trained pseudowords
 	
Testing
Word Learning
   Phonological Form Recognition Task
 	
Grammar Learning
   Phonological Form Generalization Task
	Training
	Repetition Task
	   1 Block of 32 trained pseudowords
		Training
		Repetition Task
		   1 Blocks of 32 trained pseudowords
		
		Testing
		Word Leaning
		   Phonological Form Recognition Task
		   2AFC Task
		
		Grammar Learning
		   Phonological Form Generalization Task
		   Suffix Generalization Task
		   Determiner Generalization Task
		   Determiner-Suffix Generalization Task

Figure 1: Experiment Design and Tasks

In each phase of training participants were trained on one block of 32 pseudowords which were heard once per phase. For each trial a picture of an animal or artefact appeared in the centre of the screen before a pseudoword was played which participants were instructed to repeat back. After repeating back each block of 32 pseudowords participants were allowed to take a break of up to five minutes but could move onto the next task earlier if they chose to.

After the first phase of training participants in the simultaneous condition had been exposed to all 32 trained items once with semantics and had been exposed to 16 words a second time with mismatched word meanings. In the sequential condition participants had been exposed to all 32 trained items once without semantics present.

By the end of training participants in both conditions had been exposed to the 32 words in the training set three times in total, (twice with semantics and once without). Additionally, participants had been exposed to 32 mismatch items, split between the two phases of training which had included semantics.

After the first phase of training participants completed a phonological form recognition task and a phonological form generalisation task which tested participants' learning of word forms and determiner-suffix associations respectively. Following the third and final phase of training,

participants completed the complete set of word-learning (phonological form recognition and 2AFC) and generalisation tasks (phonological form generalisation, determiner-only, suffix-only and determiner-suffix).

Participants' explicit knowledge of the associations present in the language was assessed after the final set of tasks using two questions. The responses for both questions were scored together for awareness of the determiners, determiner-semantic associations, the suffixes, suffix-semantic associations and determiner-suffix pairings to reflect the complexity of the regularities present in the language. A score of two was assigned to responses which fully specified the regularities, a score of one was assigned to responses demonstrating partial knowledge and a score of zero was assigned to responses which did not reference any phonological or semantic regularities. For a more detailed breakdown of how each explicit awareness measure was scored see the general method section.

Data analyses

All analyses reported below were performed in R.

In the analyses of the phonological form recognition task, one-tailed t-tests were used to compare the mean accuracy for familiar items (1 for correct, 0 for incorrect) against chance (0.5) in each training condition at each point in time. The effects of training condition and length of training was investigated using a mixed-effects logistic regression with accuracy coded as a binary outcome measure. Training condition and length of training were fixed factors. Both training condition (simultaneous= 0, sequential= 1) and length of training (after one phase of training= 0, after three phases of training= 1) were coded as repeated contrasts. Random effects were included for both participants and test items. A maximal model that allowed the model to converge was produced using the buildmer package.

For analyses of the 2AFC task, one-tailed t-tests were used to compare the mean accuracy for each training condition against chance (0.5). The effect of training condition was investigated using a logistic regression with accuracy coded as a binary outcome measure. Training condition was a fixed factor and was coded as a repeated contrast (simultaneous= 0, sequential= 1). Random effects were included for both participants and test items. A maximal model that was able to converge was produced using the buildmer package.

Due to an error during data collection results for the phonological form generalisation task conducted after three phases of training was excluded from the analysis. As such the analysis for the phonological form generalisation task only used results collected after one phase of training. One-

tailed t-tests compared a' scores for each training condition against .5 to assess learning of regularities. The effect of training condition was investigated using a linear regression with a' scores as the outcome measure. Training condition was coded as it was in the phonological form recognition task. Participants were included as a random effect. A maximal model that was able to converge was produced using the buildmer package.

For each semantic generalisation task, one-tailed t-tests compared a' scores against 0.5 to assess learning of the regularities. The effect of training condition was investigated using a linear regression with a' scores as the outcome measure and training condition as the fixed effect.

In the analyses of explicit knowledge, the effect of training conditions on explicit knowledge of various associations present in the language was investigated using a series of linear regressions. Each model used participants' scores for an explicit awareness subtest as the outcome measure, training condition as the fixed effect and participants as a random effect. The models investigated the effect of training condition on explicit awareness of: i) determiner phonology, ii) determiner semantics, iii) suffix phonology, iv) suffix semantics and v) determiner-suffix pairs.

Following this Pearson's correlations were used to investigate whether there was a relationship between each generalisation measure and relevant explicit awareness measures. For the phonological form generalisation task, we looked for correlations with:

1. Determiner phonology
2. Suffix phonology
3. Determiner-suffix pairs

For the determiner-suffix generalisation task we looked for correlations with:

1. Determiner phonology
2. Determiner semantics
3. Suffix phonology
4. Suffix semantics
5. Determiner-suffix pairs

For the determiner generalisation task we looked for correlations with:

1. Determiner phonology
2. Determiner semantics

For the suffix generalisation task we looked for correlations with:

1. Suffix phonology
2. Suffix semantics

3.2.3 Results

<u>Word learning</u>

Phonological form recognition was measured in the first and third phases of training for participants in the simultaneous and sequential training conditions. To investigate whether participants in each condition learned the word forms from training, one sample t-tests were used to compare the mean accuracy scores for familiar items against chance level (0.5).

Figure 2 illustrates participants' recognition of word forms after the first and third phases of training. One sample t-tests confirm that performance was significantly above chance for participants in both conditions at both points in time (Simultaneous, after one phase of training: $t(40)= 6.86$, $p<.001$; after three phases of training: $t(40)= 14.09$, $p<.001$; Sequential, after one phase of training: $t(38)= 6.11$, $p<.001$; after three phases of training: $t(38)= 14.14$, $p<.001$; after one phase of training: $M_{Simultaneous}= .69$, $M_{Sequential}= .66$; after three phases of training: $M_{Simultaneous}= .85$, $M_{Sequential}= .84$).
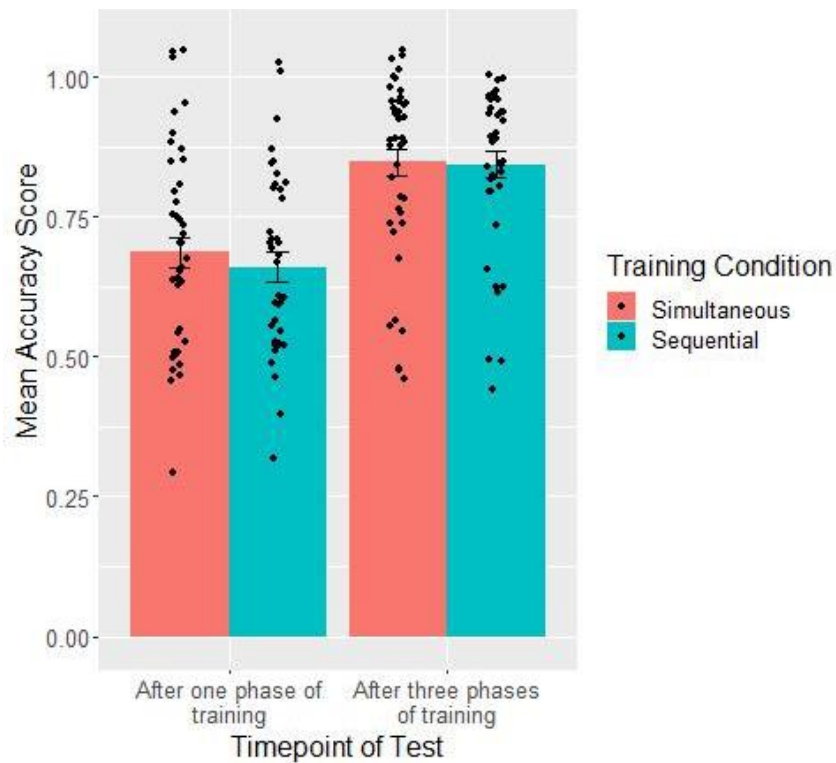
Figure 2. Accuracy (proportion correct) for the phonological form recognition task for participants in the simultaneous and sequential conditions after one and three phases of training.

A mixed-effects logistic regression was used to investigate the effects of training condition and length of training on accuracy during the phonological form recognition task. As shown in Table 5, length of training had a significant effect on phonological form recognition. There was no significant effect of training condition and there was no significant interaction between training condition and length of training.

Table 5. Regression coefficients for the fixed effects with accuracy as the binary outcome variable in the phonological form recognition task.

	Estimate	Std. Error	z-value	p-value
Training Condition	-.096	.232	-.416	.677
Length of Training	1.20	.248	4.83	<.001
Training Condition X Length of Training	.098	.355	.276	.783

Random effects included in the model: intercept by participants and item, slopes for length of training by participants and training condition by item.

Taken together these results show that participants were able to recognise word forms in both training conditions after one exposure to the training language. There was no effect of training conditions on word form learning but there was a significant benefit when participants received further exposures to the training language. These results demonstrate that participants in both conditions learned the phonological forms well and to the same level. They were able to learn some word forms from a single round of exposure to the language but further exposures led to more word forms being learned.

Figure 3 illustrates the participants' learning of word meaning after three phases of training. One sample t-tests confirm that performance was significantly above chance for participants in both training conditions (Simultaneous: t(40)= 2.65, p= .006; Sequential: t(38)= 4.68, p<.001; Mean Scores: M$_{Simultaneous}$= .55, M$_{Sequential}$= .60).
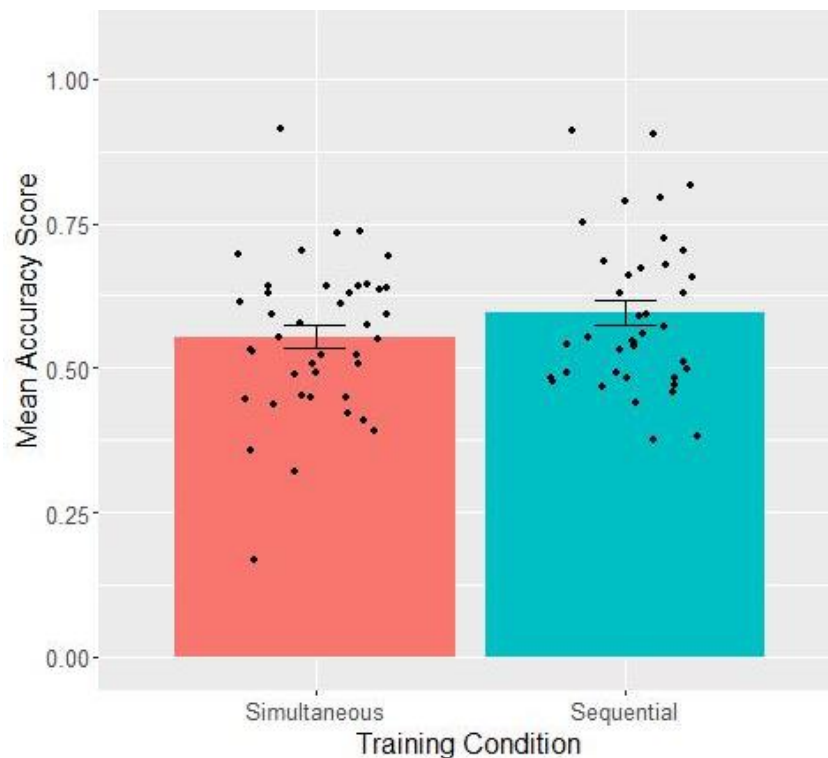
Figure 3. Accuracy (proportion correct) for the 2AFC task for participants in the simultaneous and sequential conditions after three phases of training.

A logistic regression was used to investigate the effects of training condition and length of training on accuracy during the 2AFC task. As shown in Table 6 there was no significant effect for training condition in the model.

Table 6. Regression coefficients for the fixed effects with accuracy as the binary outcome variable in the 2AFC task.

	Estimate	Std. Error	t-value	p-value
Training Condition	.195	.127	1.53	.126

Random effects included in the model: intercept by participant and item, slope for training condition by item.

Taken together with the above chance performance, this shows that participants in both conditions were able to learn the meaning of trained words after three exposures to the language. However, participants demonstrated poorer performance on the 2AFC task than participants in previous studies (Hickey, 2022; Mirković et al., 2021). As an example, adult participants in Mirković et al. (2021) had a higher mean score on the 2AFC task after 6 exposures to the language (M= .86). This suggests that learning word meaning requires more exposure to the training language.

<u>Grammatical generalisation</u>

Phonological form generalisation

Due to errors during data collection the results from the phonological form generalisation task conducted after three phases of training were excluded from data analysis. The extent to which participants could generalize associations between phonological-distributional cues from training to novel words was measured after one block of training in both conditions. A' scores were calculated to measure the level of generalisation, with a' scores above 0.5 taken as evidence that participants could generalise determiner-suffix pairs to novel items.

Figure 4 illustrates participants' ability to generalise determiner-suffix associations to novel words after one phase of training. One sample t-tests found that participants in both training conditions did not have a' scores significantly above 0.5 after the first phase of training (Simultaneous: t(40)= -.677, p= .749; Sequential: t(38)= .896, p= .188; A' scores: $M_{Simultaneous}$= .47, $M_{Sequential}$= .54).
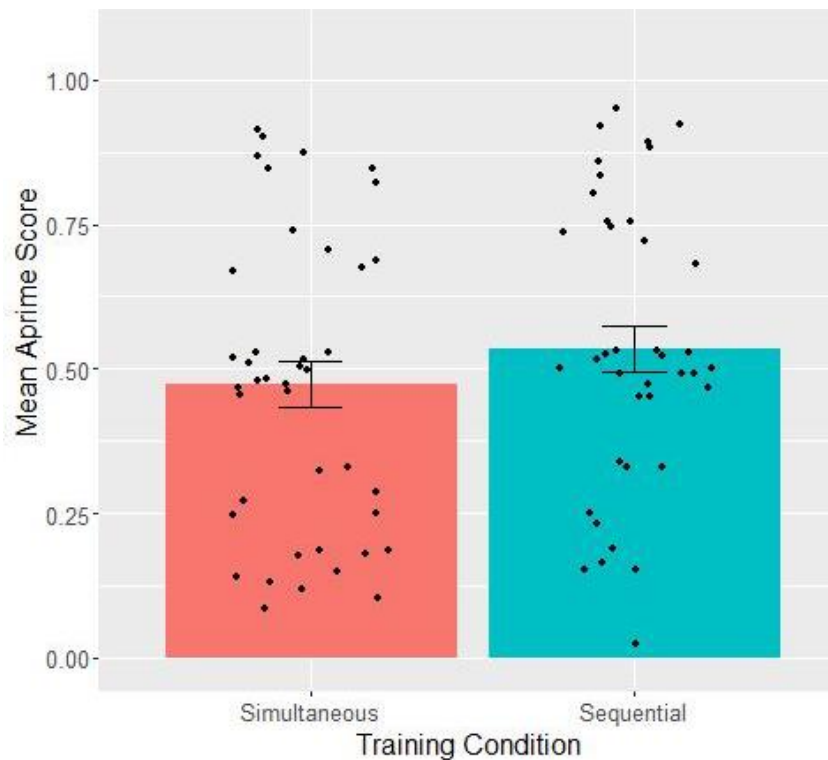
Figure 4. A' score on the phonological form generalisation task for participants in the simultaneous and sequential conditions after training.

A linear regression model was used to investigate the effect of training condition on a' score during the phonological form generalisation task. As shown in Table 7 training condition had no significant effect on phonological form generalisation in the model.

Table 7. Regression coefficients for the fixed effects with a' score as the outcome variable in the phonological form generalisation task.

	Estimate	Std. Error	t-value	p-value
Training Condition	.062	.055	1..11	.269

No random effects included in the maximal model.

Taken together these results show no evidence that participants were able to generalize associations between determiners and suffixes to novel items. There was no benefit of training condition after the initial exposure to the language. However, due to the error in data collection these findings are limited to the test conducted after a single exposure to the language. Not being able to measure participants after three phases of training, prevents us from addressing whether participants in the

sequential condition would have been able to generalize associations between determiners and suffixes to novel items after further exposure to the language. Additionally, not being able to compare phonological-form generalisation between training conditions after three exposures to the language prevents us from investigating whether an effect of training condition would have emerged after sufficient exposure to the training language.

Determiner generalisation

Participants' ability to generalize the determiner-semantic associations was tested after training was complete in both training conditions. A' scores were calculated to index the level of generalisation, with a' scores above 0.5 being taken as evidence that participants were able to generalise the association between determiners and animacy to novel items.

Figure 5 illustrates the extent to which participants could generalise semantic associations for determiners to novel items. One sample t-tests confirm that a' scores were significantly above 0.5 for participants in both training conditions (Simultaneous: $t(40)= 3.01$, $p= .002$; Sequential: $t(38)= 3.45$, $p< .001$; A' scores: $M_{Simultaneous}= .60$, $M_{Sequential}= .66$).
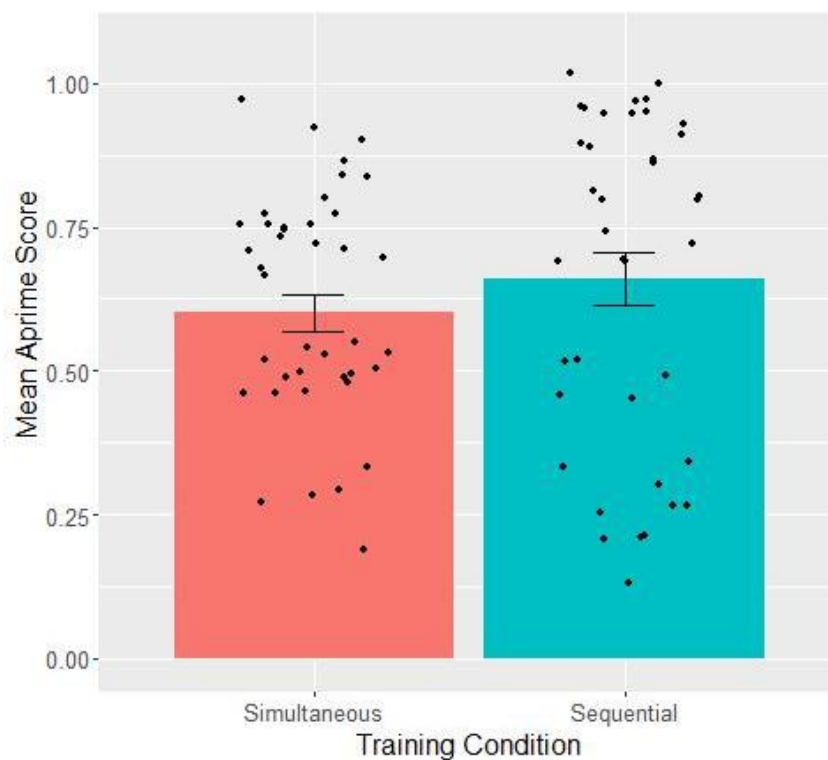
Figure 5. A' score on the determiner generalisation task for participants in the simultaneous and sequential conditions.

A linear regression was used to investigate the effect of training condition on a' score during the determiner generalisation task. As shown in Table 8, training condition had no significant effect on a' score in the model.

Table 8. Regression coefficients for the fixed effects with a' score as the outcome variable in the determiner generalisation task.

	Estimate	Std. Error	t-value	p-value
Training Condition	.060	.057	1.05	.297

No random effects included in the maximal model.

Taken together these findings demonstrate that participants were able to generalize determiner-semantic associations to novel words regardless of training condition. Training participants without semantics for the first phase of training had no effect on participants' ability to generalize determiner-semantic associations.

Suffix generalisation

Participants' ability to generalize the association between suffixes and animacy to novel items was tested after three phases of training in both the simultaneous and sequential conditions. A' scores were calculated to index the level of generalisation with a' scores above 0.5 being taken as evidence that participants were able to generalise an association to novel items.

Figure 6 illustrates the extent to which participants could generalise suffix-semantic associations to novel items after three phases. One sample t-tests confirm that a' scores for participants in both conditions were not significantly above chance after three phases of training (Simultaneous: $t(40)=$ .742, p= .231; Sequential: $t(38)=$ .533, p= .299; A' scores: $M_{Simultaneous}=$ .53, $M_{Sequential}=$ .52).
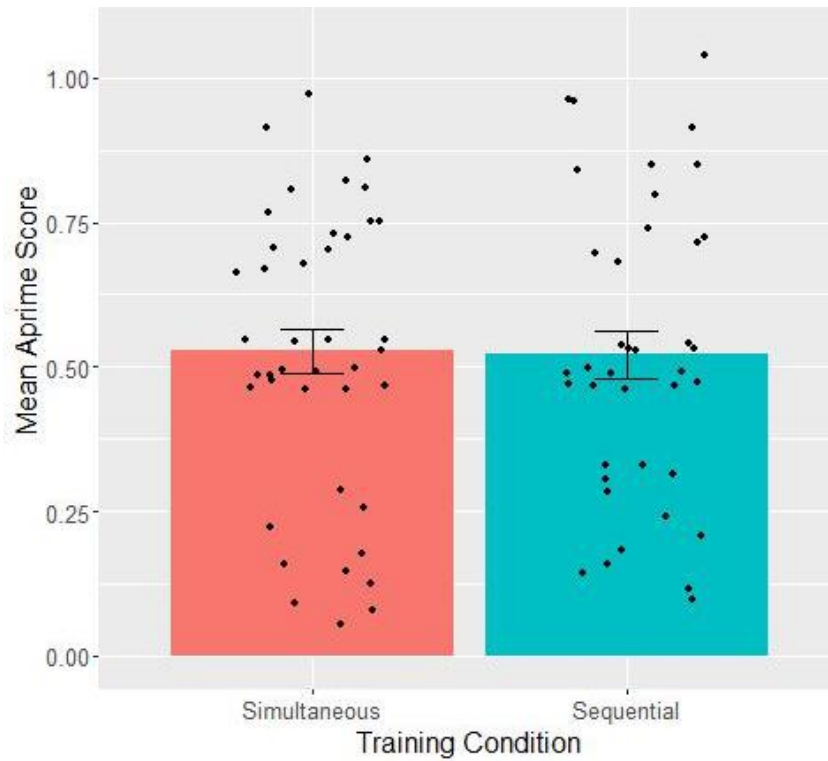
Figure 6. Performance on the suffix generalisation task for participants in the simultaneous and sequential training conditions.

A linear regression was used to investigate the effects of training condition on a' score during the suffix generalisation task. As shown in Table 9 there was no significant effect of training condition on a' score during the suffix generalisation task.

Table 9. Regression coefficients for the fixed effects with accuracy as the outcome variable in the suffix generalisation task.

	Estimate	Std. Error	t-value	p-value
Training Condition	-.007	.056	-.117	.907

No random effects included in the maximal model.

Taken together these results show that participants in both conditions were unable to generalize suffix-semantic associations after three phases of training. It is unclear based on this alone whether participants learned the suffixes but not their semantic associations or were unable to learn the suffixes at all.

Determiner-suffix generalisation

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Participants' ability to generalize associations between semantics and determiner-suffix pairs to novel items was tested after training was complete in the simultaneous and sequential training conditions. A' scores were calculated to index the level of generalisation with a' scores above 0.5 being taken as evidence that participants were able to generalise an association to novel items.

Figure 7 illustrates the extent to which participants could generalise semantic associations for the determiner-suffix pairs to novel items. One sample t-tests confirm that a' score was significantly above 0.5 for participants in the sequential condition but not for participants in the simultaneous condition (Simultaneous: $t(40)= 1.57$, $p= .062$; Sequential: $t(38)= 4.04$, $p< .001$; A' scores: $M_{Simultaneous}= .57$, $M_{Sequential}= .68$).
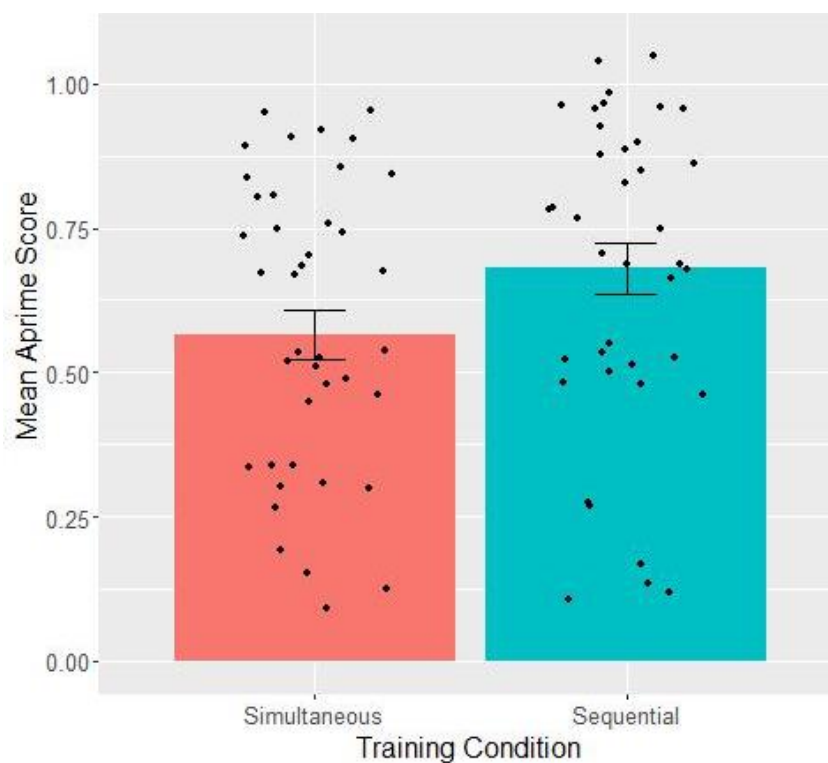
Figure 7. A' score on the determiner-suffix generalisation task for participants in the simultaneous and sequential conditions.

A linear regression was used to investigate the effect of training condition on a' score during the determiner-suffix generalisation task. As shown in Table 10 training conditions had no significant effect on a' score in the model.

Table 10. Regression coefficients for the fixed effects with a' score as the outcome variable in the determiner-suffix generalisation task.

	Estimate	Std. Error	t-value	p-value
Training Condition	.116	.061	1.89	.063

No random effects included in the maximal model.

Taken together these findings are not conclusive regarding participants' ability to generalize associations between semantics and determiner suffix pairs. The model demonstrates that there was no significant effect of training condition. In contrast, one-sample t-tests showed only participants in the sequential condition were able to generalize semantic associations for determiner-suffix pairs. These findings show that manipulating the availability of semantics did not affect generalisation. However, whether participants learned the association between semantics and determiner-suffix pairs remains unclear.

Explicit awareness of grammatical cues

Explicit awareness was assessed after participants had completed both training and testing. It was scored based on participants' ability to articulate determiner forms, determiner semantics, suffix forms, suffix semantics and determiner-suffix pairs when asked if they noticed anything about the training language.

Figure 8 illustrates the extent to which participants were able to explicitly identify determiners, suffixes, each affixes semantic associations and determiner-suffix pairs. Participants in both training conditions showed some awareness of determiners and their semantic associations as well as awareness of the suffixes' phonological forms. Participants in both groups showed comparatively little awareness of semantic associations for suffixes and associations between determiners and suffixes.
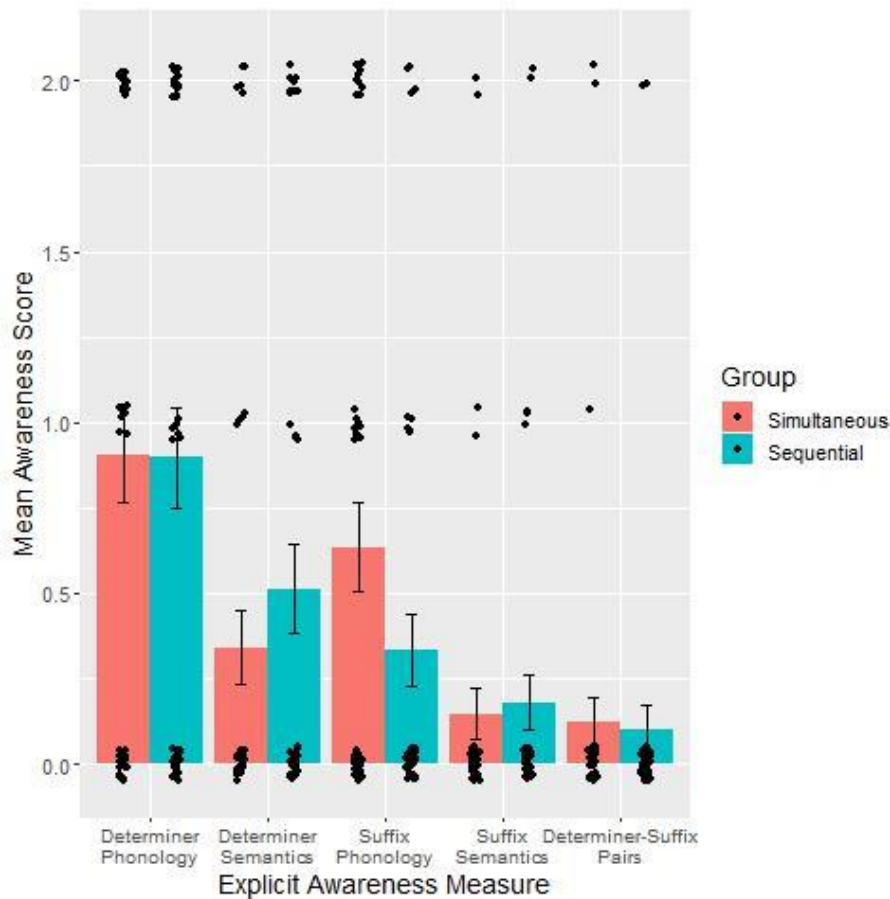
Figure 8. Mean explicit awareness scores for participants in the simultaneous and sequential conditions.

As shown in Table 11 training condition did not have a significant effect for any of the measures used to explore explicit awareness. As such, there is no evidence that manipulation of the timing of semantics affected participants' explicit awareness of determiners, suffixes their semantic associations or associations between phonological-distributional cues by the end of training.

Table 11. Linear regressions investigating training condition effects for each measure of explicit awareness.

Explicit Awareness Measure	Estimate	Std. Error	t-value	p-value
Determiner Phonology	-.005	.201	-.025	.980
Determiner Semantics	.171	.170	1.009	.316
Suffix Phonology	-.301	.168	-1.787	.078
Suffix Semantics	.033	.110	.301	.764

Determiner-Suffix Pairs	-.019	.101	-.191	.849

No random effects included in the maximal models.

Correlations between explicit awareness and generalisation

To investigate whether there was an association between explicit awareness and participants' ability to generalise semantic and phonological distributional cues several Pearson's correlations were conducted.

Correlations between phonological form generalisation after one phase of training and explicit awareness of determiner forms, suffix forms and determiner-suffix pairs were carried out for participants in each training condition. As shown by Table 12 for participants in both the simultaneous ($r(39)= .120$, $p= .046$) and sequential ($r(37)= .385$, $p= .015$) training conditions there were significant correlations between explicit awareness of determiner-suffix pairs and phonological form generalisation.

Table 12. Pearson's correlations between explicit awareness measures and phonological form generalisation.

Training Condition	Correlation	Degrees of Freedom	r statistic	p-value
Simultaneous Condition	Determiner phonology and phonological form generalisation	39	-.049	.759
	Suffix phonology and phonological form generalisation	39	.284	.072
	Determiner-suffix pairing and phonological form generalisation	39	.120	.046
Sequential Condition	Determiner phonology and phonological form generalisation	37	-.035	.834
	Suffix phonology and phonological form generalisation	37	.215	.188

Determiner-suffix pairing and phonological form generalisation		37	.385	.015

Correlations between suffix generalisation after training was complete and explicit awareness of suffix forms and suffix semantics were carried out for participants in each training condition. As shown by Table 13 in the sequential condition there was a significant correlation between awareness of suffix phonological forms and participants' ability to generalise the suffix-semantic associations (r(37)= .330, p= .40). There were no significant correlations between explicit awareness measures and suffix generalisation for participants in the simultaneous condition.

Table 13. Pearson's correlations between explicit awareness measures and suffix generalisation.

Training Condition	Correlation	Degrees of freedom	r statistic	p-value
Simultaneous Condition	Suffix phonology and suffix generalisation	39	-.003	.981
	Suffix semantics and suffix generalisation	39	.230	.148
Sequential Condition	Suffix phonology and suffix generalisation	37	.330	.040
	Suffix semantics and suffix generalisation	27	.197	.230

Correlations between determiner generalisation and explicit awareness of determiner forms and semantics were carried out for participants in each training condition. Table 14 shows that for participants trained in the sequential condition, there was a significant correlation between determiner generalisation and explicit awareness of determiner-semantics (r(37)= .338, p= .035). For participants trained in the simultaneous condition, determiner generalisation was significantly correlated with explicit awareness of determiner phonology (r(39)= .324, p= .039).

Table 14. Pearson's correlations between explicit awareness measures and determiner generalisation.

Training Condition	Correlation	Degrees of freedom	r statistic	p-value
Simultaneous Condition	Determiner phonology and determiner generalisation	39	.324	.039
	Determiner semantics and determiner generalisation	39	.303	.054
Sequential Condition	Determiner phonology and determiner generalisation	37	.018	.913
	Determiner semantics and determiner generalisation	37	.338	.035

Correlations between determiner-suffix generalisation and explicit awareness of determiner forms, determiner semantics, suffix forms, suffix semantics and determiner-suffix pairs were carried out for participants in both training conditions. As shown by Table 15 for participants in the sequential condition, determiner-suffix generalisation was significantly correlated with explicit awareness of determiner phonology (r(37)= .427, p= .007), determiner semantics (r(37)= .590, p<.001), suffix phonology (r(37)= .358, p= .025) and suffix semantics (r(37)= .368, p= .021). For participants in the simultaneous training condition, there were no significant correlations between determiner-suffix generalisation and measures of explicit awareness.

Table 15. Pearson's correlations between explicit awareness measures and determiner-suffix generalisation.

Training Condition	Correlation	Degrees of Freedom	r statistic	p-value
Simultaneous Condition	Determiner phonology and determiner-suffix generalisation	39	-.099	.537
	Determiner semantic and determiner-suffix generalisation	39	.115	.474

	Suffix phonology and determiner-suffix generalisation	39	-.053	.740
	Suffix semantics and determiner-suffix generalisation	39	.086	.593
	Determiner-suffix pairing and determiner-suffix generalisation	39	-.245	.122
Sequential Condition	Determiner phonology and determiner-suffix generalisation	37	.427	.007
	Determiner semantic and determiner-suffix generalisation	37	.590	<.001
	Suffix phonology and determiner-suffix generalisation	37	.358	.025
	Suffix semantics and determiner-suffix generalisation	37	.368	.021
	Determiner-suffix pairing and determiner-suffix generalisation	37	.242	.138

3.2.4 Discussion

Based on the competition model (Bates & MacWhinney, 1989; Culbertson et al., 2017) and discriminative learning (Arnon & Ramscar, 2012; Havron & Arnon, 2021; Ramscar et al., 2010; Ramscar & Port, 2016) semantic cues outcompete phonological-distributional cues based on earlier availability and greater value as a predictor of individual word forms. Further, blocking (Kamin, 1969) asserts that after acquiring one cue participants will evaluate unlearned cues by comparing them against that cue, if the unlearned cues do not offer additional information when making predictions then learners will block them out. Based on this, learning semantic cues can interfere with subsequent learning of phonological-distributional cues but semantic cues are not blocked out after learning phonological-distributional cues.

Experiment 1 explored whether semantic cues outcompete phonological-distributional cues for relevance as grammatical cues by manipulating participants' first exposure to the language between

two training conditions. In the sequential condition only phonological-distributional cues were available during participants first exposure to the language with semantics and semantic cues being omitted entirely. Semantics were introduced in the sequential condition after one block of training. In the simultaneous condition semantic and phonological-distributional cues were available during participants first exposure to the training language. During the second round of exposure to the training language semantics were omitted in the simultaneous condition to ensure participants in both conditions had an equal number of exposures to the semantic cues.

To investigate whether participants have learned the language before addressing their ability to generalize specific features, learning of word forms and meanings was tested using phonological form recognition and 2AFC tasks respectively. In line with previous literature (Hickey, 2022; Mirković et al., 2021; Vujović et al. 2021), participants in both conditions were able to recognise familiar word forms in the phonological form recognition task and identify the correct meaning for familiar words in the 2AFC task. Taken together these findings demonstrate that participants can recognise trained pseudowords based on their unique stems and that they have each learned the pseudowords' associated meanings. It is noteworthy that participants in both conditions were able to recognise familiar words in a phonological form recognition task carried out after the first block of training. While further exposures to the language still significantly benefited performance for the phonological form recognition task, this suggests that participants were able to recognise unique stems after only a single exposure to the language.

To investigate whether omitting semantics from participants' initial exposure to the language led to participants learning phonological-distributional cues, phonological form generalisation was compared between training conditions. After their first exposure to the language participants in both conditions were unable to generalize the associations between different phonological-distributional cues with no significant effect of training condition on performance. Due to issues during data collection we were unable to analyse participants' phonological form generalisation after further exposures to the training language. While the early results do not suggest that omitting semantics can support learning of phonological-distributional cues, the lack of data from the end of training leaves us unable to evaluate whether differences would have emerged as participants had further opportunities to learn phonological-distributional associations.

Comparisons between training conditions were used to investigate whether earlier exposure to phonological-distributional cues would interfere with learning of semantic cues. Based on blocking (Kamin, 1969), training participants on phonological-distributional cues first would not interfere with subsequent learning of semantic cues. In line with previous findings (Hickey, 2022; Mirković et al.,

2021; Vujović et al., 2021) participants were able to generalize semantic associations with determiners in both conditions and participants in the sequential condition were able to generalize semantic associations with determiner-suffix pairs in the sequential condition. However, in contrast to previous findings, participants in the simultaneous condition were unable to generalize semantic associations with determiner-suffix pairs. Linear regressions found that there was no effect of training condition on generalisation of the different semantic associations in the training language. These findings are in line with blocking, however due to the limited data from the phonological form generalisation tasks, there is no evidence that earlier exposure enabled learning of phonological-distributional cues before semantic cues.

It is noticeable that participants in both conditions comparisons against 0.5 show that participants were unable to generalize suffix-semantic associations in either training condition. This suggests that rather than performance being affected by delaying semantics, participants in both conditions had greater difficulty generalizing associations for suffixes than they did determiners. The correlations with explicit awareness align with this with participants appearing to show greater awareness of determiners and their semantic associations than they did suffixes.

The findings of Experiment 1 are inconclusive regarding the competition model and discriminative learning, based on comparisons after one exposure to the language participants were able to learn word forms and meanings to some extent but were unable to generalize phonological-distributional associations in the language. This finding does not support our prediction that omitting semantics during participants' initial exposure to the language would enable learning of phonological-distributional associations; however, it is worth noting that although non-significant, there was a trend in the predicted direction suggestive of better performance in participants trained without semantics. As increased exposure to the language benefitted learning of word forms and meanings, it is possible that further exposure to the language may have benefitted learning of phonological-distributional associations. As such differences may have emerged between conditions as participants became more familiarised with phonological-distributional cues. This leaves the question of whether semantics interfere with learning of phonological-distributional cues unanswered in Experiment 1.

In regard to blocking, the findings of Experiment 1 are also inconclusive. In contrast to predictions, learning semantics from the outset did not interfere with learning of phonological distributional cues. But as discussed, participants' early performance showed no evidence that the learned phonological forms and data from the end of training is unavailable. In line with blocking, learning phonological-distributional cues before semantics did not interfere with learning of semantic

associations. In fact while the differences were non-significant, the direction of differences across the phonological form and semantic generalisation tasks suggests that sequential training may have benefitted learning of semantic associations in the language.

The findings of Experiment 1 replicated previous studies using this paradigm (Hickey, 2022; Mirković et al., 2021) replicating the finding that participants are able to learn and generalize semantic associations with determiners when learning a language with semantic and phonological-distributional cues. Experiment 1 also replicates the finding that participants are unable to generalize the suffix-semantic association or the association between determiners and suffixes.

One noticeable difference between our findings and previous results is that participants in both conditions performed worse on the 2AFC and semantic generalisation tasks than participants in previous studies (Hickey, 2022; Mirković et al., 2021; Vujović et al., 2021). This suggests that during Experiment 1 participants' exposure to the language may have been insufficient to learn some aspects of it. While there was no difference for learning of word forms, the poorer performance on learning of word meanings and semantic associations suggests that learning of trained word meanings and the associations between semantic and phonological-distributional cues would be enhanced by further exposure to the training language.

3.3 Experiment 2

3.3.1 Introduction

Experiment 1 investigated whether omitting semantics from participants first exposure to the language would enable learners to generalize associations between phonological-distributional cues and whether this would come at the expense of learners' ability to generalize semantic cues. While generalisation of grammatical cues was the main focus of the experiment, it was important to assess whether participants had learned the training language before testing if they could apply features from it to novel words.

Experiment 1's findings are inconclusive regarding whether the presence of semantic cues interferes with learning of phonological-distributional cues. In contrast to the competition model, exposure to phonological-distributional cues without semantic present did not benefit phonological form generalisation after the first block of training. However, participants in both conditions were unable to generalize phonological-distributional cues at this point in time and further exposure to the language may have benefitted phonological form generalisation in the same way it did word learning. As data for phonological form generalisation after two additional blocks of training could

not be obtained, it is unclear in Experiment 1 whether further exposure would have enabled participants to generalize the association between determiners and suffixes.

Experiment 2 addressed whether further exposure to the training language would support learning of individual pseudowords and generalisation of semantic cues across conditions. Additionally Experiment 2 investigated whether further exposure to the training language would enable learning of phonological-distributional associations for participants exposed to word forms without semantics during the first block of training. Between Experiments 1 and 2 the total number of exposures to the language increased from three to nine. This brought the number of exposures in Experiment 2 in line with the maximum number of exposures tested in Mirković et al. (2021). Experiment 2 tested learning of word forms, word meanings and generalisation of phonological-distributional associations at multiple stages of training to examine whether further exposure to the training language enhanced learning of word forms and meanings over the course of training.

As in Experiment 1, participants in the sequential condition were trained on phonological forms without semantics present for the first phase of training, with semantics present for the remaining eight blocks of training. As such only phonological-distributional cues were available during participants' first exposure to the language while both phonological-distributional and semantic cues were available from the second exposure onwards. In the simultaneous condition participants were trained on phonological forms and semantics throughout training. This meant that across all nine blocks of training participants in the simultaneous condition had access to both semantic and phonological-distributional cues.

Experiment 1 demonstrated that participants were able to learn word forms and meanings after three exposures to each word to a level above-chance; however, it is likely that further exposures would increase the level of word learning. As such, In Experiment 2 it was predicted that increasing the number of exposures to the training language from three to nine may enhance word learning and generalisation of associations between grammatical cues.

As participants would experience a greater number of exposures to both phonological-distributional and semantic cues the concern that an additional exposure to semantics would affect semantic generalisation between training conditions was reduced. Experiment 1 controlled for the number of exposures to semantic cues between conditions by omitting semantics from one block of training in both conditions but varying which phase of training semantics were omitted from between conditions. As participants' exposure to both cues would be much greater, the effect of one less exposure to semantics was far less. To address whether consistently including semantics alongside

phonological-forms influenced learning of phonological-distributional cues, participants in the simultaneous condition were not exposed to phonological-forms without semantics during training.

Based on blocking (Kamin, 1969), learning semantics can interfere with subsequent learning of phonological-distributional cues but learning of phonological-distributional cues will not interfere with subsequent learning of semantic cues. Participants in Experiment 1 were able to generalize semantic associations for determiner-suffix pairs after three blocks of training and there was no significant effect of training on these measures. However, while training conditions in Experiment 1 did not affect generalisation of semantic cues, learning of phonological-distributional cues was not confirmed during Experiment 1. As such if further exposure to the language during Experiment 2 does enable learning of phonological-distributional associations, it is necessary to test whether this enhanced learning comes at the expense of participants' learning of semantic cues. Based on blocking, it was predicted that there would be no significant effect of training condition on generalisation of semantic associations.

Hypotheses

1. Based on previous findings, it was predicted that participants across training conditions would be able to recognise word forms and meanings.
    a. It was also predicted that increased exposure to the training language would enhance learning of word forms and meanings.
2. Based on previous studies, it was predicted that participants would be able to generalize associations between semantic and phonological-distribution cues to novel words. This meant associating the animacy of novel pictures with; i) determiners, ii) suffixes and iii) determiner-suffix pairs.
3. Based on the competition model and discriminative learning, it was predicted that participants trained on phonological forms without semantics for the first phase of training would be able to generalize associations between determiners and suffixes to novel words. In contrast it was predicted that participants trained on phonological forms and semantics for the first phase of training would be unable to generalize associations between determiners and suffixes to novel words.
    a. It was also predicted that increased exposure to the training language would enhance generalisation of associations between determiners and suffixes to novel words.

3.3.2 Methods

Participants

During recruitment, seven participants were excluded from the study for not complying with instructions during training. The resulting sample was comprised of seventy-eight monolingual, native English-speaking adults (24 male, 51 female, 3 nonbinary; mean age = 22.15 range = 18-39) with no known language disorders. Participants had normal hearing and normal or corrected-to-normal vision. Participants were recruited from Prolific and participated in the study after providing informed consent. Each participant was paid £7.50 for taking part in the study. The study was approved by the Ethics Committee at the Department of Psychology, University of York.

Participants were randomly allocated to one of two training conditions, for every participant allocated to the simultaneous condition one was assigned to the sequential only condition. After recruitment was complete, there were 39 participants in the simultaneous condition and 39 participants in the sequential condition.

<u>Materials</u>

Language training set

Table 16 shows example word-picture pairs for each training condition and grammatical class over the course of training. Experiment 2 trained participants using the same set of 32 pseudowords employed in Experiment 1. As such participants in Experiment 2 had access to the same phonological-distributional cues in the form of determiners and suffixes.

In Experiment 2, participants in the simultaneous condition were trained with phonological forms and semantics present for all nine exposures to the training language. In the sequential condition, only phonological forms were present during participants' first exposure to the language, with semantics available in all eight subsequent exposures to the language.

Table 16. Example stimuli for each training condition

Training Block	Stimuli	Simultaneous Condition		Sequential Condition	
		Animal Word	Artefact Word	Animal Word	Artefact Word
	Pseudoword	zeap-eem	cass-ool	zeap-eem	cass-ool

First Block of Training	Picture			+	+
Blocks 2-9 of Training	Pseudoword	tib-zeap-eem	ked-cass-ool	tib-zeap-eem	ked-cass-ool
	Picture				

Like in Experiment 1, a set of 32 mismatched items were included during training blocks which paired trained pseudowords with an incorrect trained picture. 16 of the 32 mismatched items were included during participants' second and third exposures to the training set. Mismatch items were not present during participants first exposure to the language and were not present during any exposures after the third.

Generalisation sets

A total of 43 novel pseudowords were used across the three phonological form generalisation tasks. Each phonological form generalisation task used 8 novel pseudowords, 4 which had consistent determiner-suffix pairs and 4 which paired determiners with suffixes from the opposite grammatical gender.

A total of 12 novel pseudowords were used across the three semantic generalisation tasks at the end of training. The determiner-suffix, determiner and suffix generalisation tasks each used 4 novel pseudowords, 2 which had affixes consistent with their semantic referents and 2 which had affixes inconsistent with their semantic referents.

Procedure

As illustrated in Figure 9, participants in both conditions completed three phases of training. Participants were tested after one, three and nine blocks of training. The training and testing sessions lasted approximately 60 minutes, all training tasks and tests were presented using the platform Gorilla.

First phase of training	Second phase of training	Third phase of training

Training
Repetition Task
    1 Block of 32 trained pseudowords
	Training
	Repetition Task
	    2 Blocks of 32 trained pseudowords
		Training
		Repetition Task
		    6 Blocks of 32 trained pseudowords

Testing
Word Learning
    Phonological Form Recognition Task
 	
Grammar Learning
    Phonological Form Generalization Task
	Testing
	Word Learning
	    Phonological Form Recognition Task
	    2AFC Task
	
	Grammar Learning
	    Phonological Form Generalization Task
		Testing
		Word Leaning
		    Phonological Form Recognition Task
		    2AFC Task
		
		Grammar Learning
		    Phonological Form Generalization Task
		    Suffix Generalization Task
		    Determiner Generalization Task
		    Determiner-Suffix Generalization Task

Figure 9. Experiment Design and Tasks

Experiment 2 was split into three phases of training, each phase of training varied in how many rounds of exposure participants had to the set of 32 trained words. For each trial a picture of an animal or artefact appeared in the centre of the screen before a pseudoword was played which participants were instructed to repeat back. After repeating back each block of 32 pseudowords participants were allowed to take a break of up to five minutes but could move onto the next task earlier if they chose to.

After the first phase of training participants in the simultaneous condition had been exposed to the training set once with semantics available throughout. In the sequential condition participants were also exposed to the training set once but semantics were not present during this exposure.

After the second phase of training participants in both training conditions had been exposed to the training set three times and had been exposed to the mismatched items once split between the second and third phases of training. Participants in the simultaneous condition had been exposed to pseudowords with semantic referents three times while participants in the sequential condition had been exposed to pseudowords three times, twice with semantic referents and once without.

After the third phase of training participants had been exposed to the training set nine times and the mismatched items once. Participants in the simultaneous condition had been exposed to pseudowords with semantic referents nine times while participants in the sequential conditions had been exposed to pseudowords nine times, eight times with semantic referents and once without.

After the first phase of training participants completed a phonological form recognition task and a phonological form generalisation task which tested participants' learning of word forms and determiner-suffix associations respectively. After the second phase of training participants completed a set of word-learning (phonological form recognition and 2AFC) tasks and a phonological

form generalisation task to test their learning of determiner-suffix associations. Following the third and final phase of training, participants completed a set of word-learning (phonological form recognition and 2AFC) and generalisation tasks (phonological form generalisation, determiner-only, suffix-only and determiner-suffix)

Like in Experiment 1, explicit knowledge of the associations present in the language was assessed using two questions after the final set of tests. The responses for both questions were scored together for awareness of the determiners, determiner-semantic associations, the suffixes, suffix-semantic associations and determiner-suffix pairs to reflect the complexity of the regularities present in the language. For a more detailed breakdown of how each explicit awareness measure was scored see the general method section.

Data analyses

All analyses reported below were performed in R.

The same analyses as in Experiment 1 were conducted to investigate levels of word learning and generalisation for participants in each training condition at each point in time. For each of the models produced during analysis a maximal model that was able to converge was produced using the buildmer package.

As participants in both conditions were tested after additional exposures to the training language in experiment 2, the mixed-effects logistic regressions for the phonological form recognition and 2AFC tasks both addressed how this additional exposure affected performance. For analyses of the phonological form recognition task, training condition (simultaneous= 0, sequential= 1) and length of training (after one block of training= 0, after three blocks of training= 1, after nine blocks of training= 2) were both coded as repeated contrasts with accuracy coded as a binary outcome measure. Random effects were included for both participants and test items.

For analyses of the 2AFC task, the effect of training condition and length of training were investigated using a mixed-effects logistic regression with accuracy coded as a binary outcome measure. Training condition and length of training were fixed factors. Both training condition (simultaneous= 0, sequential= 1) and length of training (after three blocks of training= 0, after nine blocks of training= 1) were coded as repeated contrasts. Random effects were included for both participants and test items. Due to an error during data collection, results from 11 participants in the sequential training condition and 8 participants in the simultaneous condition were excluded from analysis for the 2AFC task as they were not reliably presented with stimuli during the 2AFC task.

Due to an error during data collection results for the phonological form generalisation tasks conducted after three and six blocks of training were excluded from the analysis. As such the analysis for the phonological form generalisation task only used results collected after one block of training. The effect of training condition was investigated using a linear regression with a' scores as the outcome measure. Training condition was coded as it was in the phonological form recognition task. Participants were included as a random effect.

For each semantic generalisation task, the effect of training condition was investigated using a linear regression with a' scores as the outcome measure and training condition as the fixed effect.

In the analyses of explicit knowledge, the effect of training conditions on explicit knowledge of various associations present in the language was investigated using a series of linear regressions. Each model used participants' scores for an explicit awareness subtest as the outcome measure, training condition as the fixed effect and participants as a random effect. The models investigated the effect of training condition on explicit awareness of: i) determiner phonology, ii) determiner semantics, iii) suffix phonology, iv) suffix semantics and v) determiner-suffix pairs.

Following this Pearson's correlations were used to investigate whether there was a relationship between each generalisation measure at the end of training and relevant explicit awareness measures. For the phonological form generalisation task, we looked for correlations with:

1. Determiner phonology
2. Suffix phonology
3. Determiner-suffix pairs

For the determiner-suffix generalisation task we looked for correlations with:

1. Determiner phonology
2. Determiner semantics
3. Suffix phonology
4. Suffix semantics
5. Determiner-suffix pairs

For the determiner generalisation task we looked for correlations with:

1. Determiner phonology
2. Determiner semantics

For the suffix generalisation task we looked for correlations with:

1. Suffix phonology
2. Suffix semantics

3.3.3 Results

<u>Word learning</u>

Phonological form recognition was measured after one, three and nine blocks of training for participants in the simultaneous and sequential training conditions. To investigate whether participants in each condition learned the word forms from training, one sample t-tests were used to compare the mean accuracy scores for familiar items against chance level (0.5).

Figure 10 illustrates participants' recognition of word forms after the first, second and third blocks of training. One sample t-tests confirm that performance was significantly above chance for participants in both conditions at all three points in time (Simultaneous, after one block of training: $t(38)= 4.72$, $p<.001$; after three blocks of training: $t(38)= 15.64$, $p<.001$; after nine blocks of training: $t(38)= 21.13$, $p<.001$; Sequential, after one block of training: $t(38)= 3.51$, $p<.001$; after three blocks of training: $t(38)= 14.02$, $p<.001$; after nine blocks of training: $t(38)= 17.05$, $p<.001$; after one block of training: $M_{Simultaneous}= .62$, $M_{Sequential}= .59$; after three blocks of training: $M_{Simultaneous}= .86$, $M_{Sequential}= .86$; after nine blocks of training: $M_{Simultaneous}= .91$, $M_{Sequential}= .90$).
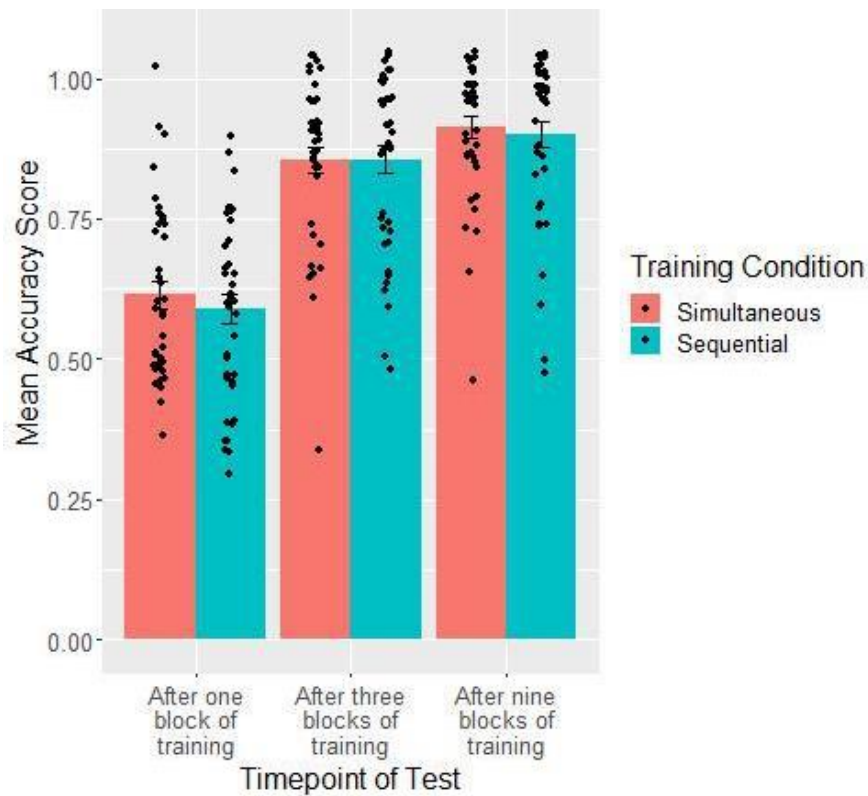
Figure 10. Accuracy (proportion correct) for the phonological form recognition task for participants in the simultaneous and sequential conditions after one and three phases of training.

A mixed-effects logistic regression was used to investigate the effects of training condition and length of training on accuracy during the phonological form recognition task. Repeated contrasts were employed to address differences in phonological form recognition between the 1, 3 and 9 blocks of training. Specifically they addressed whether increasing exposures to the language from one to three enhanced learning of phonological forms and whether a further six exposures to the language enhanced phonological form learning after three exposures to the language. As shown in Table 17, participants' phonological form recognition benefitted from the two additional exposures to the language between the first and second test. However, while borderline there was no significant benefit to phonological form generalisation after a further six exposures to the training language. There was no significant effect of training condition on phonological form recognition, nor were there any significant interactions between training condition and the times at which participants were tested.

Table 17. Regression coefficients for the fixed effects with accuracy as the binary outcome variable in the phonological form recognition task.

	Estimate	Std. Error	z-value	p-value
Training Condition	-.081	.175	-.463	.643
Time 1 vs. 2	1.38	.267	5.18	<.001
Time 2 vs. 3	.606	.311	1.95	.051
Training Condition X Time 1 vs. 2	.127	.286	.444	.657
Training Condition X Time 2 vs. 3	-.155	.359	-.431	.667

Random effects included in the model: intercept by participants and item.

Taken together these results show that participants were able to recognise word forms in both training conditions after one exposure to the training language. Omitting semantics from the first block of training had no effect on participants' word form learning but further exposures to the language did have a significant benefit for word form learning.

Figure 11 illustrates participants' learning of word meaning after three phases of training. One sample t-tests confirm that performance was significantly above chance for participants in both training conditions at both points in time (Simultaneous, after three blocks of training: $t(30)= 4.71$, $p<.001$; after nine blocks of training: $t(30)= 8.73$, $p<.001$; Sequential, after three blocks of training: $t(27)= 3.56$, $p<.001$; after nine blocks of training: $t(27)= 7.17$, $p<.001$; after three blocks of training: $M_{Simultaneous}= .59$, $M_{Sequential}= .57$, after nine blocks of training: $M_{Simultaneous}= .78$, $M_{Sequential}= .75$).
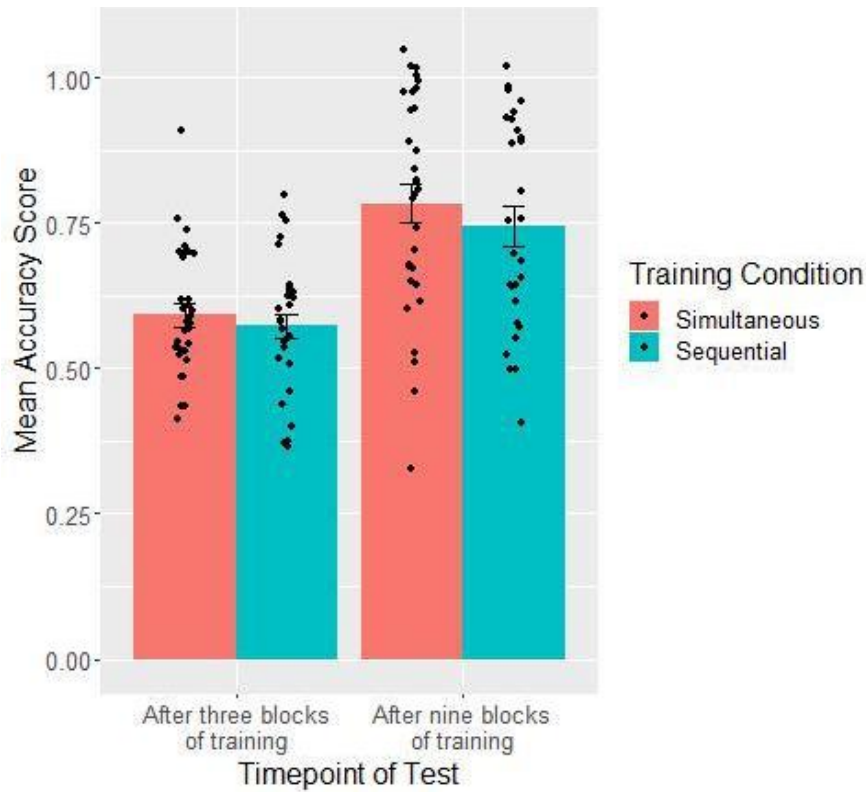
Figure 11. Accuracy (proportion correct) for the 2AFC task for participants in the simultaneous and sequential conditions after three phases of training.

A mixed-effects logistic regression was used to investigate the effects of training condition and length of training on accuracy during the 2AFC task. As shown in Table 18 length of training had a significant effect on learning of word meaning accuracy. There was no significant effect of training condition and there was no significant interaction between training condition and length of training.

Table 18. Regression coefficients for the fixed effects with accuracy as the binary outcome variable in the 2AFC task.

	Estimate	Std. Error	z-value	p-value
Training Condition	-.047	.114	-.411	.681
Length of Training	1.06	.203	5.21	<.001
Training Condition X Length of Training	.044	.285	.155	.876

Random effects included in the model: intercept by participant and item, slope for length of training by participant.

Taken together with the above chance performance, this shows that participants in both conditions were able to learn the meaning of trained words after three exposures to the language. Additional exposures to the language led to significant improvements in performance. Notably, performance after three blocks of training matches the performance of participants in experiment 1, while performance after nine blocks of training brought performance closer to the results of previous studies such as Mirković et al. (2021) (M= .86).

Grammatical generalisation

Phonological form generalisation

Due to errors during data collection the results from the phonological form generalisation task conducted after three and nine blocks of training were excluded from data analysis. The extent to which participants could generalize associations between phonological-distributional cues from training to novel words was measured after one block of training in both conditions. A' scores were calculated to measure the level of generalisation, with a' scores above 0.5 taken as evidence that participants could generalise determiner-suffix pairs to novel items.

Figure 12 illustrates participants' ability to generalise determiner-suffix associations to novel words after one phase of training. One sample t-tests found that participants in both training conditions did not have a' scores significantly above 0.5 after the first phase of training (Simultaneous: t(38)= .714, p= .240; Sequential: t(38)= -1.27, p= .894; A' scores: $M_{Simultaneous}$= .53, $M_{Sequential}$= .49).
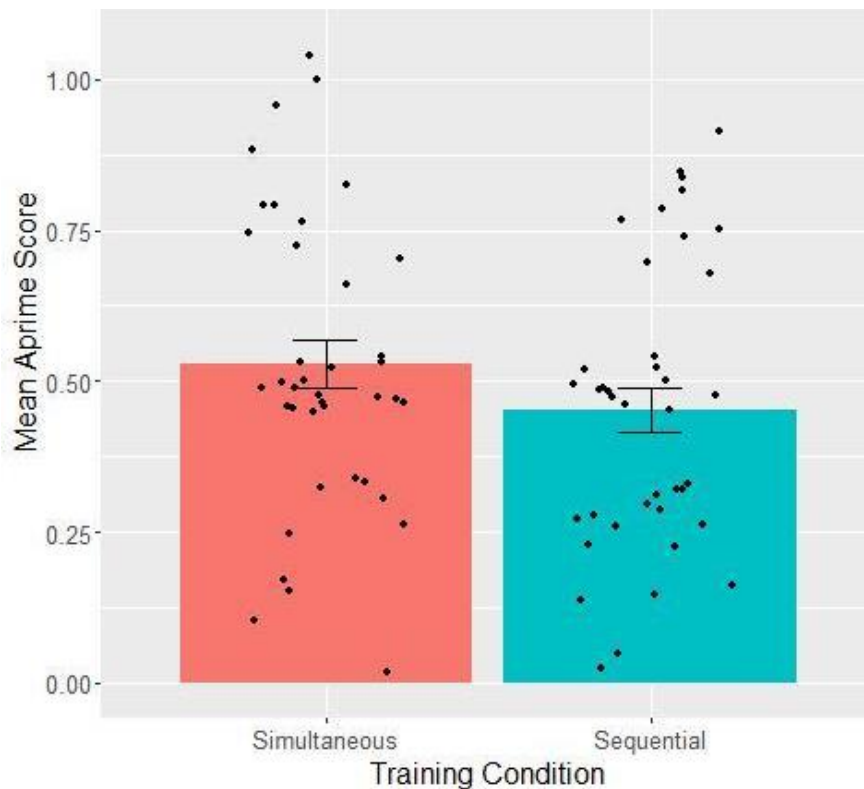
Figure 12. A' score on the phonological form generalisation task for participants in the simultaneous and sequential conditions after training.

A linear regression model was used to investigate the effect of training condition on a' score during the phonological form generalisation task. As shown in Table 19 training condition had no significant effect on phonological form generalisation in the model.

Table 19. Regression coefficients for the fixed effects with a' score as the outcome variable in the phonological form generalisation task.

	Estimate	Std. Error	t-value	p-value
Training Condition	-.077	.055	-1.39	.169

No random effects included in the maximal model.

Taken together these results show no evidence that participants were able to generalize associations between determiners and suffixes to novel items. There was no benefit of training condition after the initial exposure to the language. However, due to the error in data collection these findings are limited to the test conducted after a single exposure to the language. The measures of word learning demonstrate that recall of word forms benefited from additional exposures to the language. As such

without results collected after training was complete we cannot address whether participants would be able to generalize word forms and whether differences between training conditions would emerge.

Determiner generalisation

Participants' ability to generalize the determiner-semantic associations was tested after training was complete in the both training conditions. A' scores were calculated to index the level of generalisation, with a' scores above 0.5 being taken as evidence that participants were able to generalise the association between determiners and animacy to novel items.

Figure 13 illustrates the extent to which participants' could generalise semantic associations for determiners to novel items. One sample t-tests confirm that a' scores were significantly above 0.5 for participants in simultaneous condition but not for participants in the sequential condition (Simultaneous: t(38)= 3.23, p= .001; Sequential: t(38)= .668, p= .254; A' scores: $M_{Simultaneous}$= .66, $M_{Sequential}$= .54).
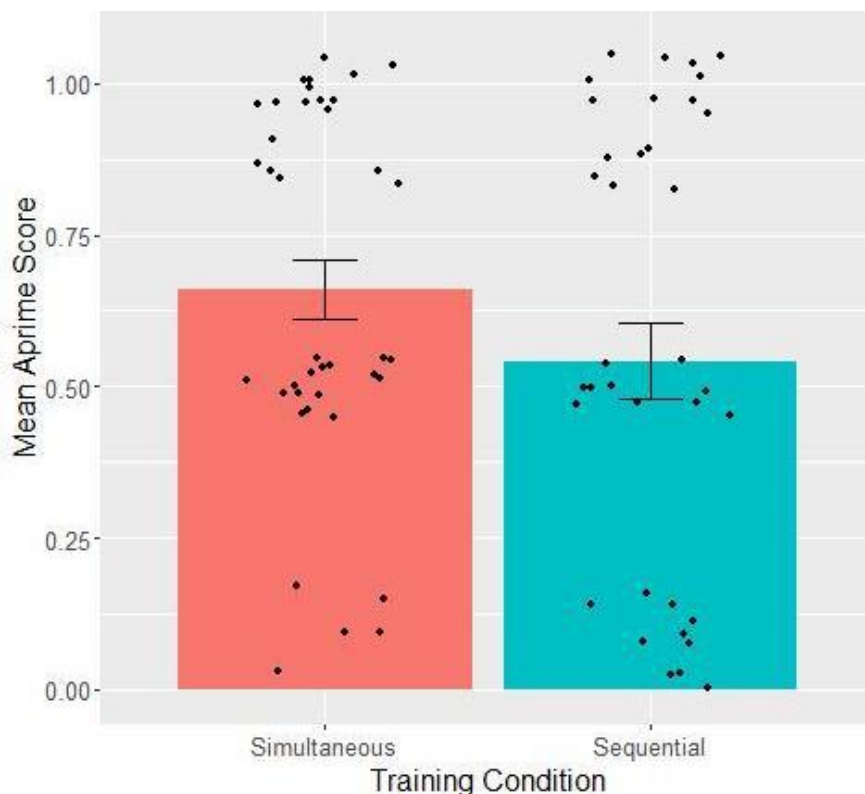
Figure 13. A' score on the determiner generalisation task for participants in the simultaneous and sequential conditions.

A linear regression was used to investigate the effect of training condition on a' score during the determiner generalisation task. As shown in Table 20, training condition had no significant effect on a' score in the model.

Table 20. Regression coefficients for the fixed effects with a' score as the outcome variable in the determiner generalisation task.

	Estimate	Std. Error	t-value	p-value
Training Condition	-.119	.080	-1.48	.141

No random effects included in the maximal model.

Taken together these findings demonstrate that participants in the simultaneous condition were able to generalize determiner-semantic associations. There is some ambiguity regarding participants in the sequential condition, their a' scores were not significantly above chance suggesting that they were unable to generalize determiner-semantic conditions. However, there was no significant effect of training condition on determiner generalisation, meaning that there is no meaningful difference between the training conditions.

Suffix generalisation

Participants' ability to generalize the association between suffixes and animacy to novel items was tested after nine blocks of training in both the simultaneous and sequential conditions. A' scores were calculated to index the level of generalisation with a' scores above 0.5 being taken as evidence that participants were able to generalise an association to novel items.

Figure 14 illustrates the extent to which participants' could generalise suffix-semantic associations to novel items after three phases. One sample t-tests found that a' scores for participants in both conditions were not significantly above chance after nine blocks of training (Simultaneous: $t(38)=$ 1.01, p= .161; Sequential: $t(38)=$ -.150, p= .559; A' scores: $M_{Simultaneous}=$ .54, $M_{Sequential}=$ .49).
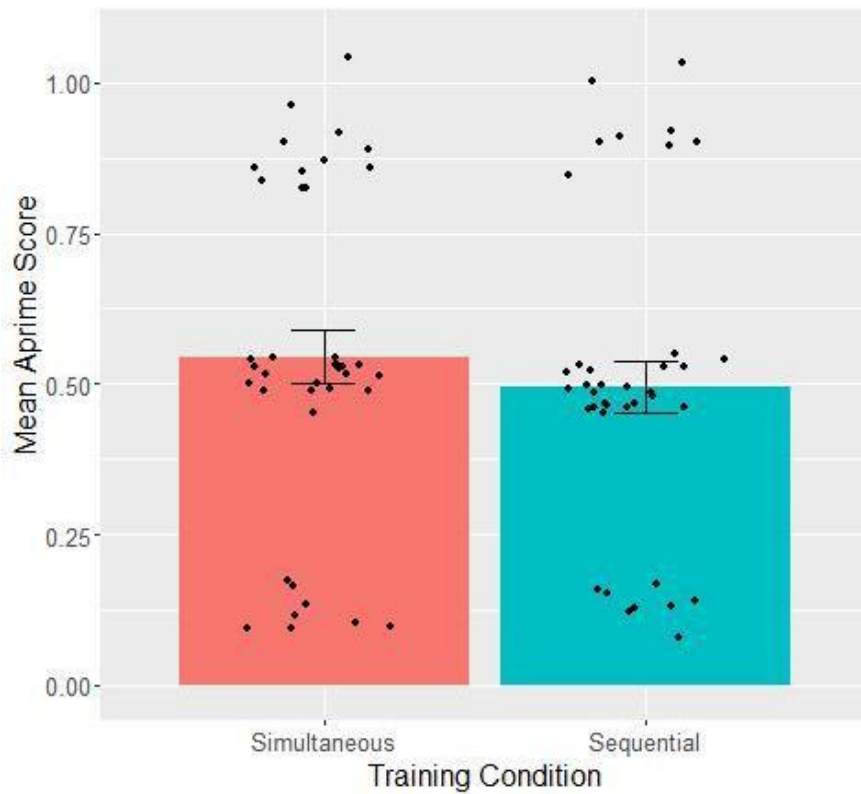
Figure 14. Performance on the suffix generalisation task for participants in the simultaneous and sequential training conditions.

A linear regression was used to investigate the effects of training condition on a' score during the suffix generalisation task. As shown in Table 21 there was no significant effect of training condition on a' score during the suffix generalisation task.

Table 21. Regression coefficients for the fixed effects with accuracy as the outcome variable in the suffix generalisation task.

	Estimate	Std. Error	t-value	p-value
Training Condition	-.051	.062	-.829	.410

No random effects included in the maximal model.

Taken together these results show that participants in both conditions were unable to generalize suffix-semantic associations after nine blocks of training. It is unclear based on this alone whether participants learned the suffixes but not their semantic associations or were unable to learn the suffixes at all.

Determiner-suffix generalisation

Participants' ability to generalize associations between semantics and determiner-suffix pairs to novel items was tested after training was complete in the simultaneous and sequential training conditions. A' scores were calculated to index the level of generalisation with a' scores above 0.5 being taken as evidence that participants were able to generalise an association to novel items.

Figure 15 illustrates the extent to which participants' could generalise semantic associations for the determiner-suffix pairs to novel items. One sample t-tests found that a' scores were not significantly above 0.5 for participants in either training condition (Simultaneous: $t(38)= 1.20$, $p= .118$; Sequential: $t(38)= .671$, $p= .253$; A' scores: $M_{Simultaneous}= .57$, $M_{Sequential}= .54$).
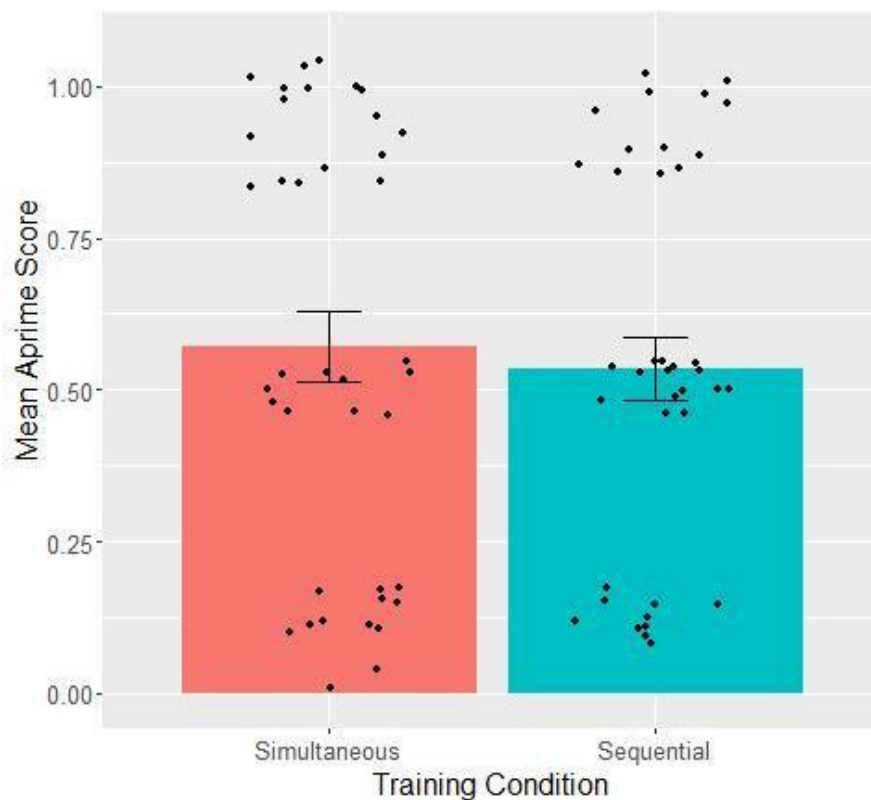
Figure 15. A' score on the determiner-suffix generalisation task for participants in the simultaneous and sequential conditions.

A linear regression was used to investigate the effect of training condition on a' score during the determiner-suffix generalisation task. As shown in Table 22 training conditions had no significant effect on a' score in the model.

Table 22. Regression coefficients for the fixed effects with a' score as the outcome variable in the determiner-suffix generalisation task.

	Estimate	Std. Error	t-value	p-value
Training Condition	-.035	.079	-.448	.655

No random effects included in the maximal model.

Taken together these findings are not conclusive regarding participants' ability to generalize associations between semantics and determiner suffix pairs. The model demonstrates that there was no significant effect of training condition. In contrast, one-sample t-tests showed only participants in the sequential condition were able to generalize semantic associations for determiner-suffix pairs. These findings show that manipulating the availability of semantics did not affect generalisation. However, whether participants learned the association between semantics and determiner-suffix pairs remains unclear.

Explicit awareness of grammatical cues

Explicit awareness was assessed after participants had completed both training and testing. It was scored based on participants' ability to articulate determiner forms, determiner semantics, suffix forms, suffix semantics and determiner-suffix pairs when asked if they noticed anything about the training language.

Figure 16 illustrates the extent to which participants were able to explicitly identify determiners, suffixes, each affixes' semantic associations and determiner-suffix pairs. Participants in both training conditions showed some awareness of determiners and their semantic associations as well as awareness of the suffix phonology. Participants in both groups showed comparatively little awareness of semantic associations for suffixes and associations between determiners and suffixes.
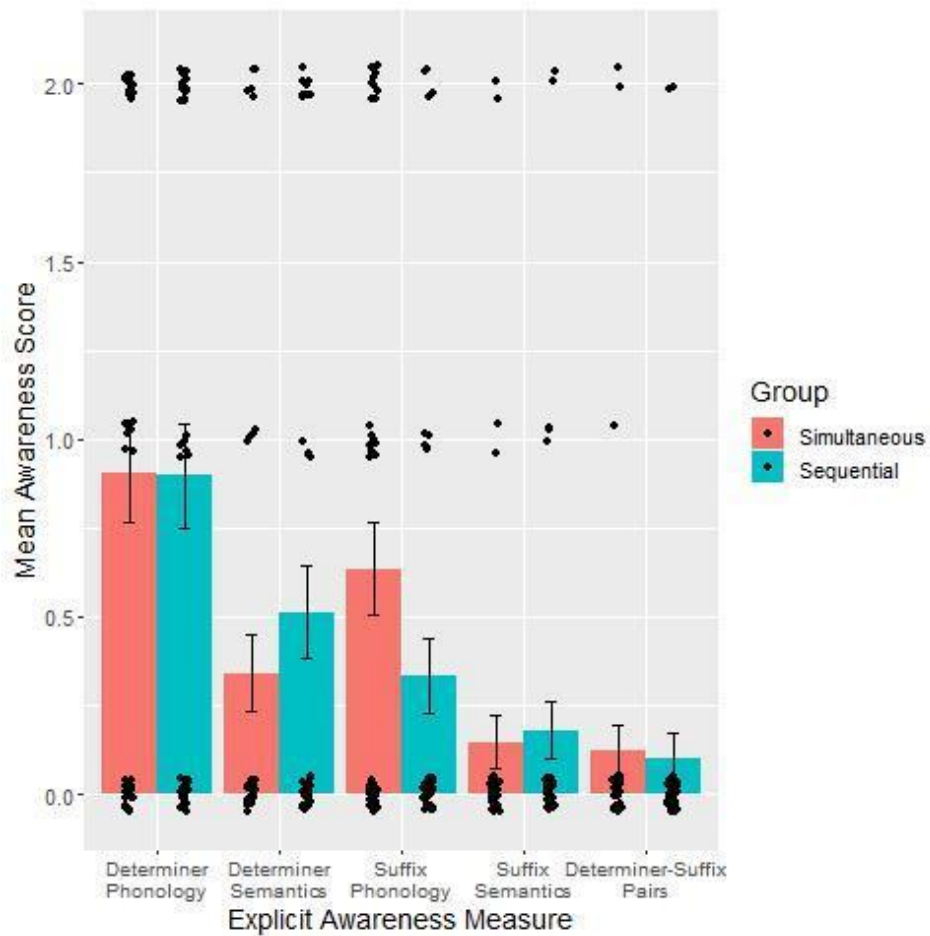
Figure 16. Mean explicit awareness scores for participants in the simultaneous and sequential conditions.

As shown in Table 23 training condition did not have a significant effect for any of the measures used to explore explicit awareness. As such, there is no evidence that manipulating the availability of semantics affected participants' explicit awareness of determiners, suffixes, their semantic associations or associations between phonological-distributional cues by the end of training.

Table 23. Linear regressions investigating training condition effects for each measure of explicit awareness.

Explicit Awareness Measure	Estimate	Std. Error	t-value	p-value
Determiner Phonology	.026	.206	.124	.901
Determiner Semantics	-.205	.189	-1.09	.280
Suffix Phonology	-.051	.127	-.426	.671
Suffix Semantics	<.001	.073	0	1.00

Determiner-Suffix Pairs	-.128	.075	-1.71	.092

No random effects included in the maximal models.

Correlations between explicit awareness and generalisation

To investigate whether there was an association between explicit awareness and participants' ability to generalise semantic and phonological distributional cues several Pearson's correlations were conducted.

Correlations between phonological form generalisation after one phase of training and explicit awareness of determiners, suffixes and determiner-suffix pairs were carried out for participants in each training condition. As no participants in the sequential condition showed explicit awareness of determiner-suffix pairs no correlations for this submeasure were carried out for participants in the sequential condition. As shown by Table 24 there were no significant correlations between the explicit awareness submeasures and phonological form generalisation.

Table 24. Pearson's correlations between explicit awareness measures and phonological form generalisation.

Training Condition	Correlation	Degrees of Freedom	r statistic	p-value
Simultaneous Condition	Determiner phonology and phonological form generalisation	37	.083	.614
	Suffix phonology and phonological form generalisation	37	.049	.766
	Determiner-suffix pairs and phonological form generalisation	37	.302	.062
Sequential Condition	Determiner phonology and phonological form generalisation	37	.014	.932
	Suffix phonology and phonological form generalisation	37	-.200	.223

	Determiner-suffix pairs and phonological form generalisation	NA	NA	NA

Correlations between determiner generalisation and explicit awareness of determiner forms and semantics were carried out for participants in each training condition. Table 25 shows that for there was a significant correlation between determiner generalisation and explicit awareness of determiner-semantics in the simultaneous (r(37)= .392, p= .014) and sequential (r(37)= .335, p= .037) training conditions.

Table 25. Pearson's correlations between explicit awareness measures and determiner generalisation.

Training Condition	Correlation	Degrees of freedom	r statistic	p-value
Simultaneous Condition	Determiner phonology and determiner generalisation	37	.185	.260
	Determiner semantics and determiner generalisation	37	.392	.014
Sequential Condition	Determiner phonology and determiner generalisation	37	.022	.897
	Determiner semantics and determiner generalisation	37	.335	.037

Correlations between suffix generalisation after training was complete and explicit awareness of suffix forms and suffix semantics were carried out for participants in each training condition. As shown by Table 26 in both conditions there were no significant correlations between explicit awareness measures and suffix generalisation for participants in the simultaneous condition.

Table 26. Pearson's correlations between explicit awareness measures and suffix generalisation.

Training Condition	Correlation	Degrees of freedom	r statistic	p-value

Simultaneous Condition	Suffix phonology and suffix generalisation	37	.003	.987
	Suffix semantics and suffix generalisation	37	.195	.235
Sequential Condition	Suffix phonology and suffix generalisation	37	.083	.614
	Suffix semantics and suffix generalisation	37	-.227	.166

Correlations between determiner-suffix generalisation and explicit awareness of determiner forms, determiner semantics, suffix forms, suffix semantics and determiner-suffix pairs were carried out for participants in both training conditions. As shown by Table 27 for participants in the sequential condition, determiner-suffix generalisation was significantly correlated with explicit awareness of determiner semantics (r(37)= .407, p= .010). For participants in the simultaneous training condition, determiner-suffix generalisation was significantly correlated with explicit awareness of determiner phonology (r(37)= .323, p= .045) and determiner semantics (r(37)= .542, p<.001).

Table 27. Pearson's correlations between explicit awareness measures and determiner-suffix generalisation.

Training Condition	Correlation	Degrees of Freedom	r statistic	p-value
Simultaneous Condition	Determiner phonology and determiner-suffix generalisation	37	.323	.045
	Determiner semantic and determiner-suffix generalisation	37	.542	<.001
	Suffix phonology and determiner-suffix generalisation	37	.055	.740.
	Suffix semantics and determiner-suffix generalisation	37	.193	.239

	Determiner-suffix pairs and determiner-suffix generalisation	37	.176	.284
Sequential Condition	Determiner phonology and determiner-suffix generalisation	37	.256	.115
	Determiner semantic and determiner-suffix generalisation	37	.407	.010
	Suffix phonology and determiner-suffix generalisation	37	-.035	.834
	Suffix semantics and determiner-suffix generalisation	37	.170	.300
	Determiner-suffix pairs and determiner-suffix generalisation	NA	NA	NA

3.3.4 Discussion

In Experiment 2, comparisons against chance after 1, 3 and 9 blocks of training demonstrate that in both conditions participants were able to recognise individual pseudowords after 1 block of training. This demonstrates that even a single exposure to the training language was sufficient to learn and be able to recognise some of the trained words. A mixed-effects logistic regression found that in line with Experiment 1 increasing the length of training from one block of training to three enhanced word recognition regardless of training condition. However there were no significant effect from increasing the length of training from three blocks of training to nine. This is in line with comparisons against previous artificial language learning studies (Hickey, 2022; Mirković et al., 2021) which demonstrate similar degrees of word learning.

Participants' also demonstrated above chance learning of trained words' meanings after both 3 and 9 blocks of training. Demonstrating even two blocks of training on word-picture pairs were sufficient for participants to learn associated meanings for some of the trained set. A mixed-effects logistic regression found that further exposure to the training language enhanced learning of word forms. This suggests that the relatively poor learning of individual word meaning observed in Experiment 1, can be attributed to the limited exposure participants had to word picture pairs during training.

Taken together these findings suggest that participants learn word forms faster than they associate them with meanings, regardless of training conditions participants were able to learn word forms after 1 block of training and after three phases of training no longer benefitted from exposure to the training language. In contrast, while participants demonstrated above chance learning of word meanings the first time it was tested they showed a significant benefit from further exposure to the language after three blocks of training.

When compared against previous artificial language learning studies (Hickey, 2022; Mirković et al., 2021), participants in Experiment 1 demonstrated poorer learning of determiner-suffix associations. After increasing the number of training blocks from three to nine in Experiment 2, it was predicted that participants would perform better on the determiner-suffix generalisation task than participants in Experiment 1. However, In contrast participants in Experiment 2 were unable to generalize semantic associations to determiner-suffix pairs in either training condition after training was complete.

When testing generalisation of semantics to determiners and suffixes separately, participants were unable to generalize semantic associations with suffixes in either condition. Participants in the simultaneous condition demonstrated the ability to generalize determiner-semantic associations whereas participants in the sequential condition did not. However, a linear regression found that training conditions did not significantly affect performance on the suffix generalisation task suggesting that in both groups participants showed little to no awareness of suffix-semantic associations.

These findings contradict previous artificial language learning studies which found that participants were able to generalize semantics to determiner-suffix pairs and suffixes but did not test whether participants could generalize determiner-semantic associations. This brings into question whether participants in Experiment 2 were able to learn semantic cues and if not which factors in the experiment interfered with learning of semantic cues.

A key aim of Experiment 1 was to examine whether delaying the inclusion of semantic cues would enable participants to generalize associations between phonological-distributional cues in the language. Participants were unable to generalize associations between different phonological-distributional cues after one exposure to the language in either condition and we were unable to obtain data after three blocks of training. This left the question of whether participants would be able to generalize phonological-distributional cues after three exposures to the training language unresolved. Experiment 2 attempted to address whether further exposure would enhance

generalisation of phonological forms and whether differences would emerge between training conditions as participants were given sufficient exposure to the training language.

As in Experiment 1 participants were unable to generalize associations between phonological-distributional cues to novel words after the first exposure to the language. Due to issues during data collection participants' ability to generalize phonological forms after further training could not be measured.

3.4 Discussion

The aim of Study 1 was to examine whether semantic and phonological-distributional cues compete with each other for validity as grammatical cues. More specifically, Study 1 examined whether learning semantic cues in a novel language interferes with learning of phonological-distributional cues available in the same language. Experiment 1 addressed this by manipulating the availability of semantic cues during participants first exposure to the training language across two training conditions and comparing their ability to generalize semantic and phonological-distributional associations in the training language.

When testing participants' acquisition of the language over the course of training, Experiments 1 and 2 found that participants recognised word forms and associated them with their specific meaning relatively quickly when compared to the time needed to associate grammatical cues with each other. In both experiments, participants were able to recognise trained words after a single exposure to the training language and while not tested until after three exposures to the language, participants were also able to associate trained words with their specific meanings at this point.

Following Experiment 1 it was observed that compared with performance in previous artificial language learning studies (Hickey, 2022; Mirković et al., 2021) recognition of word meanings, while above chance, was significantly poorer than in previous studies. In contrast, performance on the phonological form recognition task after three exposures to the training language was in line with performance in previous artificial language learning studies.

Experiment 2, demonstrated that increasing the number of exposures from three to nine enhanced learning of trained word's meanings, bringing them in line with performance in previous artificial language learning studies (Hickey, 2022; Mirković et al., 2021). Alongside this participants performance on the phonological form recognition task after three exposures to the language was in line with their performance at the end of Experiment 1. Taken together, these findings suggest that

the poor performance observed in Experiment 1 can be attributed to insufficient exposure to trained words with their associated meanings.

Experiment 2 also tested whether further exposure to the training language after three blocks of training enhanced learning of trained words' phonological forms. Repeated contrasts during a mixed-effects logistic regression demonstrated that exposure to the training language between the first and third blocks of training enhanced learning of phonological forms, replicating the findings from Experiment 1. Contrasts showed that while borderline (p= .051) six further exposures to the training language did not significantly enhance learning of phonological forms after the third block of training.

Taken together, these findings suggest that participants acquire word forms faster than their associated meanings, as while participants demonstrated above chance learning on both measures of word learning, additional only word meaning benefited from further exposure to the training language.

The broader literature provides many examples of artificial language learning studies showing that participants are able to generalize associations between different phonological-distributional cues (Frigo & McDonald, 1998; Gomez, 2002; Lew-Williams & Fernald, 2010; Vuong et al., 2016). However, in the relatively small number of studies which include both semantic and phonological-distributional cues they are unable to do so (Hickey, 2022; Mirković et al., 2021; Vujović et al., 2021). Based on the competition model and discriminative learning it was predicted that omitting semantic cues from participants first exposure to the training language would enable them to learn both phonological-distributional cues and generalize the associations between them.

However following Experiment 2, abnormalities were observed when comparing performance on the phonological form generalisation task after the third and ninth blocks of training. Upon review, it was found that grammatical items in the second phonological form generalisation task were mistakenly taken from the training set. As such for Experiments 1 and 2 performance on the second phonological form generalisation task was driven by recognition of trained words. In Experiment 2, participants showed generally poor endorsement of grammatical and ungrammatical items on the phonological form generalisation task after nine exposures to the language. Based on the issues caused by the second task, it is possible that they did not endorse any items as they could not recognise any of the novel words used as stimuli.

As such, in Experiments 1 and 2 we can confirm that participants were unable to generalize phonological-distributional associations after their first exposure to the language in either training

conditions. However, we cannot determine whether they were able to generalize phonological-distributional associations after further exposure to the language nor whether differences emerged between training conditions as participants underwent further exposures to the training language. Experiment 3 addressed this by comparing generalisation of phonological-distributional cues between participants trained with only phonological-distributional cues or both semantic and phonological-distributional cues.

In previous artificial language learning studies, participants trained on a language with semantic and phonological-distributional cues have succeeded in generalizing associations between semantic and phonological-distributional cues to novel words (Hickey, 2022; Mirković et al., 2021; Vujović et al., 2021). Mirković et al. (2021) has gone further demonstrating that participants can generalize associations between semantic cues and one of the phonological-distributional cues (suffixes) to novel words. Experiment 1 found that participants were able to generalize semantic associations with determiner-suffix pairs and determiners on their own. Experiment 2 also showed some evidence that participants were able to generalize associations between semantics and determiners on their own. However, in both experiments participants were unable to generalize associations between semantic cues and suffixes. These findings contrast previous artificial language learning studies (Hickey, 2022; Mirković et al., 2021) in which participants demonstrated generally better performance on semantic generalisation tasks including being able to generalize suffix-semantic associations.

Comparing the findings between Experiments 1 and 2 demonstrates that increased exposure to the language did not enhance participants' ability to learn and generalize associations between semantic cues. This leaves the question of why participants performed worse on these measures than participants in previous artificial language learning studies unanswered. One possible explanation is the nature of the training task used in Study 1, in which participants simply repeated the word forms. Nothing in the task required participants to make the link between the word form and its meaning. Although clearly the task was sufficient for learning individual word-meanings by the end of training, it is possible that more robust learning of this association is necessary for success on generalisation tasks. Altering the training to incorporate task demands which require the participant to link word forms and meanings may achieve this: previous studies using this paradigm have used Word Picture matching tasks as part of training, which required the participant to make a decision on whether the word and picture are a good match.

Study 1 demonstrates that learners are able to learn word forms very quickly, acquiring them from a single exposure to the language and no longer benefiting further exposures after the third. Learners

took relatively longer to associate word forms with semantics, continuing to benefit from further exposure to the language after three. Study 1 also demonstrates some evidence that participants can associate semantic cues with determiners, but performance on these measures is noticeably worse than in previous studies (Hickey, 2022; Mirković et al., 2021) and participants showed no evidence that they had learned suffix-semantic associations in either experiment. There was no evidence that participants had learned of phonological-distributional associations in Study 1, but this was only able to be measured after a single exposure to the training set. Study 2 addressed these gaps by testing how manipulating the presence of semantics affected learning of phonological-distributional associations cues after greater exposure to the training language. Study 2 also addressed whether introducing a task to training which requires participants to link word forms and meanings would enhance learning of semantic associations in the training language.

Chapter 4. Semantics as individual meanings and grammatical cues in novel grammar learning.

4.1 Introduction

In line with the competition model (Bates & MacWhinney, 1989, Culbertson et al., 2017) and discriminative learning (Arnon & Ramscar, 2012; Havron & Arnon, 2021; Ramscar et al., 2010; Ramscar & Port, 2016), previous studies suggest that the presence of semantic cues in a language interferes with learning of phonological-distributional cues. While learners were able to apply associations between phonological-distributional cues to novel words in a language without semantic cues (Frigo & McDonald, 1998; Gomez, 2002; Vuong et al., 2016) they were unable to do so when learning a language with both semantic and phonological-distributional cues (Hickey, 2022; Mirković et al., 2021; Vujović et al., 2021). Study 1 attempted to address whether the presence of semantic cues interfered with learning of phonological-distributional cues by investigating whether omitting semantics from participants' first exposure to the training language enhanced generalisation of phonological-distributional associations. Study 2 attempts to replicate and extend the findings of Study 1, examining how the presence of semantics impacts learning at the level of individual words, vs the higher-order level of grammatical regularities.

<u>Semantic benefit for word-learning</u>

From the perspective of cue competition, and as explored in Study 1, semantics may act in competition with other cues to grammatical structure in the input, such as phonological-distributional cues. On the other hand, from the perspective of word-learning, there is substantial

evidence of a semantic benefit, such that the presence of semantics supports the learning of new words. Thus, it may be that the interaction between semantics and other aspects of the linguistic input depends on whether the focus is on the lexical level, or the level of grammatical regularities.

While the competition model and discriminative learning identify semantics cues as a competitor which interferes with learning of phonological-distributional cues, Experiments 1 and 2 manipulated the availability of semantics as whole rather than its availability as grammatical cue. This was in line with how Culbertson et al. (2017) manipulated the availability of semantic cues in their experiment. While omitting semantics from the training language ensured that semantic cues couldn't interfere with learning of phonological-distributional cues, if an effect were found for phonological form generalisation, it could be argued that any difference between conditions was caused by omitting word meanings from the language entirely, rather than the absence of animacy as a semantic cue. To address this, Experiments 3 and 4 compared the effects of semantics as a whole and semantics as cues to grammatical regularities using three separate training conditions.

When predicting whether semantics as individual word meanings would affect learning of phonological-distributional cues, the semantic binding hypothesis (Patterson et al., 1994) provides a framework for considering how the presence of semantics may interact with learning at the lexical level. The semantic binding hypothesis was originally used to explain why learners were able to immediately recall known words more accurately than they did novel words. It argues that learners represent word forms as a combination of phonemes rather than as a single inflexible unit. As such when word forms are recalled inaccurately, it is because phonemes are either forgotten or recalled in the wrong order. According to the semantic binding hypothesis, when individual word meanings are available, learners associate them with specific combinations of phonemes which makes it easier to recall those phonemes together when reconstructing word forms.

In line with the semantic binding hypothesis, Savill et al. (2017) used an immediate serial recall task to demonstrate that associating pseudowords with specific meanings enhanced accuracy when recalling lists of pseudowords. In their study, participants were trained on pseudowords paired with different artefacts and pseudowords with no associated meanings. When recalling lists of four spoken words participants were able to accurately recall pseudowords which had been paired with artefacts significantly more often than pseudowords with no associated meanings. Further studies conducted by Savill and others have similarly found a benefit of semantic associations for immediate word recall (Savill et al., 2015, 2018) and recognition of trained words (Pomper & Saffran, 2018).

Taken together these findings suggest that associating trained words with specific meanings may enhance learners' recognition of trained words in an artificial language. Further if semantics do support learning of word sounds in specific sequence then this could suggest that the presence of semantics could enhance learners' acquisition of determiners and suffixes as they recur at the start and end of trained words. It is worth noting however that even if there were to be enhanced learning of trained words, this would not necessarily translate to learners being able to generalize determiner-suffix pairings to novel words.

Competition between semantic and phonological-distributional cues

Experiments 1 and 2 attempted to address whether the presence of semantic cues interfered with learning of phonological-distributional cues by investigating whether omitting semantics from participants first exposure to the training language enhanced generalisation of phonological-distributional associations. However, due to issues with data collection participants' ability to generalize associations between phonological-distributional cues only data from after a single exposure to the training language was available. While there was no significant effect of training conditions on participants' ability to generalize phonological forms after this first exposure to the language, we could not determine whether differences would emerge with further exposure to the training language. Experiments 3 and 4 addressed this by investigating how omitting semantics from the language affected generalisation of phonological forms after 8 and 12 exposures to the training language.

Performance on the semantic generalisation tasks in Experiments 1 and 2 was noticeably poorer than performance in previous studies (Hickey, 2022; Mirković et al., 2021). One explanation for this is that while previous studies trained participants with repetition and word-picture matching tasks, participants in Experiments 1 and 2 were only trained using repetition tasks. During word-picture matching tasks participants are presented with a word-picture pair and are required to decide whether the word and picture go well together. As the word-picture matching task increases participants' exposure to the training language and encourages them to consider associations between phonological forms and semantics, omitting it in Experiments 1 and 2 may have produced poorer learning of semantic associations. To address this Experiments 3 and 4 included word-picture matching tasks when training participants on word-picture pairs.

Rationale

Study 2 addressed whether the presence of semantics in the form of individual word meanings or as grammatical cues interferes with learning of phonological-distributional associations in the training language. In a set of two experiments, it also addressed whether the inclusion of individual word meanings in the language affects learning of word forms and whether word-picture matching trials enable participants to acquire and generalize semantic cues when they are present in the training language.

Experiment 3 manipulated the presence of semantics using three training conditions; phonological-forms only, lexical semantics and grammar-level semantics. Participants in all three conditions learned a set of thirty-two pseudowords. There were no semantic referents in the phonological forms only condition, leaving word forms and associations between phonological-distributional cues as the only features in the language available to learn. In the lexical semantics condition each pseudoword was associated with a specific animal or artefact but the animacy of each word's meanings had no association with the phonological-distributional cues present in the language. In the grammar-level semantics condition the animacy of each pseudowords individual meaning was associated with determiner-suffix pairs. As such semantics as individual meanings were available in the lexical semantics and grammar-level semantics conditions but semantics only served as a grammatical cue in the grammar-level semantics condition.

Experiment 3 predicted that in line with the semantic binding hypothesis (Patterson et al., 1994; Savill et al., 2015, 2017, 2018) the inclusion of individual word meanings which learners can associate with word forms will enhance learning of individual word forms in the lexical and grammar-level semantics conditions. Alongside this, Experiment 3 predicted that the presence of semantic cues in the grammar-level semantics condition would interfere with generalisation of phonological-distributional associations based on the competition model (Bates & MacWhinney, 1989; Culbertson et al., 2017) and discriminative learning (Arnon & Ramscar, 2012; Havron & Arnon, 2021; Ramscar et al. 2010; Ramscar & Port, 2016).

After two and four blocks of training performance on the phonological form generalisation task was compared between three training conditions to address whether the presence of semantics and semantics as a grammatical cue affected learning of phonological-distributional associations. Group comparisons on the phonological form recognition task were also used to address whether the presence of semantics as word meanings or grammatical cues affected participants' ability to recognise trained words after two and four blocks of training. Finally for participants trained with semantic cues, comparisons between a' scores and 0.5 were used to address whether the inclusion

of word-picture matching tasks during training would bring participants semantic generalisation in line with participants in previous studies (Hickey, 2022; Mirković et al., 2021).

Experiment 4 attempted to replicate the findings of Experiment 3 while also addressing whether participants' performance during a speeded shadowing task could be used to measure implicit awareness of phonological forms and associations between phonological-distributional cues.

The speeded shadowing task was developed as an alternative generalisation measure which would be better suited for measuring implicit knowledge (Tamminen et al., 2012). Because the speeded shadowing task measures generalisation by comparing differences in response times when words are consistent or inconsistent with the training language, it does not require participants to make explicit choices based on their implicit knowledge. Tamminen et al. (2012) contrasted this with the type of generalisation tasks used in Study 1 and previous artificial language learning studies (Hickey, 2022; Mirković et al., 2021) which do require participants to make explicit decisions about novel words, arguing that the use of repetition tasks allows for more sensitive measurement of implicit knowledge.

Previous studies conducted by Tamminen et al. (2012, 2015) have demonstrated that the speeded shadowing task can be used to measure learning of suffixes. Tamminen et al. (2012) showed that participants repeated back pseudowords with trained affixes significantly faster than they did pseudowords with novel affixes. In a later study Tamminen et al. (2015) demonstrated that participants also responded significantly faster when repeating back pseudowords which had consistent suffix-semantic associations. These findings suggest that participants respond faster when repeating back pseudowords which are congruent with the trained language. In Experiment 4, the speeded shadowing task was used to measure response times for trained pseudowords, novel pseudowords and novel pseudowords with determiner-suffix pairings inconsistent with the training language.

Based on the competition model and discriminative learning, training participants without semantics in Experiments 3 and 4 would enhance generalisation of phonological-distributional cues after training. When comparing lexical and grammar-level semantics, the semantic binding hypothesis suggests that while semantic cues interfere with learning of phonological-distributional associations in the training language, the inclusion of lexical semantics would not interfere with learning of phonological-distributional cues but would enhance phonological form recognition. Finally, based on

the poorer semantic generalisation in Experiments 1 and 2 when compared with previous literature (Hickey, 2022; Mirković et al., 2021) the inclusion of word-picture matching tasks in the semantic training conditions will bring participants performance on the semantic generalisation task in line with performance in previous studies.

For the speeded shadowing task employed in Experiment 4, the congruency effects observed in Tamminen et al. (2012) suggest that participants are able to learn word forms and phonological-distributional associations in the language they will respond faster to words with familiar stems and consistent determiner-suffix pairings.

4.2 Experiment 3

4.2.1 Introduction

Participants in experiment 3 were trained on a pseudoword language with the inclusion of semantics in the language manipulated across three training conditions. In the phonological forms only training participants were trained on phonological forms with no semantics available during training. In the lexical semantics condition participants were trained on phonological forms and semantic referents, with each word being associated with a specific animal or artefact. In the grammar-level semantics condition participants were also trained on phonological forms and semantic referents. However in addition to each pseudoword being associated with a specific animal or artefact the animacy of word meanings in the grammar-level semantics condition was associated with determiner-suffix pairs. As such while semantics as individual word meanings were available in the lexical semantics and grammar-level semantics conditions, semantics only served as a cue to the grammatical category in the grammar-level semantics condition.

Like in experiments 1 & 2 phonological form recognition and 2AFC tasks were used to measure participants' learning of word forms and meanings respectively. Based on experiments 1 & 2, it was predicted that participants across conditions would be able to learn trained word forms and that participants in the two semantic training conditions would be able to learn trained word meanings. Based on the semantic binding hypothesis (Pomper & Saffran, 2018; Savill et al., 2015, 2018) the inclusion of individual word meanings in the grammar-level and lexical semantics conditions would enhance learning of phonological forms. This led to the prediction that participants in these conditions would outperform participants in the phonological forms only condition.

Phonological form generalisation tasks were also employed in all three training conditions. They were used to investigate whether participants were able to generalize the association between phonological-distributional cues to novel words. Based on the competition model (Bates & MacWhinney, 1989; Culbertson et al., 2017) and discriminative learning (Arnon & Ramscar, 2012; Havron & Arnon, 2021; Ramscar et al. 2010; Ramscar & Port, 2016), when both semantic and phonological-distributional cues are available during language, semantic cues outcompete phonological-distributional cues for relevance. Subsequently after acquiring semantic cues learners block out phonological-distributional cues as redundant (Kamin, 1969).

As such, it was predicted that omitting semantic cues from the training language would enhance participants' ability to generalize associations between phonological-distributional cues. In comparisons against 0.5 it was anticipated that participants trained with only phonological forms and lexical semantics would be able to generalize phonological-distributional cues. In comparisons across conditions, it was expected that participants trained with lexical semantics would outperform participants trained with grammar-level semantics and that participants trained without semantics would outperform those trained with them.

Participants' ability to generalize semantic associations to determiner-suffix pairs and each affix individually was only measured in the grammar-level semantics condition. Based on Study 1 and previous studies using this paradigm, the inclusion of word-picture matching tasks during training supports learning of semantic associations in the language. As such, it was predicted that after training with repetition and word-picture matching tasks in experiment 3 participants would be able to generalize semantic associations in the training language.

4.2.2 Methods

<u>Participants</u>

During recruitment, seven participants were excluded from the study for not complying with instructions during training. The resulting sample was comprised of ninety-nine monolingual, native English-speaking adults (26 males, 70 females, 3 non-binary; mean age= 28.37 range = 18-35) with no known language disorders. Participants had normal hearing and normal or corrected-to-normal vision. Participants were recruited from Prolific and participated in the study after providing informed consent. Each participant was paid £3.75 for taking part in the study. The study was approved by the Ethics Committee at the Department of Psychology, University of York.

Participants were randomly allocated to one of three training conditions, for every participant allocated to the grammar-level semantics condition one was assigned to the lexical semantics condition and one was assigned to the phonological forms only condition. After recruitment was complete, there were 32 participants in the grammar-level semantics condition, 33 in the lexical semantics condition and 34 in the phonological forms only condition.

Materials

Language training set

In Experiment 3, the number of words in the training set was reduced from 32 to 24 matching the number of items used in Mirković et al. (2021).

The semantics presented alongside the training language were manipulated between training conditions. In the grammar-level semantics condition, semantics served as individual word meanings as well as a cue to grammatical category. In this condition, each pseudoword was presented alongside a specific picture of an animal or artefact and the animacy of the pictures were associated with one of the two determiner-suffix pairs. In the lexical semantics condition semantics served as individual word meanings but not as a grammatical cue; each trained pseudoword was associated with a specific picture of an animal or artefact but the animacy of the picture was not associated with a determiner-suffix pair. In the phonological forms only condition semantics were absent from both training and testing.

For participants in the grammar-level and lexical semantics conditions, a set of 24 mismatched items were included during training to simulate statistical noise in neutral languages. Like in previous experiments, mismatched items paired pseudowords from the training set with trained pictures from different words in the training set. Across the four training blocks participants encountered the 24 mismatched items twice, once during the repetition task and then immediately afterwards during the word-picture matching task. Each block of training included four mismatched items, half of which were animals and half artefacts.

The language was also counterbalanced in both of the semantic training conditions. In the grammar-level semantics condition half of the participants learned that "tib-eem" was associated with animals and "ked-ool" with artefacts while the half learned that "tib-eem" was associated with artefacts and "ked-ool" with animals. In the lexical semantics condition the determiner-suffix pairings were not associated with animals and artefacts, instead for each semantic category half of the words began and ended with "tib-eem" and half with "ked-ool". As such associations between semantics and

phonological-distributional cues were not counterbalanced in the lexical semantics condition, but word meanings were.

Generalisation sets

A total of 36 novel pseudowords were used across the generalisation tasks. The two phonological form generalisation tasks each used 12 novel pseudowords. In each task, 6 had consistent determiner-suffix pairings while 6 paired determiners with suffixes from the opposite grammatical gender. Half of the consistent and inconsistent pseudowords used in each task began with the determiner *tib-* and the other half began with *ked-*. The three semantic generalisation tasks employed for participants in the grammar-level semantics condition each used 4 novel pseudowords.

Procedure

As illustrated in figure 17, participants in all three training conditions completed four blocks of training and were tested after the second and fourth blocks were complete. In all three conditions participants were tested on their learning of word forms and their ability to generalize associations between phonological-distributional cues after two and four blocks of training. Participants in the two training conditions which included semantics were tested on the learning of individual word meanings after two and four blocks of training. Only participants in the grammar-level semantics condition were tested on their ability to generalize semantic associations to phonological-distributional cues after training was complete. The training and testing session lasted approximately 30 minutes and both sessions were completed in Gorilla.

As in previous experiments, participants were given a brief outline of what they were expected to do before they signed a digital consent form and answered questions regarding their age, gender and history of language disorders. Participants were not informed of their group assignments during the experiment.

First phase of training	Second phase of training
Training	Training
Repetition and Word-Picture Matching Task	Repetition and Word-Picture Matching Task
2 Blocks of 24 trained pseudowords	2 Blocks of 24 trained pseudowords
Testing	Testing
Word Learning	*Word Leaning*
Phonological Form Recognition Task	Phonological Form Recognition Task
2AFC Task	2AFC Task
Grammar Learning	*Grammar Learning*
Phonological Form Generalization Task	Phonological Form Generalization Task
	Suffix Generalization Task
	Determiner Generalization Task
	Determiner-Suffix Generalization Task

Figure 17. Experiment Design and Tasks

Training was split into two phases, with each phase consisting of two blocks. In the two semantic training conditions, each block contained 24 trained and 6 mismatched words. For each trial during training participants were shown a picture of an animal or artefact before hearing a corresponding pseudoword which they were instructed to repeat. After repeating each word participants in the semantic conditions were played the word a second time and asked to indicate whether the word and picture went well together by choosing one of two faces. After repeating back each block of 24 trained pseudowords participants were allowed to take a break of up to five minutes but could move onto the next task earlier if they chose to.

In the phonological forms only condition the pictures of animals and artefacts were replaced with a fixation cross in the centre of the screen and the word-picture matching task was removed. Instead of the word-picture matching task, which could not be used if semantics were absent from the training language, participants heard each pseudoword a second time before moving on to the next trial. This ensured that the number of exposures to trained words were equal between conditions. Mismatched items were also absent from training in the phonological forms only condition.

During the first phase of training, participants in all three training conditions heard each of the 24 trained word-picture pairs four times. During each block of training participants heard each trained word once before repeating it back and again immediately afterwards. Participants in the two conditions with semantics present also encountered 12 mismatched items in the first phase of training. During each block, they heard six mismatched words twice, first when repeating back the word and again when deciding whether the word and picture went together.

After the first phase of training participants in all three conditions completed phonological form recognition and phonological form generalisation tasks to measure their learning of word forms and associations between phonological-distributional cues. In the lexical semantics and grammar-level semantics trained conditions participants also completed a 2AFC task.

After the second phase of training participants in all three conditions completed an additional phonological form recognition task. Participants in the two semantic training conditions completed a second 2AFC task. Finally participants in the grammar-level semantics condition completed a set of generalisation tasks (phonological form generalisation, determiner-only, suffix-only and determiner-suffix).

Participants' explicit knowledge of the associations present in the language was assessed after the final set of tasks using two questions. In the phonological forms only condition and lexical semantics condition, participants' responses were scored for awareness of the determiner phonology, suffix phonology and determiner-suffix pairings to reflect the complexity of the regularities present in the language.

As participants in the grammar-level semantics condition were trained on semantic cues in addition to phonological-distributional cues, their responses during debriefing were also scored for explicit awareness of determiner and suffix semantic associations. For a more detailed breakdown of how each explicit awareness measure was scored see the general method section.

Data analyses

All analyses reported below were performed in R.

The same analyses used in previous experiments were conducted to investigate levels of word learning and generalisation for participants in each training condition at each point in time. For all models a maximal model that was able to converge was produced using the buildmer package.

For the phonological form recognition task, the effects of training condition and length of training were investigated using a mixed-effects logistic regression with accuracy coded as a binary outcome measure. Training condition and length of training were fixed factors. Training condition (phonological forms only= 0, lexical semantics= 1, grammar-level semantics= 2) was coded as a Helmert contrast, comparing performance for the lexical semantics condition against the grammar-level semantics condition for the first hypothesis and comparing performance in the phonological forms only condition against performance in the two semantic conditions for the second. Length of training (after one phase of training= 0, after two phases of training= 1) was coded as a repeated

contrast. Random effects were included for both participants and test items. In the phonological forms only condition, results from 1 participant were excluded from analysis of the phonological form recognition tasks as they selected the same answer for all 12 trials.

For analyses of the 2AFC task, the effect of training condition and length of training were investigated using a mixed-effects logistic regression with accuracy coded as a binary outcome measure. Training condition and length of training were fixed factors. Both training condition (lexical semantics= 0, grammar-level semantics= 1) and length of training (after one phase of training= 0, after two phases of training= 1) were coded as repeated contrasts. Random effects were included for both participants and test items. Results from 2 participants in the lexical semantics condition were excluded from analysis for the 2AFC tasks as they were timed out on more than 20% of the 2AFC trials.

For the phonological form generalisation task, the effect of training condition was investigated using a linear regression with a' scores as the outcome measure and training condition as the fixed effect. Training condition (phonological forms only= 0, lexical semantics= 1, grammar-level semantics= 2) was coded as a Helmert contrast, comparing performance for the lexical semantics condition against the grammar-level semantics condition for the first hypothesis and comparing performance in the phonological forms only condition against performance in the two semantic conditions for the second.

For the three semantic generalisation tasks, modelling was not used as generalisation of semantic cues was only tested after training was complete in the grammar-level semantics training condition.

In the analyses of explicit knowledge, the effect of training conditions on explicit knowledge of various associations present in the language was investigated using a series of linear regressions. Each model used participants' scores for an explicit awareness subtest as the outcome measure and training condition as the fixed effect. Training condition was coded as a Helmert contrast (phonological forms only= 0, lexical semantics= 1, grammar-level semantics= 2). The models investigated the effect of training condition on explicit awareness of: i) determiner phonology, ii) suffix phonology and iii) determiner-suffix pairs. Models were not produced for explicit awareness of determiner semantics or suffix semantics as only participants in the grammar-level semantics condition had the opportunity to learn them.

Following this Pearson's correlations were used to investigate whether there was a relationship between participants' ability to generalize phonological forms and explicit awareness measures. We looked for correlations with:

1. Determiner phonology
2. Suffix phonology
3. Determiner-suffix pairs

For the grammar-level semantics condition, correlations were also used to investigate whether there was a relationship between participants' ability to generalize semantic associations and explicit awareness measures. For the determiner-suffix generalisation task we looked for correlations with:

1. Determiner phonology
2. Determiner semantics
3. Suffix phonology
4. Suffix semantics
5. Determiner-suffix pairs

For the determiner generalisation task we looked for correlations with:

1. Determiner phonology
2. Determiner semantics

For the suffix generalisation task we looked for correlations with:

1. Suffix phonology
2. Suffix semantics

4.2.3 Results

Word Learning

Phonological form recognition was measured after two and four blocks of training for participants in all three training conditions. To investigate whether participants in each condition learned the word forms from training, one sample t-tests were used to compare the mean accuracy for familiar items against chance level (0.5).

Figure 18 illustrates participants' recognition of word forms after two and four blocks of training. In the grammar-level semantics condition, results from 5 participants were excluded for the phonological form recognition task due to reported issues viewing stimuli. One sample t-tests confirm that performance was significantly above chance for participants across conditions at both points in time (Phonological forms only, after two blocks of training: $t(32)= 15.62$, $p<.001$; after four blocks of training: $t(32)= 12.42$, $p<.001$; Lexical semantics, after two blocks of training: $t(32)= 16.94$,

p<.001; after four blocks of training: t(32)= 10.28, p<.001; Grammar-level semantics, after two blocks of training: t(31)= 17.61, p<.001; after four blocks of training: t(31)= 15.23, p<.001; after two blocks of training: M$_{Phonological Forms Only}$ = .88, M$_{Lexical Semantics}$= .91, M$_{Grammar-level Semantics}$= .92; after four blocks of training: M$_{Phonological Forms Only}$= .87, M$_{Lexical Semantics}$= .88, M$_{Grammar-level Semantics}$= .89).
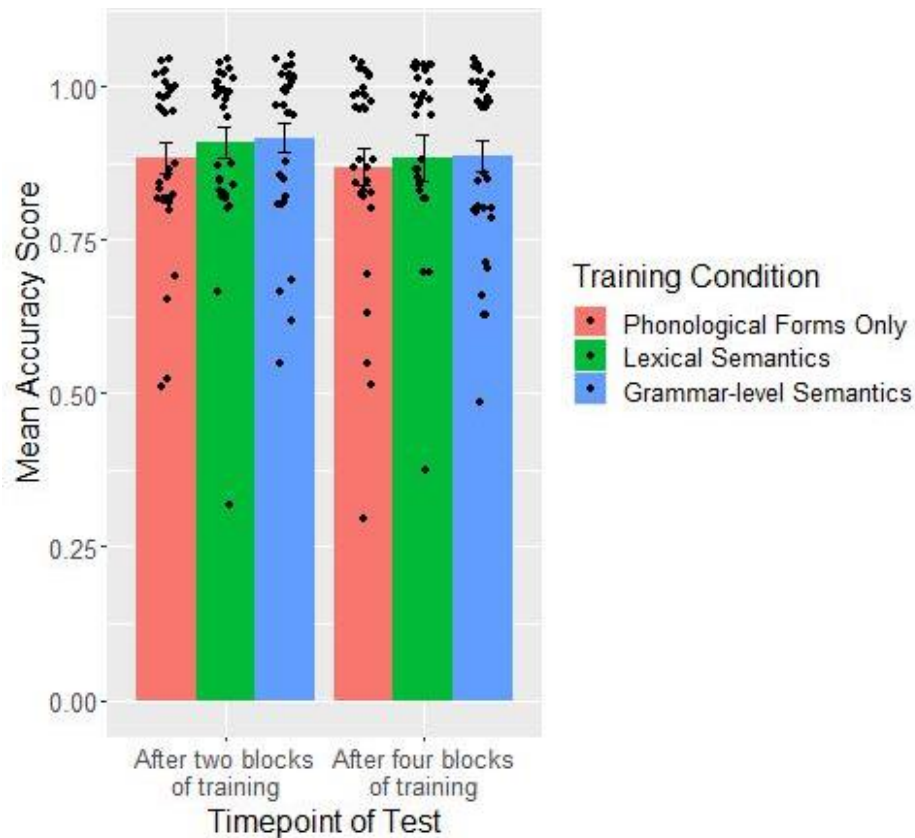
Figure 18. Accuracy (proportion correct) for the phonological form recognition task for participants trained with phonological forms only, lexical semantics and grammar-level semantics after two and four blocks of training.

A mixed-effects logistic regression was used to investigate the effects of training condition and length of training on the accuracy during the phonological form recognition task. Helmert contrasts showed that there was no difference in word recognition between participants trained with grammar-level or lexical semantics, nor was there a difference between participants trained with and without semantics. There was no effect of length of training on word recognition and no interactions between length of training and comparisons between different training conditions.

Table 28. Regression coefficients for the fixed effects with accuracy as the binary outcome variable in the phonological form recognition task.

	Estimate	Std. Error	z-value	p-value
Lexical Semantics vs. Grammar-level Semantics	.100	.126	.798	.425
Phonological Forms Only vs. Grammar-level + Lexical Semantics	-.048	.071	-.674	.500
Length of Training	-.333	.338	-.984	.325
Length of Training X Lexical Semantics vs. Grammar-level Semantics	-.095	.137	-.693	.489
Length of Training X Phonological Forms Only vs. Grammar-level + Lexical Semantics	-.097	.075	-1.29	.198

Random effects included in the model: intercepts by items and participants, and slope for Length of Training by participants.

Taken together these results show that participants were able to recognise word forms regardless of the presence of semantics and semantic cues after two and four blocks of training. Increased exposure to the training language between the second and fourth blocks of training did not enhance learning of word form recognition and there was no effect of semantics and semantic cues on word form learning. Across all three training conditions and at each point in time participants' performance was noticeably close to ceiling. Overall, these results demonstrate that participants were able to learn word forms across conditions after only four exposures to the training language.

Figure 19 illustrates participants' learning of word meanings after two and four blocks of training in the lexical semantics and grammar-level semantics training conditions. One sample t-tests confirmed that performance was significantly above chance for participants in conditions after two and four blocks of training (Lexical semantics, after two blocks of training: $t(30)= 5.96$, $p<.001$; after four blocks of training: $t(30)= 9.63$, $p<.001$; Grammar-level semantics, after two blocks of training: $t(31)= 3.72$, $p<.001$; after four blocks of training: $t(31)= 10.78$, $p<.001$; after two blocks of training: $M_{Lexical Semantics}= .68$, $M_{Grammar-level semantics}= .62$; after four blocks of training: $M_{Lexical Semantics}= .78$, $M_{Grammar-level semantics}= .79$).
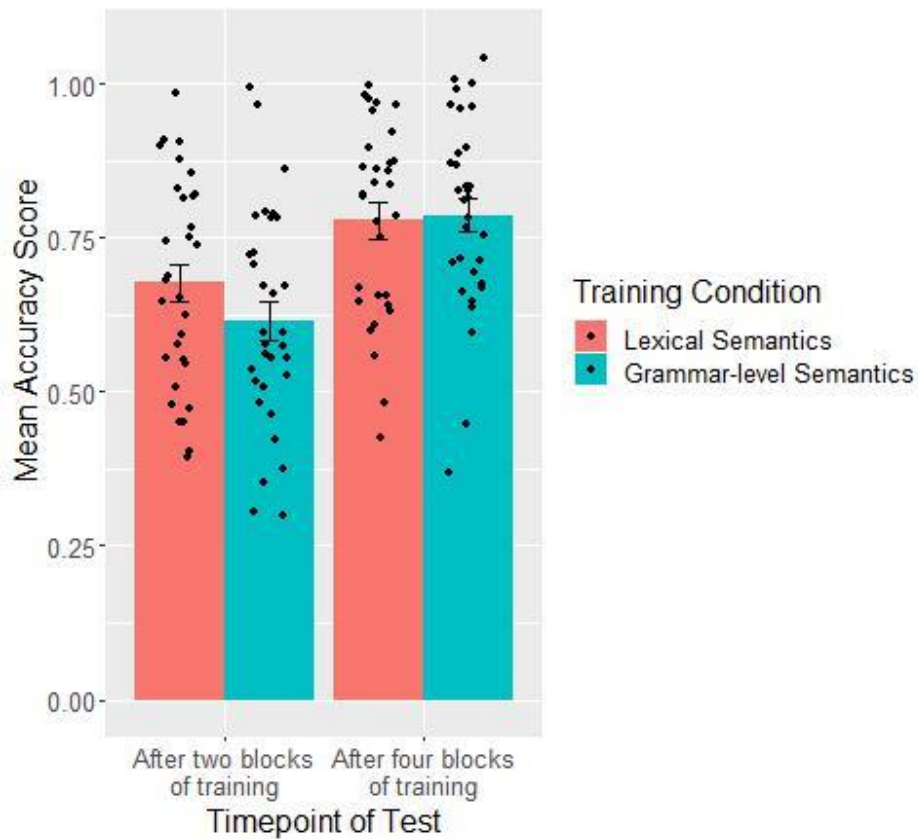
Figure 19. Accuracy (proportion correct) for the 2AFC task for participants in the grammar-level semantics and lexical semantics conditions after two and four blocks of training.

A mixed-effects logistic regression was used to investigate the effects of training condition and length of training on accuracy during the 2AFC task. As shown in Table 29, additional exposure to the training language between the second and fourth blocks of training enhanced learning of trained words' meanings. There were no significant effects for training condition nor was there a significant interaction between training condition and length of training.

Table 29. Regression coefficients for the fixed effects with accuracy as the binary outcome variable in the 2AFC task.

	Estimate	Std. Error	z-value	p-value
Training Condition	-.300	.210	-1.43	.154
Length of Training	.648	.147	4.40	<.001
Training Condition X Length of Training	.331	.198	1.68	.094

Random effects included in the model: intercepts by participants, and slope for Length of Training by participants.

Taken together with the above chance performance in both conditions at both points in time, these findings suggest that participants were able to learn word meanings after four exposures to the training language regardless of whether semantics were associated with phonological-distributional cues. While training condition did not affect recognition of word meanings, additional exposure to the training language following the second block of training did enhance learning of individual words' meanings. This suggests that even after four exposures to the language participants are still not as familiarised with each trained word's meaning as they could be.

Grammatical generalisation

Phonological form generalisation

The extent to which participants could generalise associations between phonological cues from training to novel words was measured after two and four blocks of training across all three training conditions. A' scores were calculated to measure the level of generalisation, with a' scores above 0.5 taken as evidence that participants could generalise determiner-suffix pairs to novel items.

Figure 20 illustrates how well participants in each training condition were able to generalise associations between phonological-distributional cues after two and four blocks of training. One sample t-tests confirm that participants across training conditions in all three training conditions had a' scores significantly above 0.5 after training was complete (Phonological forms only, after two blocks of training: $t(33)= -2.57$, $p= .993$; after four blocks of training: $t(33)= 2.42$, $p= .011$; Lexical semantics, after two blocks of training: $t(32)= -.230$, $p= .590$; after four blocks of training: $t(32)= 1.58$, $p= .062$; Grammar-level semantics, after two blocks of training: $t(31)= -2.72$, $p= .995$; after four blocks of training: $t(31)= 2.00$, $p= .027$; after two blocks of training: $M_{Phonological Forms Only}= .42$, $M_{Lexical Semantics}= .49$, $M_{Grammar-level Semantics}= .40$; after four blocks of training: $M_{Phonological Forms Only}= .57$, $M_{Lexical Semantics}= .56$, $M_{Grammar-level Semantics}= .57$).
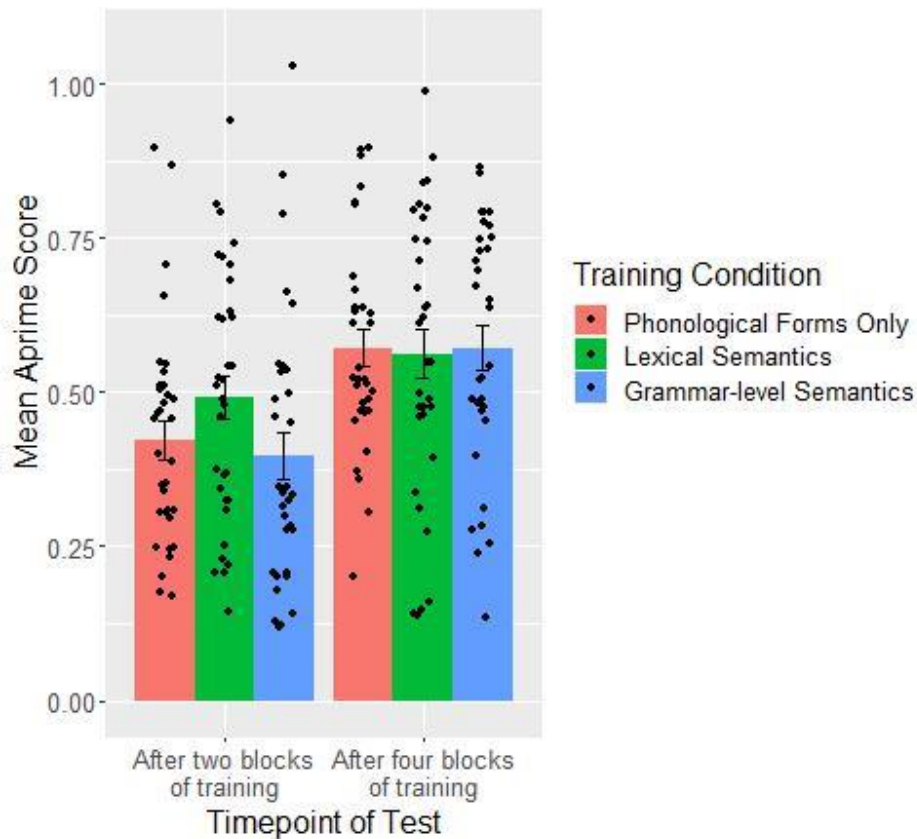
Figure 20. A' score on the phonological form generalisation task for participants in the phonological forms only, lexical semantics and grammar-level semantics training conditions after two and four blocks of training.

A linear mixed-effects regression was used to investigate the effects of training condition and length of training on a' score during the phonological form generalisation task. Helmert contrasts found that there was no difference in word recognition between participants trained with grammar-level or lexical semantics, nor was there a difference between participants trained with and without semantics. The increased exposure to the language between the second and fourth blocks of training enhanced generalisation of determiner-suffix pairs but there were no interactions between length of training and comparisons between training conditions.

Table 30. Regression coefficients for the fixed effects with a' score as the outcome variable in the phonological form generalisation task.

	Estimate	Std. Error	t-value	p-value
Lexical Semantics vs. Grammar-level Semantics	.047	.025	1.91	.058

Phonological Forms Only vs. Grammar-level + Lexical Semantics	-.008	.014	-.536	.592
Length of Training	.131	.028	4.63	<.001
Length of Training X Lexical Semantics vs. Grammar-level Semantics	-.052	.035	-1.48	.142
Length of Training X Phonological Forms Only vs. Grammar-level + Lexical Semantics	.009	.020	.456	.649

No random effects included in the maximal model

Taken together, these results suggest that participants across conditions were able to generalize the association between determiners and suffixes to novel words after four blocks of training. While performance was not above chance after four blocks of training in the lexical semantics condition (p= .062), the lack of effect for training condition on phonological form generalisation and the borderline difference when compared against chance suggest that participants were able to generalize phonological forms across training conditions. There was a borderline significant difference in phonological form generalisation between the lexical and grammar-level semantics training conditions (p= .058), but by after the fourth block of training any differences between training conditions vanished.

Participants across conditions were unable to generalize determiner-suffix pairs after two blocks of training but were generally able to do so after four blocks. Taken together with the significant effect of length of training on phonological form generalisation this suggests that participants need more than four exposures to the training language to associate determiners and suffixes with each other.

Semantic generalisation

Participants' ability to generalize associations between semantic and phonological-distributional cues was tested after four blocks of training in the grammar-level semantics condition. Participants in the phonological forms only and lexical semantics conditions were not tested on their ability to generalize semantic cues as they had no experience with semantics as a grammatical cue. A' scores were calculated to index the level of generalisation with a' scores above 0.5 being taken as evidence that participants were able to generalise an association to novel items.

Figure 21 illustrates the extent to which participants trained on grammar-level semantics could generalise semantic associations for determiner-suffix pairs, determiners and suffixes after four blocks of training. One sample t-tests confirm that participants' a' scores were significantly above 0.5 when generalizing semantics to determiner-suffix pairs and determiners. However, performance was not above 0.5 when generalizing semantics to suffixes (Determiner-Suffix Generalisation Task: $t(31)$= 2.36, p= .013; Determiner Generalisation Task: $t(31)$= 2.95, p= .003; Suffix Generalisation Task: $t(31)$= -1.70, p= .950; A' scores: $M_{Determiner-Suffix Pairs}$= .63, $M_{Determiner}$= .68, $M_{Suffixes}$= .41).
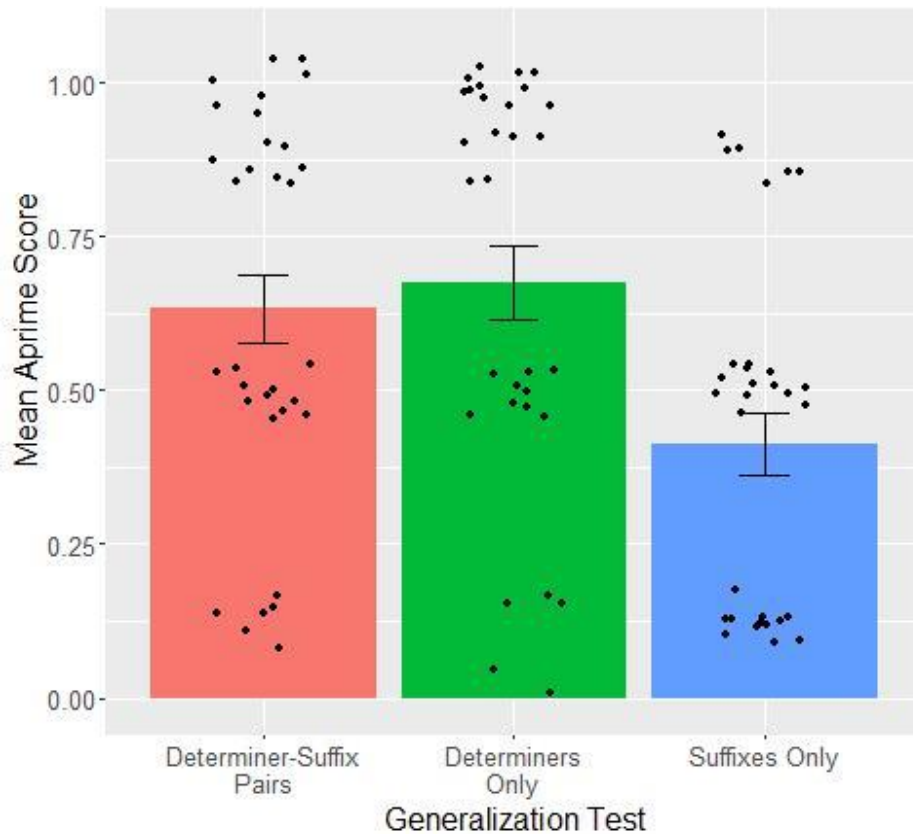
Figure 21. Performance on the determiner-suffix, determiner and suffix generalisation tasks for participants in the grammar-level semantics condition after four blocks of training.

These findings show that after eight exposures to the training language, participants were able to generalize semantic associations for determiner-suffix pairs and determiners but not for suffixes. This suggests that participants are able to generalize semantic associations to determiners but not suffixes when encountering novel words.

Explicit awareness of grammatical cues

Explicit awareness was assessed after participants had completed both training and testing. In all three training participants responses were scored based on individual awareness of determiner forms, suffix forms and determiner-suffix pairs. As participants in the grammar-level semantics condition were trained with both phonological-distributional and semantic cues, they were also scored for awareness of determiner-semantic and suffix-semantic associations.

Figure 22 illustrates the extent to which participants across all three training conditions were able to explicitly identify the phonological forms and determiner-suffix pairs in the training language. Across training conditions participants showed awareness of determiners in the training language, but generally showed poorer awareness of suffixes and determiner-suffix pairs in the training language.
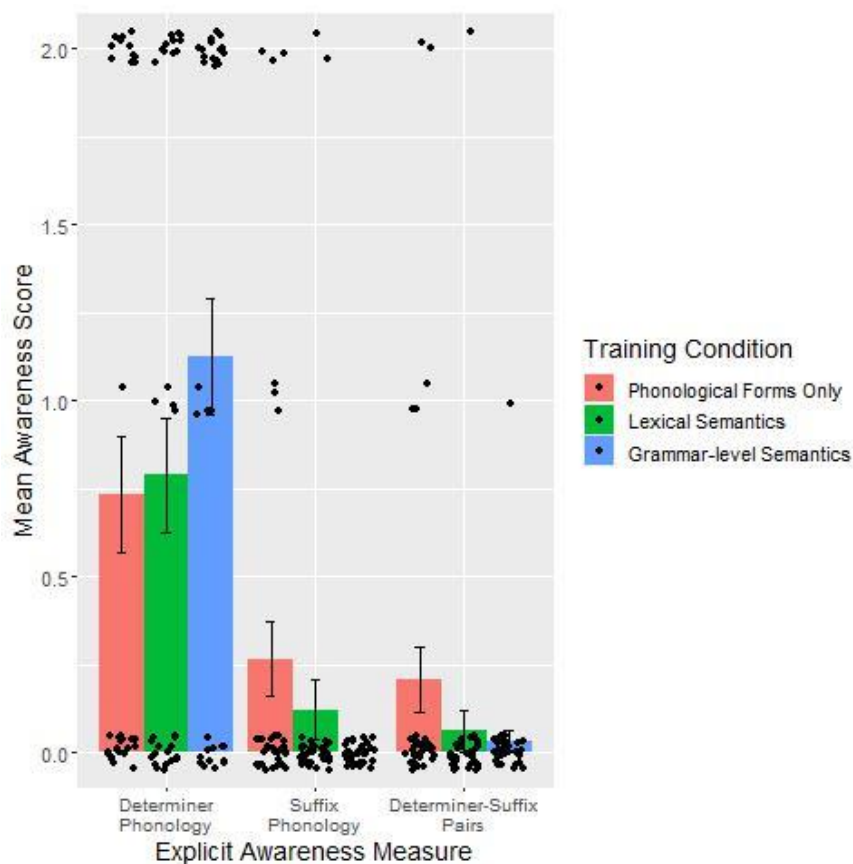
Figure 22. Mean explicit awareness scores for participants in the phonological forms only, lexical semantics and grammar-level semantics training conditions.

As shown in Table 31 participants' awareness of each phonological-distributional cue and the associations between them did not differ based on whether semantics served as a grammatical cue. In both semantic conditions, participants were generally able to identify determiners when asked about the language but were unable to identify suffixes or associations between determiners and

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suffixes. When comparing participants trained on only phonological forms against participants in the two semantic conditions, training participants without semantics enhanced explicit awareness of suffixes and while non-significant showed a similar borderline advantage for awareness of determiner-suffix pairs (p= .054)

Table 31. Linear regressions investigating training condition effects for each measure of explicit awareness.

Explicit Awareness Measure	Comparison	Estimate	Std. Error	z-value	p-value
Determiner Phonology	Lexical Semantics vs. Grammar-level Semantics	-.169	.117	-1.44	.153
	Phonological Forms Only vs. Grammar-level + Lexical Semantics	-.074	.067	-1.11	.271
Suffix Phonology	Lexical Semantics vs. Grammar-level Semantics	.061	.057	1.07	.289
	Phonological Forms Only vs. Grammar-level + Lexical Semantics	.068	.032	2.11	.038
Determiner-Suffix Pairs	Lexical Semantics vs. Grammar-level Semantics	.015	.048	.305	.761
	Phonological Forms Only vs. Grammar-level + Lexical Semantics	.053	.027	1.95	.054

No random effects included in the maximal models

Figure 23 illustrates the extent to which participants in the grammar-level semantics condition were able to explicitly identify the phonological forms, their semantic associations and determiner-suffix pairs in the training language. Participants trained with phonological-distributional and semantic cues were generally able to identify the determiners and associate them with semantic cues but showed no awareness of suffixes or their semantic associations. Given that participants in the grammar-level semantics condition were unable to identify suffixes by the end of training this raises the possibility that participants' inability to identify determiner-suffix pairs was caused by the lack of prerequisite knowledge of the suffixes.
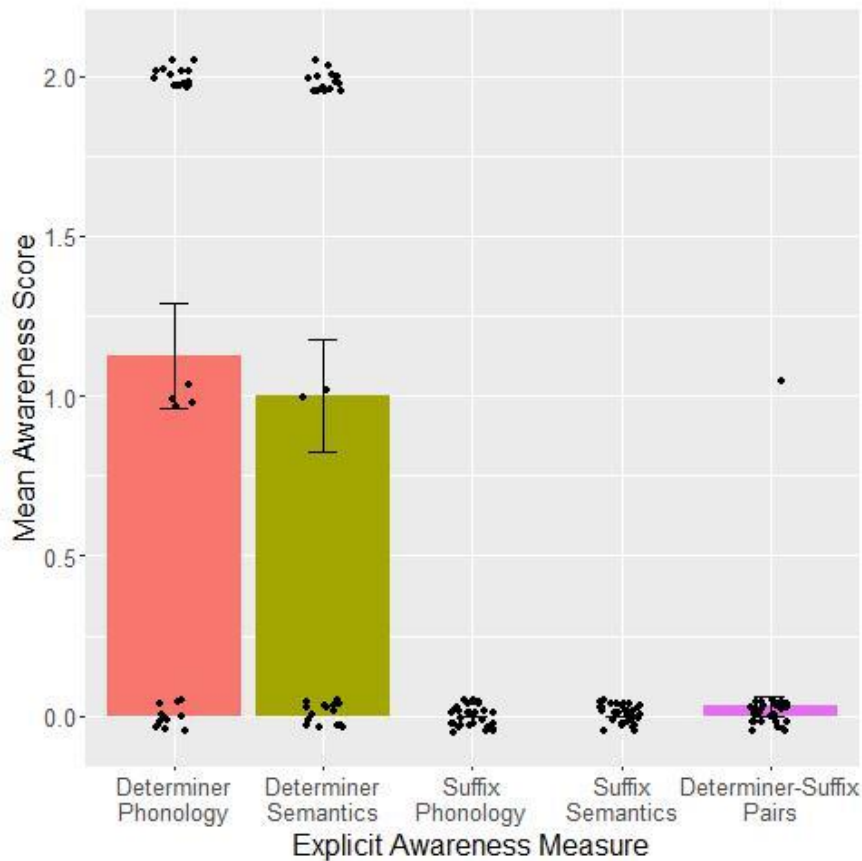
Figure 23. Mean explicit awareness scores for participants in the grammar-level semantics training condition.

Correlations between explicit awareness and generalisation

To investigate whether there was an association between explicit awareness and participants' ability to generalise semantic and phonological distributional cues several Pearson's correlations were conducted.

Correlations between phonological form generalisation after training was complete and explicit awareness of determiner forms, suffix forms and determiner-suffix pairs were carried out for participants in each training condition. As shown by Table 32 across all three training conditions there were no significant correlations between explicit awareness of phonological forms and performance on the phonological form generalisation task.

Table 32. Pearson's correlations between explicit awareness measures and phonological form generalisation

Training Condition	Correlation	Degrees of Freedom	r statistic	p-value

Phonological Forms Only	Determiner phonology and phonological form generalisation	32	.150	.397
	Suffix phonology and phonological form generalisation	32	-.093	.601
	Determiner-suffix pairs and phonological form generalisation	32	.228	.194
Lexical Semantics	Determiner phonology and phonological form generalisation	31	-.138	.445
	Suffix phonology and phonological form generalisation	31	-.213	.235
	Determiner-suffix pairs and phonological form generalisation	31	-.247	.167
Grammar-level Semantics	Determiner phonology and phonological form generalisation	30	.244	.179
	Suffix phonology and phonological form generalisation	30	NA	NA
	Determiner-suffix pairs and phonological form generalisation	30	-.196	.282.

As no participants in the grammar-level semantics condition were able to identify suffixes or the semantic associations, no correlations could be carried out between explicit awareness measures and performance on the suffix generalisation task. Correlations between determiner generalisation and explicit awareness of determiner forms and determiner semantics were carried out for participants in the grammar-level semantics condition. As shown by table 33, there were correlations between participants' ability to generalize determiner-semantic associations and their ability to identify determiners and their semantic associations after training was complete.

Table 33. Pearson's correlations between explicit awareness measures and determiner generalisation

Training Condition	Correlation	Degrees of freedom	r statistic	p-value
Grammar-level Semantics	Determiner phonology and determiner generalisation	30	.411	.019
	Determiner semantics and determiner generalisation	30	.547	.001

Correlations between determiner-suffix generalisation and explicit awareness of determiner forms, determiner semantics, suffix forms, suffix semantics and determiner-suffix pairs were carried out for participants in the grammar-level semantics training condition. As shown by Table 34 participants' ability to generalize semantic associations with determiner-suffix pairs were correlated with explicit awareness of determiners and their semantic associations.

Table 34. Pearson's correlations between explicit awareness measures and determiner-suffix generalisation

Training Condition	Correlation	Degrees of Freedom	r statistic	p-value
Grammar-level Semantics	Determiner phonology and determiner-suffix generalisation	30	.426	.015
	Determiner semantic and determiner-suffix generalisation	30	.553	.001
	Suffix phonology and determiner-suffix generalisation	30	NA	NA
	Suffix semantics and determiner-suffix generalisation	30	NA	NA
	Determiner-suffix pairs and determiner-suffix generalisation	30	.210	.249

4.2.2 Discussion

In addition to evaluating the influence of semantic cues on participants ability to generalize phonological-distributional association, Experiment 3 addressed whether semantics as individual word meanings affects participants' learning of word forms and phonological-distributional associations. The competition model and discriminative learning do not predict how the presence of meanings which are not grammatical cues affects acquisition of phonological-distributional cues. The semantic binding hypothesis offers some predictions for how the presence of word meaning affects phonological-distributional associations in a language. The semantic binding hypothesis argues that individual word meanings are associated with word forms due to being encountered together and subsequently can support participants' learning of associations between sounds in the same word. This suggests that the inclusion of semantics in the form of word meanings enhances learning of word forms but it is unclear whether this would be expected to extend to enhanced learning of determiner-suffix associations when grouped with novel word stems. In Experiment 3, it was predicted that the inclusion of word meanings in the two semantic training conditions would enhance learning of word forms compared with participants in the grammar-level semantics condition.

Experiment 3 also addressed whether introducing word-picture matching tasks to training would enable participants to learn semantic associations for suffixes in the language. This was based on the poorer evidence of suffix-semantic generalisation observed in Experiments 1 and 2 when compared with performance in previous artificial language learning studies (Hickey, 2022; Mirković et al., 2021).

Experiment 3 found that participants trained with semantic cues were able to generalize phonological-distributional associations. In fact a mixed-effects linear regression found that omitting semantic cues during training had no significant effect on participants ability to generalize phonological-distributional cues. While this does not contradict the assumption that participants favour semantic cues over phonological-distributional ones, it does challenge blocking, suggesting that acquiring semantic cues doesn't interfere with subsequent learning of phonological-distributional ones.

When evaluating the findings of experiment 3 it is notable that while significantly above 0.5 in most conditions, participants performance on the phonological form generalisation task is relatively poor, with only a subset of participants actually endorsing pseudowords with consistent determiner-suffix pairings. This raises the concern that if omitting semantics does enhance learning of word forms, participants' generally poor generalisation of phonological-distributional cues across training

conditions could prevent differences in phonological form generalisation from emerging in experiment 3.

Experiment 3 also addressed the semantic binding hypothesis (Patterson et al., 1994; Pomper & Saffran, 2018; Savill et al., 2015, 2018), investigating how the presence of individual word meanings unrelated to grammatical class affected learning of word forms and phonological-distributional associations in the language. The semantic binding hypothesis asserts that the presence of semantics enhances learning of phonological associations within a word as they co-occur during learning and recall. In the context of an artificial language learning study this led to the prediction that omitting semantics in the phonological forms only condition would negatively affect learning of word forms. However, in contrast to our predictions participants across conditions demonstrated above chance awareness of word forms and there was no significant effect of omitting semantics on phonological form recognition.

Finally in experiment 3 it was observed that while participants trained with grammar-level semantics were able to generalize semantic associations to determiner-suffix pairs and determiners on their own, they were unable to generalize suffix-semantic associations in the language.

Across our previous experiments, participants have demonstrated generally poor performance on both the phonological form and semantic generalisation tasks. As an example of this, in experiment 3 comparisons between mean a' scores and 0.5 demonstrated that participants could generalize associations between phonological-distributional cues. However, this significant difference was driven by a subset of participants who endorsed consistent words more often than inconsistent words. When observing participants' individual performances on the task it was clear that many participants demonstrated performance at or below 0.5, showing that in practice many participants do not learn to associate phonological-distributional cues with each other regardless of their assigned training condition. When evaluating whether statistical learning tasks can be used to measure individual differences, Seigelman et al. (2016) observed that this was a consistent issue across statistical learning tasks. When evaluating various statistical learning tasks they noted that there is currently a reliance on group level differences when measuring statistical learning because when participants are observed individually most do not demonstrate significant evidence of statistical learning.

The finding that only a subset of participants are capable of statistical learning in generalisation tasks is contrary to the understanding of statistical learning as a broad mechanism which enables adults, children and infants to passively learn from their environment. To address this experiment 4

investigated whether the speeded shadowing task employed by Tamminen et al. (2012, 2015) could be to measure learning of phonological-distributional cues. As the speeded shadowing task does not require participants to make an explicit choice to endorse consistent or inconsistent pseudowords, it was predicted that participants may display greater awareness of phonological-distributional cues when repeating back consistent and inconsistent pseudowords.

4.3 Experiment 4

4.3.1 Introduction

Our previous experiments have addressed how the inclusion of semantics and semantic cues in a language will influence learning of phonological-distributional cues.

Following on from Experiment 3, Experiment 4 aimed to replicate the key findings from Experiment 3 and investigate whether participants' response times when repeating back pseudowords can be used to measure knowledge of word forms and phonological-distributional associations. As in the previous experiment, participants in Experiment 4 were split into three training conditions. Across conditions the participants were trained on a set of 24 pseudowords which included determiners and suffixes as phonological-distributional cues. In the phonological forms only condition participants were only trained on the pseudowords with no semantics available during training. In the grammar-level semantics condition each pseudoword was associated with a specific picture of an animal or artefact. Further the animacy of each word meaning was associated with determiner-suffix pairs. In the lexical semantics condition each word was associated with a specific picture of an animal or artefact, while each word had a specific meaning the animacy of each word's meaning was not associated with determiner-suffix pairings.

In Experiment 4, participants' learning of word forms and meanings was used to determine whether participants were able to learn trained words before testing whether they could generalize features from the training language to novel words. While the semantic binding hypothesis suggested that the inclusion of lexical or grammar-level semantics would enhance learning of familiar word forms, findings from Experiment 3 did not support this. Based on Experiment 3's findings it was predicted that across conditions participants would demonstrate knowledge of word forms and that in the two semantic conditions participants would be able to recognise familiar word meanings.

Experiment 4 used a phonological form generalisation task to measure learning of phonological-distributional cues. While the competition model and discriminative learning suggested that the inclusion of semantic cues in the grammar-level semantics condition would interfere with learning of

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phonological-distributional cues, findings from Experiment 3 did not support this. As such based on the findings from Experiment 3 it was predicted that participants across conditions would be able to generalize associations between phonological-distributional cues.

As in previous experiments, participants' learning of semantic cues was measured using three semantic generalisation tasks. Performance on the determiner-suffix and determiner generalisation tasks was used to investigate whether participants were reliably able to generalize semantic associations to the determiners. Following previous experiments, which showed no evidence of suffix-semantic generalisation, performance on the suffix generalisation task was of particular interest. Based on findings in Experiments 1, 2 and 3 it was predicted that participants would be able to generalize semantic associations to determiner-suffix pairs and suffixes but would be unable to do so for suffixes.

In addition to replicating key findings from Experiment 3, Experiment 4 addressed whether learning of trained word forms and associations between phonological-distributional cues could be measured using a speeded shadowing task based on Tamminen et al. (2012, 2015). In a meta-analysis of the statistical and implicit learning literatures Christiansen (2019) observed that while statistical learning is conceptualised as a passive process which produces implicit knowledge, decision making tasks require participants to demonstrate their implicit knowledge by making an explicit decision regarding the language. In addition to not directly measuring implicit knowledge, Siegelman et al. (2017) argues that decision making tasks may obscure subtler effects on implicit learning tasks due to their all or nothing nature. Taken together, these findings suggest that the phonological form recognition task and the generalisation tasks employed in the present study may not be sensitive enough to pick up on subtle differences in implicit knowledge elicited by manipulating cue availability during training. The speeded shadowing task employed by Tamminen et al. (2012, 2015) provides an alternative measure of word learning and generalisation of phonological-distributional cues which does not require participants to make explicit decisions during testing.

Tamminen et al. (2012) has demonstrated that when repeating back pseudowords, participants took less time to begin repeating back pseudowords which they had been exposed to during training compared with pseudowords which had familiar stems but novel affixes. They also demonstrated that when repeating back pseudowords with novel stems participants responded faster when the words had familiar affixes. In a later study Tamminen et al. (2015) trained participants on a language where each word had one of four suffixes (*-nule*, *-afe*, *-lomb*, *-esh*) and each suffix was associated with a semantic category (person, place, tool and cost). They found that when repeating back

sentences ending with the pseudowords, participants responded faster when repeating back sentences which had suffixes consistent with the semantic context provided by the sentence.

Taken together, these findings demonstrate that learners respond faster when repeating back pseudowords which align with the expectations they have formed based on the trained language. In Tamminen et al. (2012) learners responded faster when repeating back words with familiar stems and affixes. In Tamminen et al. (2015) learners responded faster when the suffix-semantic associations in novel words matched the suffix-semantic associations present in the training language.

Based on Tamminen et al. (2012, 2015), it was predicted that participants would respond faster when repeating back novel pseudowords which had determiner-suffix pairs consistent with the pairings in the training language. This would demonstrate that participants had acquired implicit knowledge of the associations between determiners and suffixes in the training language and that they recognised when novel words violated this association. It was also predicted that participants would respond faster when repeating back familiar pseudowords heard during training compared with novel pseudowords which had determiner-suffix pairs consistent with the training language. This would demonstrate that participants had learned individual word forms and recognised that a novel pseudoword was unfamiliar.

4.3.2 Methods

<u>Participants</u>

During recruitment, six participants were excluded from the study for not complying with instructions during training. The resulting sample was comprised of ninety-six monolingual, native English-speaking adults (39 males, 56 females, 1 non-binary; mean age= 25.59 range = 18-35) with no known language disorders. Participants had normal hearing and normal or corrected-to-normal vision. They were recruited from Prolific and participated in the study after providing informed consent. Each participant was paid £6 to take part in the study. The study was approved by the Ethics Committee at the Department of Psychology, University of York.

Like in Experiment 3, for every participant allocated to the grammar-level semantics condition one was assigned to the lexical semantics condition and one was assigned to the phonological forms only condition. After recruitment was complete, there were 31 participants in the grammar-level semantics condition, 32 in the lexical semantics condition and 33 in the phonological forms only condition.

Materials

Language training set

The training set in Experiment 4 was composed of the same 24 pseudowords used in Experiment 3. The animals and artefacts used as semantic referents in the lexical semantics and grammar-level semantics conditions also matched those used in Experiment 3. The three training conditions used in Experiment 4 were identical to those used in Experiment 3.

A set of 24 mismatched words were included in the language during training in the grammar-level and lexical semantics conditions to simulate statistical noise. As the number of exposures to the training language increased from 8 to 12 due to the two additional blocks of training in Experiment 4, the 24 mismatched items were divided between six blocks of training instead of four. As such during each block of training 4 mismatched items were heard twice, once during the repetition task and then a second time during the word-picture matching task.

Like in Experiment 3, the language was also counterbalanced in both semantic training conditions.

Generalisation sets

A total of 24 novel pseudowords were used across the generalisation tasks. The phonological form generalisation task used 12 novel pseudowords, 6 words had consistent determiner-suffix pairings while the other 6 paired determiners with suffixes from the opposite grammatical gender. The three semantic generalisation tasks employed for participants in the grammar-level semantics condition each used 4 novel pseudowords.

Speeded shadowing task

The speeded-shadowing task was used as an alternative to both the phonological form recognition and phonological form generalisation tasks. The speeded shadowing task measured implicit awareness of both individual word forms and phonological-distributional associations in the training language. However instead of employing decision making tasks to measure learning like the phonological form recognition and generalisation tasks, the speeded shadowing task measured whether there was a difference in response times when repeating back words with novel stems or inconsistent determiner-suffix pairings. Before the task began, participants were instructed to listen to each pseudoword and to repeat the word back as quickly and accurately as possible after they had heard it. Participants were also informed they would only have a few seconds to repeat each word before they would be moved onto the next trial.

During each trial, participants saw a fixation cross in the middle of the screen and were immediately played a pseudoword. Participants had 3000 ms to listen to the pseudoword and repeat it back before they were moved onto the next trial. In each trial, a 3000 ms recording was made of both the stimuli being played and of the participants repeating back the pseudoword. Like in Tamminen et al. (2012, 2015), response times were measured by comparing how many seconds it took for participants to begin repeating the word after the stimuli had started to play. This was done to account for the fact that participants would occasionally begin speaking before the stimulus had finished playing. Both the stimuli and the participants responses were captured in a single uninterrupted recording to ensure that we could reliably measure the time taken for participants to start speaking after the stimuli started to play without connection issues interfering with the recording. Participants did not receive any feedback on their responses during the speeded shadowing task.

A total of 24 pseudowords were used for the speeded shadowing task, presented over two blocks of repetitions. Semantics were omitted from the speeded shadowing task meaning no pictures were present during any of the word repetitions. The first of the two blocks consisted of 12 words taken from the 24-word training set. Of the trained words used in the speeded shadowing task, 6 began *tib-* and ended with *-eem* and 6 began with *ked-* and ended with *-ool*.

The second block of repetitions consisted of 12 novel pseudowords which used the same determiners (*tib-* and *ked-*) and suffixes (*-eem* and *-ool*) as the training language but used novel stems which hadn't been heard during training. The 12 novel words were further subdivided into 6 consistent and 6 inconsistent pseudowords. The consistent novel words had determiner-suffix pairings consistent with the training language (*tib-eem* and *ked-ool*) while the inconsistent novel pseudowords had determiner-suffix pairings which were not heard together during training (*tib-ool* and *ked-eem*).

Before comparing response times for different word types in the speeded shadowing task, individual responses were coded by the experimenter for accuracy. For these checks, successful repetitions of the played stimuli were coded as correct while instances where no speech was recorded or where words other than the target stimuli were spoken were coded as incorrect. Incorrect responses were excluded during data analysis and data from participants who did not respond correctly for at least 80% of the trials were excluded from the analysis.

Based on the novelty effect, if participants had learned a feature of the language such as word stems or determiner-suffix associations it would take them longer to repeat back words that break from

the language they are familiar with. As such, if participants response times were greater when repeating back consistent novel words compared to when they were repeating back trained words, it was taken as evidence that they had learned individual word forms from the training set. Similarly, if participants response times were greater when repeating back inconsistent novel words compared to consistent novel words, this was taken as evidence that they had generalized the association between determiners and suffixes in the training language.

Procedure

As illustrated in Figure 24, participants in all three training conditions completed six blocks of training and were tested after the third and sixth blocks were complete. After each block of training participants were allowed to take a break of up to five minutes but could move onto the next task earlier if they chose to. In all three conditions participants completed a phonological form recognition task after the third and sixth blocks of training and a phonological form generalisation task after six blocks of training. The phonological form recognition task and the phonological form generalisation task were used to measure learning of word forms and associations between phonological-distributional cues.

After the second phonological form recognition task, participants completed a speeded shadowing task. The speeded shadowing task presented participants with two blocks of items, the first block played participants 12 words heard during the training set while the second block played participants 6 novel pseudowords with consistent determiner-suffix pairings and 6 novel pseudowords with inconsistent determiner-suffix pairings. The order in which items were presented within each training block was randomised however the training block including only trained words was always presented before the training block containing only novel words.

The speeded shadowing task, measured participants' response times when repeating back trained pseudowords, novel pseudowords and novel pseudowords with inconsistent determiner-suffix pairings. Response times for different word types were compared to investigate whether participants demonstrated implicit knowledge of word forms and associations between phonological-distributional cues during word repetition. The speeded shadowing task was included alongside the phonological form recognition and generalisation tasks to investigate whether participants' implicit knowledge would be more apparent in a task which did not require participants to make explicit decisions regarding the language.

After six blocks of training, participants in the two semantic training conditions completed a 2AFC task and participants in the grammar-level semantics condition also completed three separate

semantic generalisation tasks. The 2AFC task and semantic generalisation tasks tested whether participants had learned trained words' meanings and were able to associate semantic cues with phonological–distributional cues respectively. The training and testing session lasted approximately 45 minutes and was completed in Gorilla.

Like in previous experiments participants were given an outline of what they would be doing before signing a digital consent form but were not informed of group assignments during the experiment. Information regarding age, gender and history of language disorders was obtained from a questionnaire before training began.

After three blocks of training	After six blocks of training
Phonological forms only	

Word Learning
    Phonological Form Recognition Task
	Word Learning
	    Phonological Form Recognition Task
	    2AFC Task
	
	Word and Grammar Learning
	    Speeded Shadowing Task
	
	Grammar Learning
	    Phonological Form Generalization Task

Lexical Semantics	

Word Learning
    Phonological Form Recognition Task
	Word Learning
	    Phonological Form Recognition Task
	    2AFC Task
	
	Word and Grammar Learning
	    Speeded Shadowing Task
	
	Grammar Learning
	    Phonological Form Generalization Task

Grammar-level Semantics	

Word Learning
    Phonological Form Recognition Task
	Word Learning
	    Phonological Form Recognition Task
	    2AFC Task
	
	Word and Grammar Learning
	    Speeded Shadowing Task
	
	Grammar Learning
	    Phonological Form Generalization Task
	    Suffix Generalization Task
	    Determiner Generalization Task
	    Determiner-Suffix Generalization Task

Figure 24. Tasks by Condition in Experiment 4

Participants' explicit knowledge of the associations present in the language was assessed after the final set of tasks using two questions. In the phonological forms only condition and lexical semantics condition, participants' responses were scored for awareness of the determiner phonology, suffix phonology and determiner-suffix pairings to reflect the complexity of the regularities present in the language.

As participants in the grammar-level semantics condition were trained on semantic cues in addition to phonological-distributional cues, their responses during debriefing were also scored for explicit awareness of determiner and suffix semantic associations. For a more detailed breakdown of how each explicit awareness measure was scored see the general method section.

Data analyses

All analyses reported below were performed in R.

The same analyses used in previous experiments were conducted to investigate levels of word learning and generalisation for participants in each training condition at each point in time. For all models a maximal model that was able to converge was produced using the buildmer package.

In the analyses of the phonological form recognition task, The effects of training condition and length of training were investigated using a mixed-effects logistic regression with accuracy coded as a binary outcome measure. Training condition and length of training were fixed factors. Training condition (phonological forms only= 0, lexical semantics= 1, grammar-level semantics= 2) was coded as a Helmert contrast, comparing performance for the lexical semantics condition against the grammar-level semantics condition for the first hypothesis and comparing performance in the phonological forms only condition against performance in the two semantic conditions for the second. Length of training (after three blocks of training= 0, after six blocks of training= 1) was coded as a repeated contrast. Random effects were included for both participants and test items.

For the 2AFC task, the effect of training condition was investigated using a mixed-effects logistic regression with accuracy coded as a binary outcome measure. Training condition was a fixed factor which was coded as a repeated contrast (lexical semantics= 0, grammar-level semantics= 1). Random effects were included for both participants and test items. A maximal model that was able to converge was produced using the buildmer package.

For the phonological form generalisation task, the effect of training condition was investigated using a linear regression with a' scores as the outcome measure and training condition as the fixed effect. Training condition (phonological forms only= 0, lexical semantics= 1, grammar-level semantics= 2)

was coded as a Helmert contrast, comparing performance for the lexical semantics condition against the grammar-level semantics condition for the first hypothesis and comparing performance in the phonological forms only condition against performance in the two semantic conditions for the second.

For the three semantic generalisation tasks, modelling was not used as generalisation of semantic cues was only tested after training was complete in the grammar-level semantics training condition.

In the analyses of explicit knowledge, the effect of training conditions on explicit knowledge of various associations present in the language was investigated using a series of linear regressions. Each model used participants' scores for an explicit awareness subtest as the outcome measure and training condition as the fixed effect. Training condition was coded as a Helmert contrast (phonological forms only= 0, lexical semantics= 1, grammar-level semantics= 2). The models investigated the effect of training condition on explicit awareness of: i) determiner phonology, ii) suffix phonology and iii) determiner-suffix pairs. Models were not produced for explicit awareness of determiner semantics or suffix semantics as only participants in the grammar-level semantics condition had the opportunity to learn them.

Following this Pearson's correlations were used to investigate whether there was a relationship between participants' ability to generalize phonological forms and explicit awareness measures. We looked for correlations with:

1. Determiner phonology
2. Suffix phonology
3. Determiner-suffix pairs

For the grammar-level semantics condition, correlations were also used to investigate whether there was a relationship between participants' ability to generalize semantic associations and explicit awareness measures. For the determiner-suffix generalisation task we looked for correlations with:

1. Determiner phonology
2. Determiner semantics
3. Suffix phonology
4. Suffix semantics
5. Determiner-suffix pairs

For the determiner generalisation task we looked for correlations with:

1. Determiner phonology

2. Determiner semantics

For the suffix generalisation task we looked for correlations with:

1. Suffix phonology
2. Suffix semantics

Repetition times for trained words, novel words and novel words with inconsistent determiner-suffix pairings were recorded during the speeded shadowing task after training was complete. Before analysis trials where participants failed to respond or did not respond with the correct pseudoword were excluded. Additionally, responses for two trials were excluded because the participant began to repeat the word as soon as it started playing. Results from 1 participant in the phonological forms only condition and 2 participants in the grammar-level semantics conditions were excluded from analysis of the speeded shadowing task as they failed to repeat the correct stimuli for at least 80% of the trials.

A linear mixed-effects regression was used to investigate whether participants' response times differed when repeating back pseudowords with novel stems or determiner-suffix pairings inconsistent with the training set. In the mixed effects linear regression, the outcome measure was participants' response times with training condition and word type as fixed effects. Training condition (phonological forms only= 0, lexical semantics= 1, grammar-level semantics= 2) was coded as a Helmert contrast, comparing performance for the lexical semantics condition against the grammar-level semantics condition for the first hypothesis and comparing performance in the phonological forms only condition against performance in the two semantic conditions for the second. Word type was coded using custom contrasts, which compared response times for novel pseudowords against trained pseudowords for the first hypothesis and inconsistent novel words against consistent novel words for the second hypothesis.

4.3.3 Results

<u>Word Learning</u>

Phonological form recognition was measured after three and six blocks of training for participants in all three training conditions. To investigate whether participants in each condition learned the word forms from training, one sample t-tests were used to compare the mean accuracy for familiar items against chance level (0.5).

Figure 25 illustrates participants' recognition of word forms after three and six blocks of training. One sample t-tests confirm that performance was significantly above chance for participants across conditions at both points in time (Phonological forms only, after three blocks of training: t(32)= 12.95, p<.001; after six blocks of training: t(32)= 28.25, p<.001; Lexical semantics, after three blocks of training: t(31)= 12.08, p<.001; after six blocks of training: t(31)= 25.87, p<.001; Grammar-level semantics, after three blocks of training: t(30)= 14.67, p<.001; after six blocks of training: t(30)= 31.06, p<.001; after three blocks of training: $M_{Phonological Forms Only}$= .88, $M_{Lexical Semantics}$= .87, $M_{Grammar-level Semantics}$= .87; after six blocks of training: $M_{Phonological Forms Only}$= .96, $M_{Lexical Semantics}$= .96, $M_{Grammar-level Semantics}$= .96).
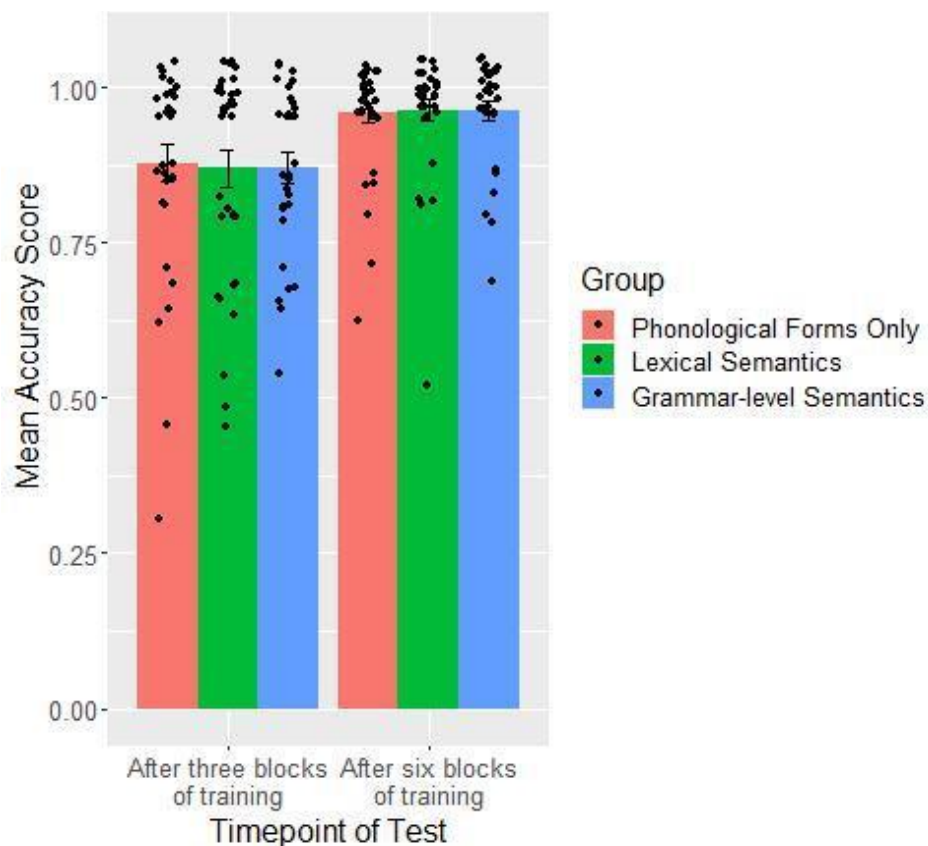
Figure 25. Accuracy (proportion correct) for the phonological form recognition task for participants trained with phonological forms only, lexical semantics and grammar-level semantics after three and six blocks of training.

A mixed-effects logistic regression was used to investigate the effects of training condition and length of training on the accuracy during the phonological form recognition task. Neither training condition nor length of training predicted performance on the phonological form recognition task. This suggests that the presence of semantics as individual word meanings or a grammatical cue did not affect word form recognition. The lack of significant interaction between training condition and

length of training demonstrates that increased exposure to the language did not lead to greater differences between training conditions.

Table 35. Regression coefficients for the fixed effects with accuracy as the binary outcome variable in the phonological form recognition task.

	Estimate	Std. Error	z-value	p-value
Lexical Semantics vs. Grammar-level Semantics	.080	.111	.727	.467
Phonological Forms Only vs. Grammar-level + Lexical Semantics	.083	.065	1.28	.199
Length of Training	.82	.455	1.81	.070
Length of Training x Lexical Semantics vs. Grammar-level Semantics	.024	.151	.158	.877
Length of Training x Phonological Forms Only vs. Grammar-level + Lexical Semantics	-.137	.086	-1.59	.111

Random effects included in the model: intercepts by items and participants.

Taken together these results show that participants were able to recognise word forms regardless of the presence of semantics and semantic cues by the third block of training. Further exposure to the training language did not have a significant positive effect on word form recognition although the direction of the difference in all three conditions between the two tests suggests there may have been a small positive effect. Across all three conditions and at each point in time participants' performance was noticeably close to ceiling suggesting that participants were able to recognise word forms quickly regardless of whether semantic cues were present.

Figure 26 illustrates participants' learning of word meanings after six blocks of training in the lexical semantics and grammar-level semantics training conditions. One sample t-tests confirmed that performance was significantly above chance for participants in both conditions after training was complete (Lexical semantics: $t(31)= 14.60$, $p<.001$; Grammar-level semantics: $t(30)= 4.97$, $p<.001$; Mean accuracy scores: $M_{Lexical Semantics}= ..80$, $M_{Grammar-level semantics}= .73$).
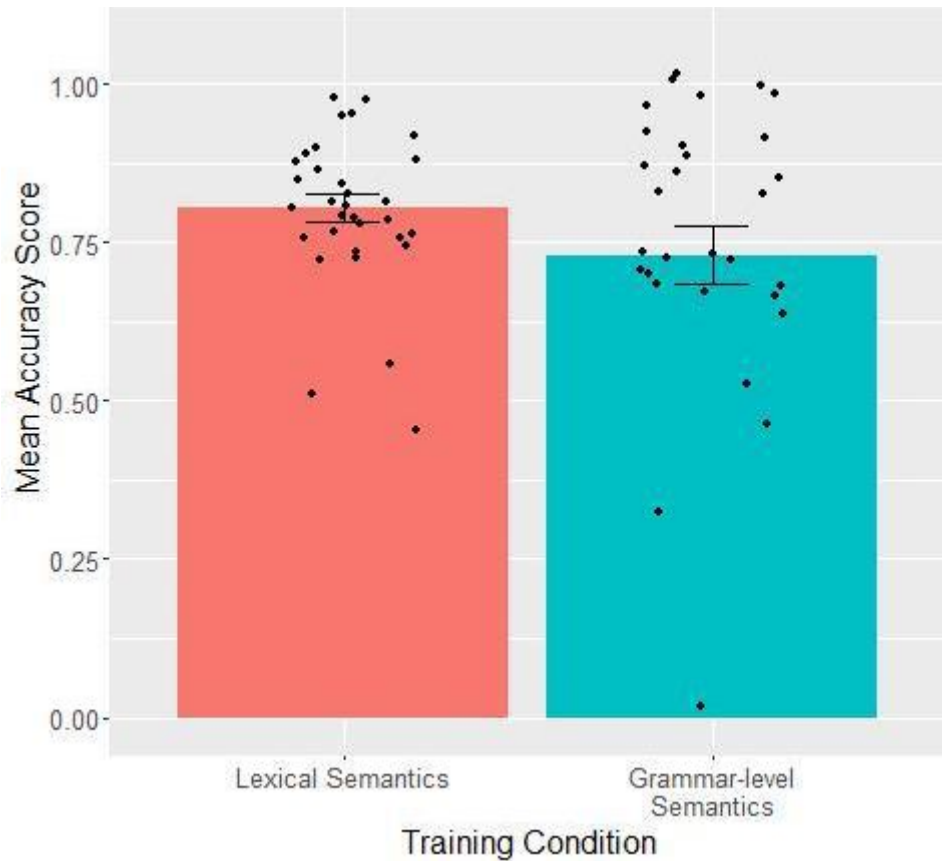
Figure 26. Accuracy (proportion correct) for the 2AFC task for participants in the grammar-level semantics and lexical semantics conditions after training is complete.

A mixed-effects logistic regression was used to investigate the effect of training condition on accuracy during the 2AFC task. As shown in Table 36, participants' recognition of word meaning did not differ based on whether semantics were available as individual word meanings or a grammatical cue in the language.

Table 36. Regression coefficients for the fixed effects with accuracy as the binary outcome variable in the 2AFC task.

	Estimate	Std. Error	z-value	p-value
Training Condition	-.348	.328	-1.05	.295

Random effects included in the model: intercepts by participants.

Taken together with the above chance performance in both conditions, this suggests that participants were able to learn word meanings during training regardless of whether semantics were associated with phonological-distributional cues.

Grammatical generalisation

Phonological form generalisation

The extent to which participants could generalise associations between phonological cues from training to novel words was measured after training was complete in all three training conditions. A' scores were calculated to measure the level of generalisation, with a' scores above 0.5 taken as evidence that participants could generalise determiner-suffix pairs to novel words.

Figure 27 illustrates how well participants in each training condition were able to generalise associations between phonological-distributional cues after training was complete. One sample t-tests found that a' scores were not significantly above 0.5 in any of the training conditions after training was complete (Phonological forms only: $t(32)= -2.12$, $p= .979$; Lexical semantics: $t(31)= .175$, $p= .431$; Grammar-level semantics: $t(30)= .042$, $p= .483$; A' scores: $M_{Phonological\ Forms\ Only}= .44$, $M_{Lexical\ Semantics}= .51$, $M_{Grammar-level\ Semantics}= .50$).
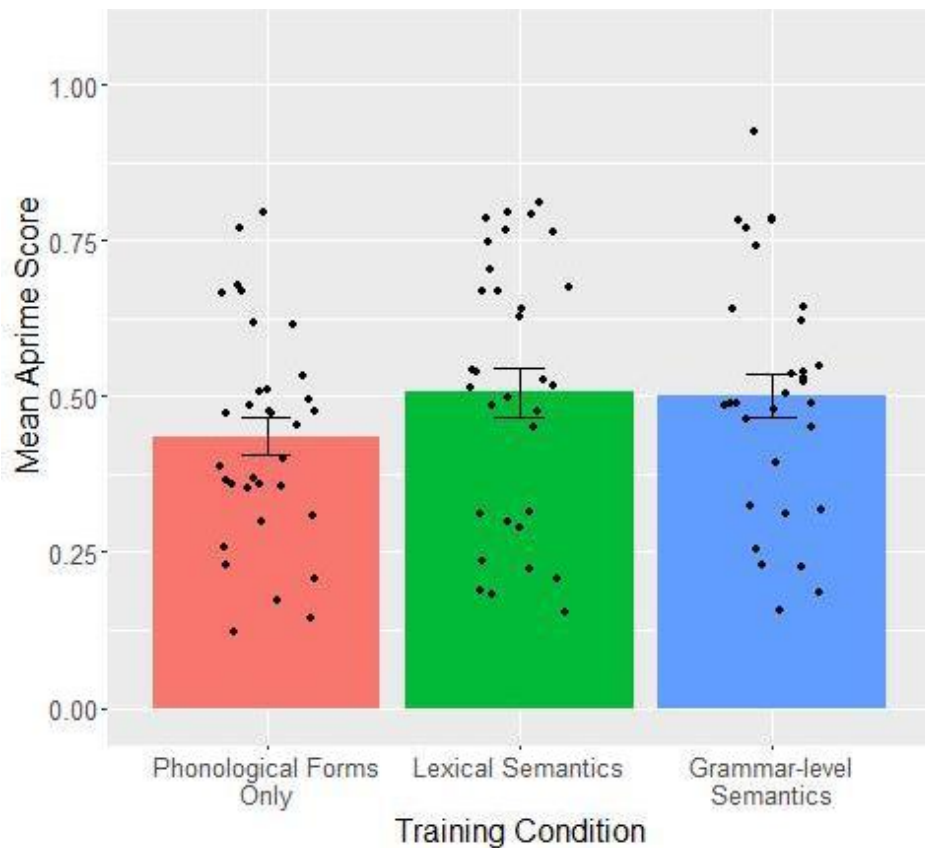
Figure 27. A' score on the phonological form generalisation task for participants in the phonological forms only, lexical semantics and grammar-level semantics training conditions.

A linear regression was used to investigate the effect of training condition on a' score in the phonological form generalisation task. Helmert contrasts found that generalisation of phonological-distributional associations did not differ between participants trained with grammar-level or lexical semantics, nor was there a difference between participants trained with and without semantics.

Table 37. Regression coefficients for the fixed effects with a' score as the outcome variable in the phonological form generalisation task.

	Estimate	Std. Error	t-value	p-value
Lexical Semantics vs. Grammar-level Semantics	.003	.025	.109	.913
Phonological Forms Only vs. Grammar-level + Lexical Semantics	-.023	.014	-1.60	.114

No random effects included in the maximal model

Taken together, these results suggest that participants across conditions were unable to generalize the association between determiners and suffixes to novel words after 12 exposures to the training language. This contrasts with performance in experiment 3, in which participants were able to generalize associations between determiners and suffixes after only 8 exposures to the training language.

Semantic generalisation

Participants' ability to generalize associations between semantic and phonological-distributional cues was tested after six blocks of training in the grammar-level semantics condition. Like in experiment 3, generalisation of semantic associations in the training language was not tested in the phonological forms only and lexical semantics conditions. A' scores were calculated to index the level of generalisation with a' scores above 0.5 being taken as evidence that participants were able to generalise an association to novel items.

Figure 28 illustrates the extent to which participants trained on grammar-level semantics could generalise semantic associations for determiner-suffix pairs, determiners and suffixes after six blocks of training. One sample t-tests confirm that participants' a' scores were significantly above 0.5 when generalizing semantics to determiner-suffix pairs. However, performance was not above 0.5 when generalizing semantics to determiners and suffixes individually (Determiner-Suffix Generalisation Task: $t(30)= 4.19$, $p<.001$; Determiner Generalisation Task: $t(30)= .727$, $p= .236$; Suffix Generalisation Task: $t(30)= -.607$, $p= .726$; A' scores: $M_{Determiner-Suffix Pairs}= .71$, $M_{Determiners}= .55$, $M_{Suffixes}= .47$).
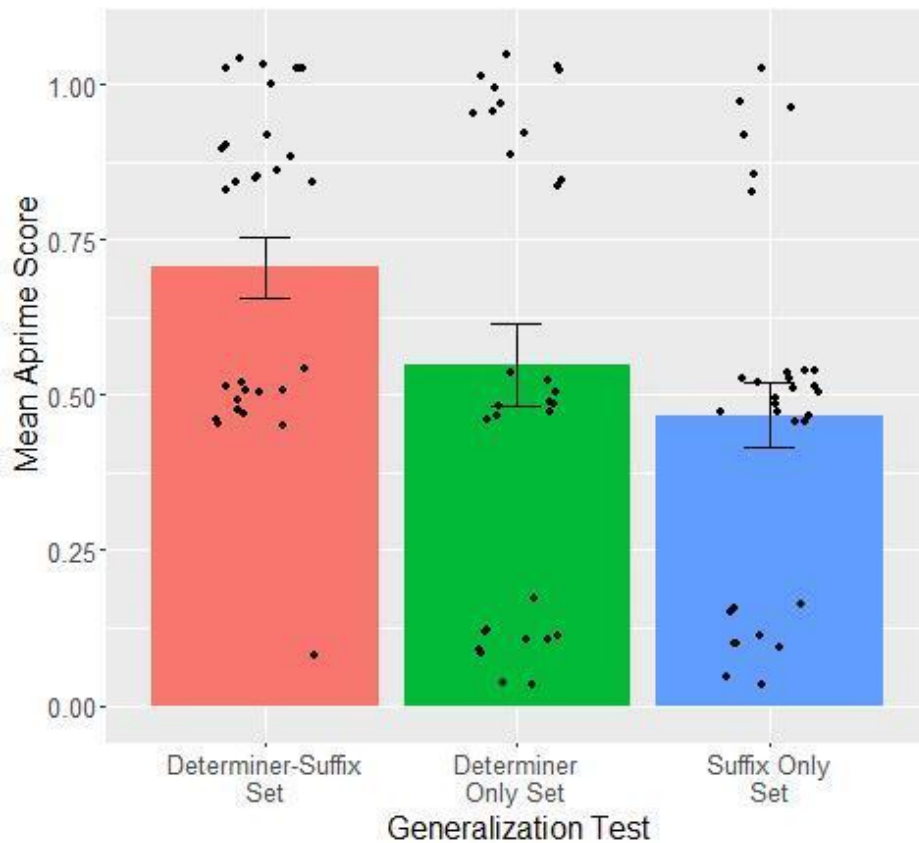
Figure 28. Performance on the determiner-suffix, determiner and suffix generalisation tasks for participants in the grammar-level semantics condition after six blocks of training.

These findings show that after eight exposures to the training language, participants were able to generalize semantic associations for determiner-suffix pairs but were unable to generalize associations for determiners and suffixes individually. These findings contradict experiment 3 in which participants were able to generalize semantic associations to determiners on their own. This also raises the question of how participants are able to associate semantic associations to determiner-suffix pairs without being able to do so for either component of the pairs.

Explicit awareness of grammatical cues

Explicit awareness was assessed after participants had completed both training and testing. In all three training participants responses were scored based on individual awareness of determiner forms, suffix forms and determiner-suffix pairs. As participants' in the grammar-level semantics condition were trained with both phonological-distributional and semantic cues, they were also scored for awareness of determiner-semantic and suffix-semantic associations.

Figure 29 illustrates the extent to which participants across both semantic training conditions were able to explicitly identify the phonological forms and determiner-suffix pairs in the training language. In both of the semantic training conditions participants showed some awareness of determiners but poor awareness of suffixes and determiner-suffix associations in the language. In the phonological forms only condition participants showed little awareness of phonological forms or associations between them after training was complete. These findings suggest that participants were unable to identify suffixes and subsequently were unable to associate them with determiners.
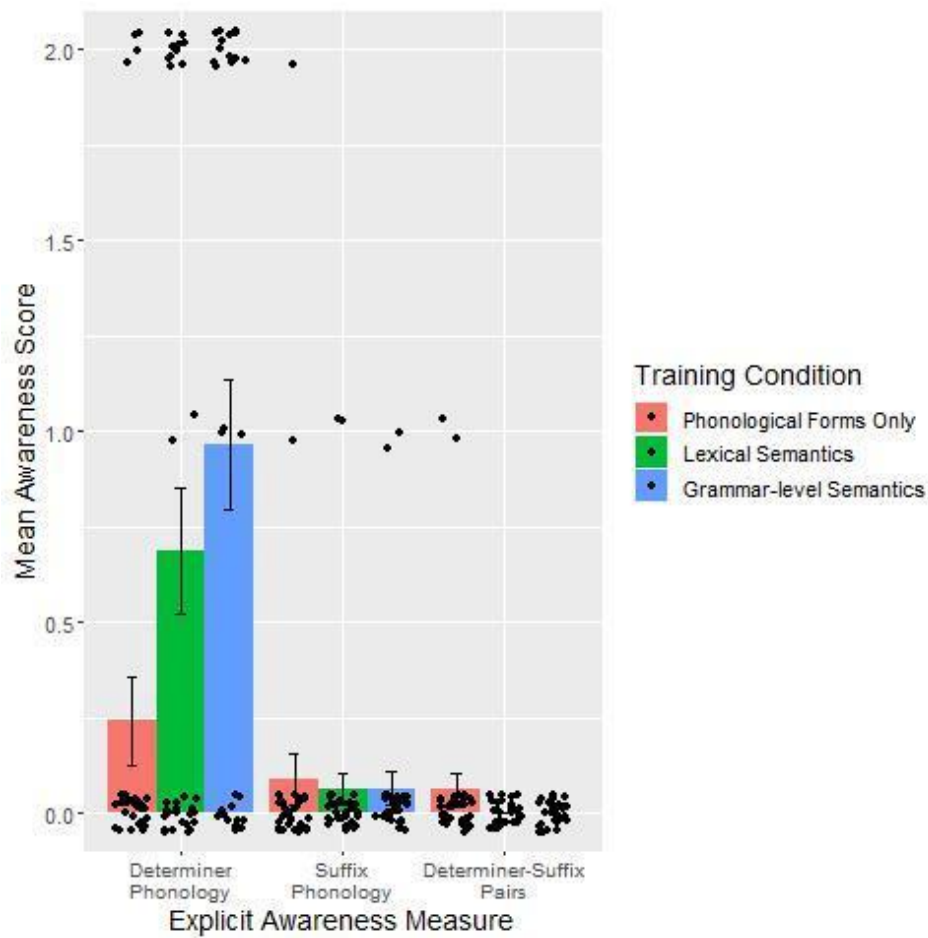
Figure 29. Mean explicit awareness scores for participants in the phonological forms only, lexical semantics and grammar-level semantics training conditions.

As shown in Table 38 participants' explicit awareness of determiners, suffixes and determiner-suffix pairs did not differ based on whether or not semantics served as a grammatical cue. However, while explicit awareness of determiner-suffix associations was not affected by the omitting semantics from training, awareness of individual phonological-distributional cues was. Omitting semantics from the

training language had a significant negative effect on participants' ability to explicitly identify both determiners and suffixes after training was complete.

Table 38. Linear regressions investigating training condition effects for each measure of explicit awareness.

Explicit Awareness Measure	Comparison	Estimate	Std. Error	t-value	p-value
Determiner Phonology	Lexical Semantics vs. Grammar-level Semantics	-.140	.108	-1.30	.196
	Phonological Forms Only vs. Grammar-level + Lexical Semantics	-.195	.061	-3.19	.002
Suffix Phonology	Lexical Semantics vs. Grammar-level Semantics	-.001	.038	-.027	.979
	Phonological Forms Only vs. Grammar-level + Lexical Semantics	.068	.032	2.11	.038
Determiner-Suffix Pairs	Lexical Semantics vs. Grammar-level Semantics	<.001	.017	0.00	1.00
	Phonological Forms Only vs. Grammar-level + Lexical Semantics	.020	.010	1.98	.050

No random effects included in the maximal models

Figure 30 illustrates the extent to which participants in the grammar-level semantics condition were able to explicitly identify the semantic associations for determiners and suffixes alongside their ability to identify determiners, suffixes and determiner-suffix pairs. Participants trained with semantics as a grammatical cue were able to identify semantic associations for determiners but not suffixes. Taken together with participants' greater ability to identify determiners in both semantic training conditions, this suggests that determiners were more likely to be learned than suffixes.
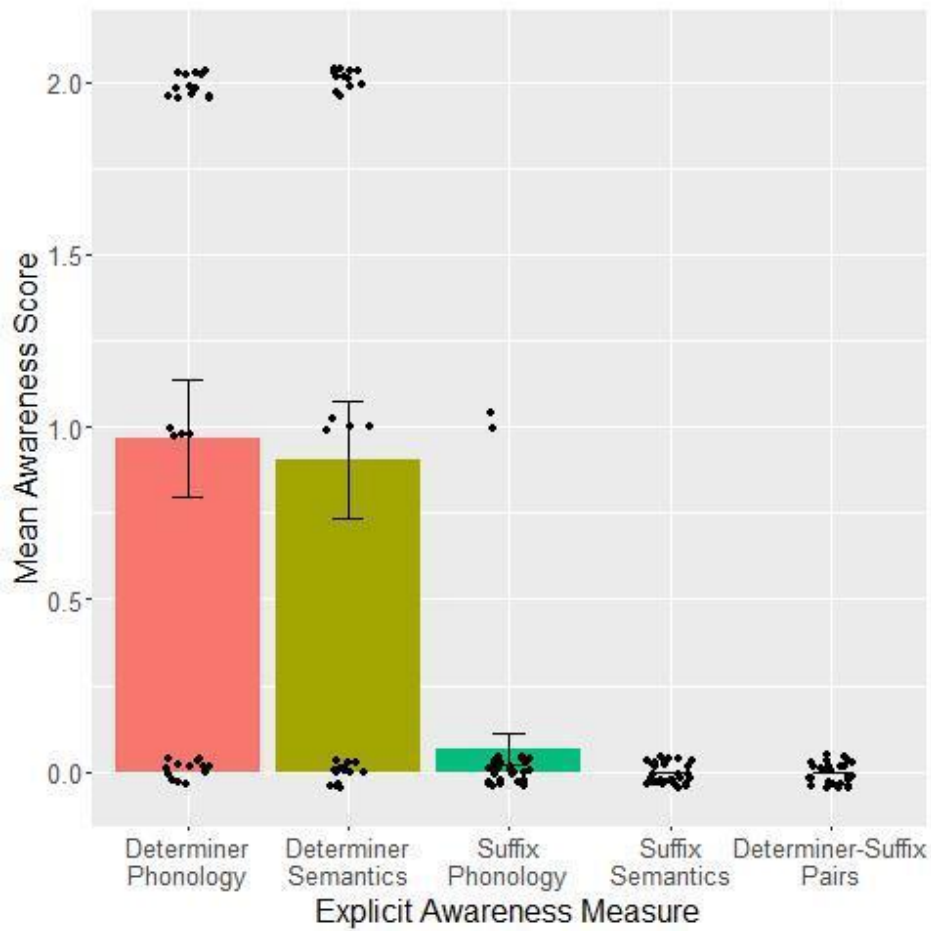
Figure 30. Mean explicit awareness scores for participants in the grammar-level semantics training condition.

Correlations between explicit awareness and generalisation

To investigate whether there was an association between explicit awareness and participants' ability to generalise semantic and phonological distributional cues several Pearson's correlations were conducted. Correlations between phonological form generalisation after training was complete and explicit awareness of determiner forms, suffix forms and determiner-suffix pairs were carried out for participants in each training condition. As seen in Table 39, there were no significant correlations between explicit awareness of phonological forms and performance in the phonological form generalisation task across conditions.

Table 39. Pearson's correlations between explicit awareness measures and phonological form generalisation

Training Condition	Correlation	Degrees of Freedom	r statistic	p-value

Phonological Forms Only	Determiner phonology and phonological form generalisation	31	-.075	.678
	Suffix phonology and phonological form generalisation	31	-.048	.793
	Determiner-suffix pairing and phonological form generalisation	31	-.236	.187
Lexical Semantics	Determiner phonology and phonological form generalisation	30	-.021	.909
	Suffix phonology and phonological form generalisation	30	-.077	.677
	Determiner-suffix pairing and phonological form generalisation	30	NA	NA
Grammar-level Semantics	Determiner phonology and phonological form generalisation	29	.156	.402
	Suffix phonology and phonological form generalisation	29	.098	.600
	Determiner-suffix pairing and phonological form generalisation	29	NA	NA

For the semantic generalisation tasks correlations between explicit awareness measures and generalisation of semantic associations were only conducted for participants in the grammar-level semantics training condition. Correlations were carried out between determiner-suffix generalisation and explicit awareness of determiner forms, determiner semantics, suffix forms, suffix semantics and determiner-suffix pairs. As shown by Table 40, there was an association between participants ability to generalize semantic associations with determiner-suffix pairs and their ability to verbalise determiner-semantic associations after training was complete.

Table 40. Pearson's correlations between explicit awareness measures and determiner-suffix generalisation

Training Condition	Correlation	Degrees of Freedom	r statistic	p-value
Grammar-level Semantics	Determiner phonology and determiner-suffix generalisation	29	.300	.101
	Determiner semantic and determiner-suffix generalisation	29	.500	.004
	Suffix phonology and determiner-suffix generalisation	29	.043	.817
	Suffix semantics and determiner-suffix generalisation	29	NA	NA
	Determiner-suffix pairing and determiner-suffix generalisation	29	NA	NA

For determiner generalisation, correlations were carried out to investigate whether there were any associations with explicit awareness of determiners and their semantic associations. As shown by Table 41, participants' ability to generalize determiner-semantic associations to novel items was associated with their ability to identify determiners and verbalise their semantic associations by the end of training.

Table 41. Pearson's correlations between explicit awareness measures and determiner generalisation

Training Condition	Correlation	Degrees of freedom	r statistic	p-value
Grammar-level Semantics	Determiner phonology and determiner generalisation	29	.693	<.001
	Determiner semantics and determiner generalisation	29	.848	<.001

For suffix generalisation, correlations were carried out to investigate whether there were any associations with explicit awareness of suffixes and their semantic associations. As shown by Table 42, participants' ability to generalize suffix-semantic associations to novel items was not associated with their ability to identify suffixes or verbalise their semantic associations. When evaluating this finding it is notable that only two participants were able to identify even one of the two suffixes during training and that neither participant was able to identify both.

Table 42. Pearson's correlations between explicit awareness measures and suffix generalisation

Training Condition	Correlation	Degrees of freedom	r statistic	p-value
Grammar-level Semantics	Suffix phonology and suffix generalisation	29	-.309	.090
	Suffix semantics and suffix generalisation	29	NA	NA

<u>Word form learning and phonological form generalisation in the speeded shadowing task</u>

Response times for different word types during the speeded shadowing task were measured after six blocks of training in all three training conditions. Figure 31 illustrates how long participants took to

begin repeating back trained words, novel words with consistent determiner-suffix pairs and novel words with inconsistent determiner-suffix pairs during the speeded shadowing task.
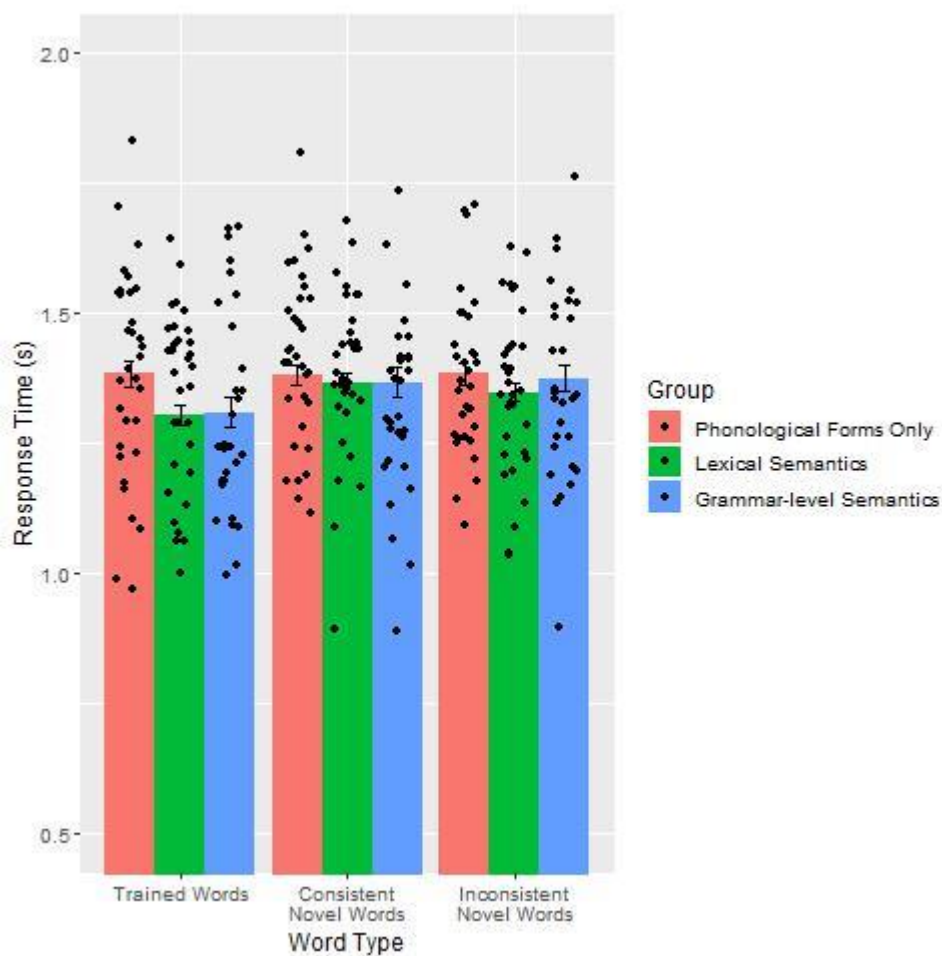
Figure 31. Response times (seconds) for the speeded shadowing task for participants trained with phonological forms only, lexical semantics and grammar-level semantics after six blocks of training.

A mixed-effects linear regression was used to investigate the effects of training condition and word type on response time during the speeded shadowing task. Across training conditions there was evidence that participants responded slower when repeating novel words (novel words vs. trained words). Participants in the two semantic conditions responded faster when repeating back pseudowords from the training set compared with novel pseudowords, as shown by the phonological forms only vs. semantics x novel words vs. trained words interaction.

The grammatical consistency of novel words did not predict response times in the regression (inconsistent novel words vs. consistent novel words). However, participants in the two semantic conditions did respond faster to inconsistent novel words than they did consistent novel words, as

shown by the phonological forms only vs. semantics x inconsistent novel words vs. consistent novel words interaction. This suggests that they recognised some difference between novel words based on whether they had consistent determiner-suffix pairs.

Table 43. Regression coefficients for the fixed effects with response time (ms) as the outcome variable in the speeded shadowing task.

	Estimate	Std. Error	t-value	p-value
Lexical Semantics vs. Grammar-level Semantics	-.006	.015	-.334	.739
Phonological Forms Only vs. Semantics	.012	.015	1.40	.160
Novel Words vs. Trained Words	.026	.011	2.34	.019
Inconsistent Novel Words vs Consistent Novel Words	.012	.013	.948	.343
Lexical Semantics vs. Grammar-level Semantics x Novel Words vs. Trained Words	-.003	.004	-.846	.398
Phonological Forms Only vs. Semantics x Novel Words vs. Trained Words	-.013	.002	-6.28	<.001
Lexical Semantics vs. Grammar-level Semantics x Inconsistent Novel Words vs. Consistent Novel Words	-.007	.004	-1.72	.086
Phonological Forms Only vs. Semantics x Inconsistent Novel Words vs. Consistent Novel Words	-.005	.002	-2.23	.026

Random effects included in the model: intercepts by items and participants.

4.3.4 Discussion

Experiment 4 investigated the effect of semantic cues on learning of word forms and associations between phonological-distributional cues. Based on the competition model (Bates & MacWhinney, 1989; Culbertson et al., 2017) and discriminative learning (Arnon & Ramscar, 2012; Havron & Arnon, 2021; Ramscar et al., 2010; Ramscar & Port, 2016) the presence of semantic cues in a language interferes with learning of phonological-distributional cues in the same language. In contrast, the semantic binding hypothesis (Patterson et al., 1994; Pomper & Saffran, 2018; Savill et al., 2015,

2018) suggests that the presence of semantics as individual word meanings not tied to grammatical class enhance learning of word forms.

Following Experiment 3 it was observed that while participants were able to generalize phonological-distributional associations in two of the three training conditions, most participants were unable to generalize phonological-distributional associations. This raises the possibility that the inclusion of semantic cues does interfere with learning of phonological-distributional associations but that the difference caused by this cannot be observed using only a small subset of the participants. To address this Experiment 4 incorporated a speeded shadowing task, which could be used as an alternative measure of word form learning and generalisation of phonological-distributional cues. As the speeded shadowing task did not require participants to demonstrate their knowledge of phonological-distributional cues by making explicit judgements, it was predicted that more participants would demonstrate learning of phonological-distributional cues in the speeded shadowing task.

In line with previous experiments, participants in Experiment 4 were able to recognise trained words after three and six blocks of training. Participants in both semantic training conditions were also able to recognise word meanings. Contrary to the semantic binding hypothesis, a mixed effects logistic regression showed that omitting semantics from the training language had no significant effect on participants' ability to recognise word forms. The same regression also showed that participants' performance did not significantly improve between the third and sixth blocks of training. Like in previous experiments participants were able to learn trained words and associate them with meanings provided during training.

In the speeded shadowing task participants demonstrated learning of word forms by repeating back trained pseudowords faster than they did novel pseudowords. This is in line with findings for the phonological form recognition task which also found that participants were able to recognise word forms across training conditions. Notably in line with the semantic binding hypothesis, participants trained with semantics responded faster for trained pseudowords than novel pseudowords while participants trained without semantics showed no evidence of word form learning.

In contrast to Experiment 3, participants in Experiment 4 were unable to generalize associations between phonological-distributional cues across conditions in any of the training conditions. Taken together with the poor performance on the phonological form generalisation task observed across our experiments, this suggests that participants may struggle to associate phonological-distributional cues with each other. Contrary to the competition model and discriminative learning, a linear mixed-

effects regression found that omitting semantic cues had no significant effect on participants ability to generalize phonological-distributional cues. Alongside Experiment 3's findings these results show that omitting semantics and semantic cues does not enable participants to generalize phonological-distributional cues.

Similarly during the speeded shadowing task, participants did not respond faster when repeating back pseudowords with consistent determiner-suffix pairings compared with pseudowords which had inconsistent determiner-suffix pairings. Notably, interactions in a mixed-effects linear regression showed that participants' response times for consistent and inconsistent items did differ in the semantic training conditions but not in the phonological forms only condition. This contradicts the competition model and discriminative learning by suggesting that the inclusion of semantics and semantic cues enhanced participants' awareness of phonological-distributional associations in the language. When evaluating these findings it is notable that there was no significant difference based on only the inclusion of semantic cues and that contrary to the congruency effect participants response times in the semantic conditions was faster when repeating back inconsistent pseudowords.

During the semantic generalisation tasks participants in the grammar-level semantics condition were able to generalize semantic associations to determiner-suffix pairs, but were unable to generalize semantics to determiners and suffixes separately. This is in line with our previous experiments which also demonstrated that participants were unable to generalize suffix-semantic associations. Taken together these findings suggest that participants are either unable to learn suffixes or are unable to associate them with semantic cues. Participants inability to generalize determiner-semantic associations in experiment 4 contrasts our previous experiments which found that participants were able to do so.

Measures of explicit awareness are in line with implicit knowledge demonstrated in the generalisation tasks. While some participants in the semantic training conditions were able to explicitly identify determiners in the training language, very few were able to identify suffixes or determiner-suffix pairings. Notably linear regressions investigating how the presence of semantics and semantic cues affect explicit awareness showed that omitting semantics from the language enhanced explicit awareness of suffixes and determiner-suffix pairings but had a negative effect on participants ability to identify determiners.

Overall, it is unclear based on experiment 4 whether participants are able to generalize phonological-distributional cues in the training language which in turn complicates the question of

whether semantic cues interfere with learning of phonological-distributional cues. While experiment 3 found that participants were able to generalize phonological-distributional cues, experiment 4 was unable to replicate this finding and in the speeded shadowing task participants similarly showed no knowledge of determiner-suffix associations. While there is ambiguity regarding participants' ability to generalize associations between phonological-distributional cues, it is clear that omitting semantics from the training language did not enable learning of phonological-distributional cues.

In regards to the semantic binding hypothesis, experiment 4 provides some evidence that the inclusion of semantics in the training language can enhance learning of word forms. While this was not apparent in the phonological form recognition task, the speeded shadowing task demonstrates that participants responded faster to words with familiar stems in the semantic training conditions.

4.4 Discussion

Experiments 3 and 4 addressed whether the presence of semantics as individual word meanings and as grammatical cues interferes with learning of phonological-distributional cues during language acquisition and whether associating words with individual meanings supports learning of word forms. These questions are addressed in both experiments, however Experiment 4 also addresses whether speeded shadowing can be used as an alternative measure of word form learning and phonological-distributional generalisation which does not require participants

Competition between semantic and phonological-distributional cues

Based on the competition model (Bates & MacWhinney 1989; Culbertson et al., 2017) and discriminative learning (Arnon & Ramscar, 2012; Havron & Arnon, 2021; Ramscar et al. 2010; Ramscar & Port, 2016) when semantic and phonological-distributional cues are available in a language, participants favour semantics as they are available earlier and can be used to predict individual word stems. Based on blocking (Kamin, 1969), after learning a semantic cues learners will block out phonological-distributional cues as they do provide additional information which can be used to make predictions. Within these theories semantics as individual word meanings and semantics as cues for grammatical class are often treated interchangeably. The competition model generally asserts that semantics compete as a cue for grammatical class and as such, based on the competition model the presence of semantics as a cue interferes with learning of phonological-distributional cues but the presence of semantics tied to individual word meanings would not.

Previous studies seem to support this, participants trained on a language with semantic cues being unable to generalize phonological-distributional associations (Hickey, 2022; Mirković et al., 2021;

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Vujović et al., 2021) while participants trained on a language with individual word meaning not associated with grammatical classes have been able to (Frigo & McDonald, 1998; Gomez, 2002; Vuong et al., 2016). In Experiments 3 and 4 this led to the prediction that omitting semantic cues from the training language would enhance performance on the phonological form generalisation task. Additionally, it was predicted that participants trained with lexical semantics or phonological forms only would be able to generalise phonological-distributional associations while participants trained with grammar-level semantics would be unable to.

In Experiments 3 and 4 omitting semantics from the training language had no effect on performance in the phonological form generalisation task. Comparisons between participants trained on grammar-level or lexical semantics showed that omitting semantics as a cue of grammatical class had no effect on phonological form generalisation. Likewise, comparisons between the phonological form only condition and the two semantic training conditions showed that omitting semantics entirely also had no effect on phonological form generalisation.

Between Experiments 3 and 4 participants' ability to generalize phonological forms at all has proven inconsistent. In Experiment 3 participants in the phonological forms only and grammar-level semantics conditions demonstrated performance above 0.5 while participants in the lexical semantics condition were unable to do the same. In Experiment 4 participants across conditions did not demonstrate significant evidence of phonological-form generalisation.

In addition to the phonological form generalisation task Experiment 4 also employed a speeded shadowing task to measure learning of phonological-distributional associations. In the speeded shadowing task, longer response times when repeating back pseudowords with inconsistent determiner-suffix pairings was used to measure learning of phonological-distributional cues. While response times generally weren't longer for novel words, interactions found in the linear mixed-effects regression found that participants responded faster when repeating back inconsistent pseudowords in the two semantic training conditions. While this does seem to suggest some response from participants when determiner-suffix pairings are inconsistent, the direction of the difference does not match our prediction and the effect is quite small.

Taken together these findings suggest that the presence of semantic cues in the training language does not interfere with phonological-distributional cues. While this does contradict the competition model and discriminative learning it is worth noting that participants' generally poor level of learning of phonological-distributional associations in Experiments 3 and 4 may be preventing us from observing effects from including or omitting semantic cues.

Benefits from semantic associations for word form learning

According to the semantic binding hypothesis (Patterson et al., 1994), learners associate different sounds heard in the same word with each other and use these associations to recall words more accurately. Because word meanings co-occur with word forms during acquisition and recall learners will use semantics to bolster their recall of word forms. Studies investigating immediate serial recall have demonstrated that trained words which were associated with specific word meanings were recalled more accurately than trained words which had not been associated with a specific meaning (Pomper & Saffran, 2018; Savill et al, 2015, 2018).

In Experiments 3 and 4 this led to the prediction that the omitting semantics from the training language would enhance performance on the phonological form recognition tasks. In both experiments participants demonstrated above chance word learning across training conditions. Contrary to the semantic binding hypothesis, omitting semantics from the training language had no significant effect on learning of word forms in either experiment.

In Experiment 4 the speeded shadowing task was included as a second measure of word learning. In line with the findings for the phonological form recognition task, participants displayed awareness of trained word forms by repeating back trained words faster than they did novel words. In addition, interactions in the linear mixed-effects regression showed that the difference in response time was greater in the two semantic conditions compared with the phonological forms only condition. This supports the semantic binding hypothesis suggesting that during word repetition participants were able to recognise trained words if they were encountered with semantic associations during training.

Learning of determiners and suffixes

In Experiments 3 and 4 only participants in the grammar-level semantics condition were trained on a language in which animacy was associated with grammatical gender. As such only participants in the grammar-level semantics condition were tested on their ability to generalize associations between semantic and phonological-distributional cues. Based on Experiments 1 and 2 it was predicted that participants would be able to generalize associations between semantic cues and determiner-suffix pairs and determiners. While participants in Experiments 1 and 2 were unable to generalize suffix-semantic associations, one possibility raised at the end of Experiment 2 was that the inclusion of word-picture matching tasks as employed in Experiments 3 and 4 may enhance semantic generalisation.

In both Experiment 3 and 4 participants were able to generalize semantic associations to determiner-suffix pairs, however only participants in Experiment 3 were able to generalize semantic associations to determiners. In both experiments participants were unable to generalize semantic associations to suffixes. These findings are inconclusive regarding whether participants can generalize semantic association to determiners but generally we have found that participants can generalize semantic associations to the determiners. In contrast participants have been consistently unable to generalize suffix-semantic associations in our experiments.

Alongside the consistently poorer explicit awareness of suffixes found across our experiments this raises the concern that participants are unable to learn suffixes in our artificial language learning paradigm. When considered in relation to phonological form generalisation this raises the possibility that participants are unable to generalize associations between determiners and suffixes because they have not acquired prerequisite knowledge of suffixes in the training language.

Speeded shadowing task as a measure of phonological-distributional cue learning

Experiment 4 employed the speeded shadowing task alongside typical phonological form recognition and generalisation measures as an alternative way to measure learning of word forms and determiner-suffix associations. Compared with the phonological form recognition and generalisation tasks the speeded shadowing task does not require participants to display implicit knowledge through explicit decision making tasks. As such it was predicted that knowledge of the language and differences between training conditions would be more apparent in the speeded shadowing task.

In previous studies Tamminen et al. (2012, 2015) demonstrated that participants recognised trained word forms by showing that they repeated back trained words faster than untrained words. They also demonstrated that participants were able to learn of affixes (Tamminen et al., 2012) and associations between word meanings and affixes (Tamminen et al., 2015) by showing that participants took longer to respond when repeating back words which deviated from the training language. Based on Tamminen et al. (2012, 2015) it was predicted that participants would showcase learning of determiner-suffix associations by taking longer to repeat back words which had determiner-suffix pairings inconsistent with the training language. Alongside this it was predicted that they would showcase learning of word forms by taking longer to repeat back words with novel stems.

As discussed previously the speeded shadowing task showed some promise as an alternative measure of word form learning and phonological form generalisation. Like the phonological form recognition task, it found that participants were generally able to recognise familiar word forms.

Further it found a significant difference in word recognition caused by omitting semantics from the training language which was predicted by the semantic binding hypothesis but could not be found in the phonological form recognition task.

Like the phonological form generalisation task participants were unable to recognise when novel words had determiner-suffix pairings inconsistent with the training language. However, a significant interaction found during analysis showed that participants trained with semantics available during training responded faster when repeating back novel words with inconsistent determiner-suffix pairings. Compared with the phonological form generalisation task this appears to be evidence that the speeded shadowing task found an interaction that could not be observed in a more explicit decision making task. However, the direction of these findings contradicts the predictions made by Tamminen et al. (2012, 2015). Rather than participants processing words which are congruent with their understanding of the language faster like in Tamminen et al. (2012, 2015) they were instead quicker when repeating back inconsistent novel words. This inconsistency raises concerns about our ability to rely on the speeded shadowing task to analyse how manipulations during training affect participants' learning of word forms and cues.

Chapter 5. Competition between phonological-distributional cues in novel grammar learning.

5.1 Introduction

Experiments 3 and 4 addressed whether the presence of semantic cues interfere with learning of phonological-distributional cues by manipulating the whether semantics were available as individual word meanings and as grammatical cues across three conditions and comparing generalisation of phonological-distributional associations between conditions. In both experiments the competition model and discriminative learning predicted that when semantic cues were omitted from training, participants would learn the two phonological-distributional cues in the training language as they would no longer be outcompeted by the more relevant semantic cues. As such it was predicted that participants trained without semantics or semantic cues would be able to generalize associations between the two phonological-distributional cues. In contrast, it was predicted that participants trained with semantic cues present in the language would not be able to generalize the association between the two phonological-distributional cues.

Contrary to our predictions, in Experiments 3 and 4, the inclusion of semantics in the training language did not affect participants' ability to generalize associations between determiners and

suffixes. This leaves unresolved the question of why participants' perform poorly when generalizing associations between phonological-distributional cues in our studies. If semantic cues don't outcompete phonological-distributional cues for relevance then why weren't participants able to generalize the associations between phonological-distributional cues in previous studies using this paradigm and the majority of the experiments presented in this thesis.

Competition between determiners and suffixes

One possibility based on the competition model is that participants aren't able to associate determiners and suffixes because determiners are outcompeting suffixes for relevance as grammatical cues. Previous literature identified early availability (Arnon & Ramscar, 2012; Culbertson et al., 2017; Havron & Arnon, 2021) and how informative a cue is when predicting upcoming word sounds (Arnon & Ramscar, 2012; Havron & Arnon, 2021) as features which enable semantic cues to outcompete phonological-distributional cues for relevance. When considered as two separate phonological-distributional cues, determiners are heard before suffixes during word presentation and when making predictions narrow down the possible word stems which will follow. In contrast, as the last sound heard in each word suffixes are the last available cue and cannot be used to make predictions about the word. As such participants may be blocking out suffixes in favour of determiners.

The cohort model of spoken word-recognition (Marslen-Wilson, 1987) similarly argues that determiners have greater value as a predictor of word stems. The cohort model argues that when listening to speech there is a critical point where learners can predict the word being spoken based on previous information and the early phonological features of the word. According to the model, when anticipating upcoming words listeners access a cohort of potential words based on the sentence prior to the word and then select the appropriate word from that cohort based on the word's earliest phonological features.

In Marslen-Wilson et al. (1988) they found that when comparing recognition times for target words in the context of sentences and in isolation, participants were able to recognise words faster when the target word was heard in a sentential context. In the context of artificial language learning tasks this suggests that participants attend to sounds at the beginning of words, which lead to them favouring determiners over suffixes during training.

Taken together, discriminative learning and the cohort model both suggest that participants might favour determiners over suffixes as a cue of grammatical class. This is because when considered separately from suffixes, determiners are available earlier in each word and are more informative

when predicting word stems. In an artificial language learning context this would lead to participants learning determiners and their semantic associations while blocking out suffixes.

<u>Suffix learning in our previous experiments</u>

The results of Experiments 3 and 4 provide some evidence that as predicted by discriminative learning and the cohort model, participants have been learning determiners but not suffixes. Across Experiments 1-4 participants have been unable to generalize suffix-semantic associations in the language to novel words. In contrast, they have been able to generalize determiner-semantic associations in Experiments 1-3. Additionally, when measuring explicit awareness in the previous experiments participants have generally displayed far greater explicit awareness of determiners and their semantic association than suffixes.

Across Experiments 1-4 participants have been able to generalize associations between semantics and determiner-suffix pairs. In Experiments 1-4, generalisation was correlated with explicit awareness of determiner-semantic associations but not explicit awareness of suffix-semantic associations. This suggests that performance in the determiner-suffix generalisation task might in part be driven by awareness of determiner-semantic associations.

In our experiments participants have been unable to generalize suffix-semantic associations, however they have been able to in studies which only used suffixes as a phonological-distributional cue (Tamminen et al., 2015; Vujovic et al., 2021). This suggests that the omission of determiners may enable participants to learn associations for the suffixes. While these studies are not a direct comparison between participants trained with and without determiners their findings are in line with our predictions.

These results suggest that participants are learning determiners and their semantic associations to a greater extent than suffixes. Further, participants may not have acquired knowledge of the suffixes present in the training language during our first four experiments. This lines up with the competition model, suggesting that determiners outcompeted suffixes for relevance in the training language. As determiners were encountered earlier in each word, discriminative learning would suggest that suffixes were blocked out as they would be a redundant and less informative cue when compared to determiners.

<u>Rationale</u>

Experiments 5 and 6 address whether determiners and suffixes compete with each other for relevance as grammatical cues. Additionally, they address whether sequential presentation of cues,

with less favoured cues presented earlier in training, will enable participants to learn all of the associations present in the training language.

Experiment 5 investigated whether the presence of determiners in the training language interferes with learning of suffixes. After three blocks of training, a suffix generalisation task was used to investigate whether omitting the determiner from the training language enabled participants to learn associations between suffixes and animacy of word meaning. After six phases of training, suffix and determiner generalisation tasks were used to investigate whether sequential training of suffixes followed by determiners enabled participants to generalize semantic associations for both cues. A phonological form generalisation task was used to test whether delaying the inclusion of determiners in the training language enabled participants to generalize the association between determiners and suffixes.

Experiment 6 expanded on Experiment 5 by investigating whether sequential presentation of both the phonological-distributional cues and the semantic cue would enable participants to learn associations between determiners and suffixes in the language.

Based on previous literature, we hypothesise that participants might favour semantic cues over phonological cues as they are more salient (Culbertson et al., 2017), are available earlier during learning (Arnon & Ramscar, 2012; Culbertson et al., 2017; Havron & Arnon, 2021; Ramscar et al., 2010) and are a more informative predictor of upcoming stems (Arnon & Ramscar, 2012; Havron & Arnon, 2021; Ramscar et al., 2010). When comparing the two phonological-distributional cues in the training language participants similarly might favour determiners over suffixes. Taken together these suggest a hierarchy of grammatical cues. In the training language, animacy of word meaning might be at the top of this hierarchy, determiners below animacy and suffixes below both animacy and determiners.

Blocking (Kamin, 1969) suggests that when learning multiple grammatical cues participants might compare unlearned cues with cues that they have already learned, blocking out the unlearned cue if it is redundant. In Experiment 6, participants were trained in two conditions to assess a possible role for blocking. In the sequential condition, participants were trained on a language with only stems and suffixes for the first phase of training. Determiners were added in the second phase of training and semantics were added in the third. In the simultaneous condition semantics were present across all three phases of training. After nine blocks of training, participants' ability to generalize determiner-semantic, suffix-semantic and determiner-suffix associations were compared between

training conditions to investigate whether sequential presentation of all three cues enabled participants to learn all of the associations present in the training language.

5.2 Experiment 5

5.2.1 Introduction

Experiment 5 manipulated the phonological-distributional cues presented to participants during their initial exposure to the language via two training conditions. In the determiner-suffix training condition participants were exposed to a language in which each pseudoword had a determiner, stem and suffix. In the suffix only training condition participants were exposed to a language in which each pseudoword had a stem and suffix but the determiner was absent. Both conditions used the same 24 pseudoword stems, 12 for each grammatical class, with each grammatical class cued by determiners, suffixes and animacy of the pseudowords meaning.

Training was split into two phases. In the suffix only condition participants learned the language without the determiners for the first phase but trained with determiners during the second. In the determiner-suffix condition participants learned a language with determiners present during both phases of training.

After one phase of training, participants in the suffix only condition were exposed to suffixes and animacy as cues of grammatical class without determiners present in the language. Based on the competition model (Bates & MacWhinney, 1989, Culbertson et al., 2017) and discriminative learning (Arnon & Ramscar, 2012; Havron & Arnon, 2021; Ramscar et al., 2010; Ramscar & Port, 2016), this would enable participants to learn suffixes and generalize their associations as they would not be outcompeted for relevance by determiners during the first phase of training. In contrast, the competition model and discriminative learning argue that participants in the determiner-suffix training would learn determiners first as they are available earlier in each word and can be used to narrow down candidate stems. As such blocking (Kamin, 1969), as part of discriminative learning, argues that participants will not learn suffixes after acquiring determiners as they would be a redundant cue of grammatical class and could not be used to predict individual words.

Taken together this led to the prediction that participants in the suffix only condition would be able to generalize suffix-semantic associations while participants in the determine-suffix training condition would not. In line with our previous experiments it was also predicted that participants would demonstrate above chance performance on the 2AFC and phonological form recognition

tasks. This would demonstrate that six exposures to the training language would be sufficient to learn word forms and meanings.

During the second phase of training, participants in the suffix only condition were trained on suffixes and their semantic associations in the language and were then given the opportunity to learn determiners and their semantic associations. Based on blocking, participants in the suffix only condition would not block out determiners after learning suffixes as determiners provide additional predictive value by reducing uncertainty when predicting upcoming stems. As such, after the second phase of training it was predicted that participants in both conditions would be able generalize determiner-semantic associations. However, as participants in the determiner-suffix condition would continue to block out suffixes, only participants in the suffix only condition would be able to generalize suffix-semantic associations.

As participants in the suffix only condition would have the opportunity to learn both determiners and suffixes during training, it was predicted that only participants in the suffix only condition would be able to generalize determiner-suffix associations at the end of training.

Research questions

1. Will participants trained with only suffixes be able to generalize suffix-semantic associations after three blocks of training?
    a. Will participants trained with only suffixes be significantly more likely to generalize suffix-semantic associations than participants trained with both affixes?
2. Will participants trained with only suffixes during the first phase of training be able to generalize suffix-semantic associations after training is complete?
    a. Will participants trained with only suffixes during the first phase of training be significantly more likely to generalize suffix-semantic associations than participants trained with both affixes from the beginning of training?
3. Will participants trained with only suffixes during the first phase of training be able to generalize determiner-semantic associations after training is complete?
    a. Will participants' training condition significantly affect their ability to generalize determiner-semantic associations?
4. Will participants trained with only suffixes during the first phase of training be able to generalize determiner-suffix pairings after training is complete?

a. Will participants trained with only suffixes during the first phase of training be significantly more likely to generalize determiner-suffix pairings than participants trained with both affixes from the beginning of training?

5.2.2 Methods

<u>Participants</u>

During recruitment, eight participants were excluded from the study for not complying with instructions during training. The resulting sample was comprised of sixty monolingual, native English-speaking adults (38 males, 22 females; mean age = 22.28 range = 19-35) with no known language disorders. Participants had normal hearing and normal or corrected-to-normal vision. Participants were recruited from Prolific and participated in the study after providing informed consent. Each participant was paid £9.00 to take part in the study. The study was approved by the Ethics Committee at the Department of Psychology, University of York.

Participants were randomly allocated to one of two training conditions, for every participant allocated to the determiner-suffix condition one was assigned to the suffix only condition. After recruitment was complete, there were 29 participants in the determiner-suffix condition and 31 participants in the suffix only training condition.

<u>Materials</u>

Language training set

Participants were trained on a set of 24 pseudowords. Table 44 shows example word-picture pairs for each training condition and grammatical class in Experiment 5. The training language used in the determiner-suffix condition matches the language outlined in the general methods section. Pseudowords were composed of a determiner (*tib-* or *ked-*), a unique stem, and a suffix (*-eem* or *-ool*). Each pseudoword was associated with a specific animal or artefact and the animacy of the pictures was associated with one of two determiner-suffix pairs.

The same 24 word stems were used during the suffix only condition. However, in the first phase of training determiners were omitted from the training language. As such in the first phase of training each pseudoword consisted of a unique stem and a suffix (*-eem* or *-ool*). Each pseudoword was associated with a specific animal or artefact and the animacy of the picture was associated with one of two suffixes. During the second phase of training participants in the suffix only condition were trained on the same language used throughout the determiner-suffix condition.

Table 44. Example stimuli for each training condition

Training Condition	Determiner-suffix Condition		Suffix Only Condition	
	Animal Word	Artefact Word	Animal Word	Artefact Word
First Phase of Training	tib-zeap-eem	ked-cass-ool	zeap-eem	cass-ool
Second Phase of Training	tib-zeap-eem	ked-cass-ool	tib-zeap-eem	ked-cass-ool

A set of 24 mismatched items were created which paired trained pseudowords with an incorrect trained picture to simulate statistical noise in natural language acquisition. Mismatched pictures matched the grammatical class of the pseudoword but displayed a different animal or artefact. Each of the six training blocks presented participants with mismatched items for 4 trials. Participants encountered each of the 24 mismatch items once over the course of training.

Generalisation sets

A total of 44 novel pseudowords were used across the generalisation tasks. Each novel pseudoword in the semantic generalisation tasks was presented alongside a novel picture of an animal or artefact.

The phonological form generalisation task used 12 novel pseudowords. There were 6 consistent pseudowords which had determiner-suffix pairings consistent with the training set, of these 3 words paired *tib-* with *-eem* and 3 paired *ked-* with *-ool*. Inconsistent pseudowords paired determiners with suffixes from the opposite grammatical gender. Of the 6 inconsistent pseudowords, 3 paired *tib-* with *-ool* and 3 paired *ked-* with *-eem*.

A total of 32 novel pseudowords were used across the semantic generalisation tasks. The two suffix generalisation tasks each used 8 novel pseudowords. The determiner and determiner-suffix generalisation tasks each used 8 novel pseudowords. As outlined in the general methods section

consistent items in each task had determiner-suffix pairs which matched the animacy of their assigned picture, while inconsistent items varied between each test.

For the suffix generalisation task conducted after the first phase of training, determiners were omitted from the eight novel words used to test participants in the suffix only condition. This was done to match the language participants in the suffix only condition were trained on in the first phase of training.

Procedure

As illustrated in Figure 32, participants in both conditions completed two phases of training. Participants were tested after each phase of training was complete. The training and testing session lasted approximately 60 minutes. All training tasks and tests were presented using the platform Gorilla.

Before training participants were given an outline of what would be expected of them during the experiment, after which they signed a digital consent form and answered questions regarding their age, gender and whether they had a history of language disorders. Participants completed a sound and microphone test, to confirm that they would be able to hear pseudowords during the experiment and that their repetitions would be picked up by their speaker during training. Participants were not given any information on group assignments prior to or during the experiment.

First phase of training	Second phase of training

Training
Repetition and Word-Picture Matching Task
    3 Blocks of 24 trained pseudowords
	Training
	Repetition and Word-Picture Matching Task
	    3 Blocks of 24 trained pseudowords

Testing
Word Learning
    Phonological Form Recognition Task
    2AFC Task
	Testing
	Word Leaning
	    Phonological Form Recognition Task
	    2AFC Task

Grammar Learning
    Suffix Generalization Task
	Grammar Learning
	    Phonological Form Generalization Task
	    Suffix Generalization Task
	    Determiner Generalization Task
	    Determiner-Suffix Generalization Task

Figure 32. Experiment Design and Tasks

There were two phases of training. Each phase of training consisted of three blocks of 24 trained and 4 mismatched words. For each trial a picture of an animal or artefact appeared in the middle of the

screen before a pseudoword was played which participants were instructed to repeat back. After repeating the pseudoword, participants were played the word again and asked to choose either a smiley or a sad face to indicate whether they believed the word and picture went well together. After repeating back each block of 24 trained pseudowords participants were allowed to take a break of up to five minutes but could move onto the next task earlier if they chose to.

After the second phase of training participants in both training conditions had been exposed to the training set three times and had been exposed to the mismatched items once split between the second and third phases of training. Participants in the simultaneous condition had been exposed to pseudowords with semantic referents three times while participants in the sequential condition had been exposed to pseudowords three times, twice with semantic referents and once without.

After the first phase of training participants in both conditions had been exposed to the training set six times. After the second phase of training participants in both conditions had been exposed to the training set twelve times.

After the first phase of training participants completed a phonological form recognition task and a phonological form generalisation task which tested participants' learning of word forms and determiner-suffix associations respectively. They also completed a suffix generalisation task which tested learning of suffix-semantic associations. Following the second phase of training, participants completed a set of word-learning (phonological form recognition and 2AFC) and generalisation tasks (phonological form generalisation, determiner-only, suffix-only and determiner-suffix)

Like in previous Experiments, explicit knowledge of the associations present in the language was assessed using two questions after the final set of tests. The responses for both questions were scored together for awareness of the determiners, determiner-semantic associations, the suffixes, suffix-semantic associations and determiner-suffix pairs to reflect the complexity of the regularities present in the language. For a more detailed breakdown of how each explicit awareness measure was scored see the general method section.

Data analyses

All analyses reported below were performed in R.

The same analyses used in previous experiments were conducted to investigate levels of word learning and generalisation for participants in each training condition at each point in time. For all models a maximal model that was able to converge was produced using the buildmer package.

In the analyses of the phonological form recognition task, the effects of training condition and length of training were investigated using a mixed-effects logistic regression with accuracy coded as a binary outcome measure. Training condition and length of training were fixed factors. Both training condition (determiner-suffix= 0, suffix only= 1) and length of training (after one phase of training= 0, after two phases of training= 1) were coded as repeated contrasts. Random effects were included for both participants and test items.

For analyses of the 2AFC task, the effect of training condition and length of training were investigated using a mixed-effects logistic regression with accuracy coded as a binary outcome measure. Training condition and length of training were fixed factors. Both training condition (determiner-suffix= 0, suffix only= 1) and length of training (after one phase of training= 0, after two phases of training= 1) were coded as repeated contrasts. Random effects were included for both participants and test items.

In the analyses of phonological form generalisation, the effect of training condition was investigated using a linear regression with a' scores as the outcome measure and training condition as the fixed effect. Both training condition (determiner-suffix= 0, suffix only= 1) and length of training (after one phase of training= 0, after two phases of training= 1) were coded as repeated contrasts. Participants were included as a random effect.

For analyses of suffix generalisation, the effects of training condition and length of training were investigated using a linear mixed-effects model with a' scores as the outcome measure. Training condition (determiner-suffix= 0, suffix only= 1) and length of training (after one phase of training= 0, after two phases of training= 1) were coded as repeated contrasts. Participants were included as a random effect.

For the determiner and determiner-suffix generalisation tasks, the effect of training condition was investigated using a linear regression with a' scores as the outcome measure and training condition as the fixed effect.

In the analyses of explicit knowledge, the effect of training conditions on explicit knowledge of various associations present in the language was investigated using a series of linear regressions. Each model used participants' scores for an explicit awareness subtest as the outcome measure, training condition as the fixed effect and participants as a random effect. The models investigated the effect of training condition on explicit awareness of: i) determiner phonology, ii) determiner semantics, iii) suffix phonology, iv) suffix semantics and v) determiner-suffix pairs.

Following this Pearson's correlations were used to investigate whether there was a relationship between each generalisation measure at the end of training and relevant explicit awareness measures. For the phonological form generalisation task, we looked for correlations with:

1. Determiner phonology
2. Suffix phonology
3. Determiner-suffix pairs

For the determiner-suffix generalisation task we looked for correlations with:

1. Determiner phonology
2. Determiner semantics
3. Suffix phonology
4. Suffix semantics
5. Determiner-suffix pairs

For the determiner generalisation task we looked for correlations with:

1. Determiner phonology
2. Determiner semantics

For the suffix generalisation task we looked for correlations with:

1. Suffix phonology
2. Suffix semantics

5.2.3 Results

Word learning

Phonological form recognition was measured after three and six blocks of training for participants in the determiner-suffix and suffix only training conditions. To investigate whether participants in each condition learned the word forms from training, one sample t-tests were used to compare the mean accuracy for familiar items against chance level (0.5).

Figure 33 illustrates participants' accuracy in this task after three and six blocks of training. One sample t-tests confirm that performance was significantly above chance for participants in both training conditions at both points in time (Determiner-Suffix, after three blocks of training: $t(28)=$ 14.49, $p<.001$; after six blocks of training: $t(28)=$ 17.28, $p<.001$; Suffix Only, after three blocks of

training: t(30)= 22.74, p<.001; after six blocks of training: t(30)= 30.24, p<.001; after three blocks of training: M_{Determiner-Suffix}= .93, M_{Suffix Only}= .92; after six blocks of training: M_{Determiner-Suffix}= .92, M_{Suffix Only}= .97).

Figure 33. Accuracy (proportion correct) for the phonological form recognition task for participants in the determiner-suffix and suffix only conditions after three and six blocks of training.

A mixed-effects logistic regression was used to investigate the effects of training condition and length of training on the accuracy during the phonological form recognition task. As shown in Table 45 there were no significant effects for training condition or length of training in the model. Additionally there was no significant interaction between training condition and length of training.

Table 45. Regression coefficients for the fixed effects with accuracy as the binary outcome variable in the phonological form recognition task.

	Estimate	Std. Error	z-value	p-value
Training Condition	-.008	.706	-.008	.993
Length of Training	-.080	.981	-.082	.935
Training Condition X Length of Training	1.16	.982	.712	.477

No random effects included in the maximal model

Taken together these results show that participants were able to recognise word forms in both training conditions after three blocks of training. Further training did not lead to improvements in word form recognition and there was no effect of training conditions on word form learning. Across both training conditions and at each point in time participants' performance was noticeably close to ceiling. In sum, these results demonstrate that participants in both training conditions learned the phonological forms well and to the same level. Participants learned phonological forms to this level after only six exposures to the language.

Figure 34 illustrates the participants' learning of word meaning after three and six blocks of training using the 2AFC task. One sample t-tests confirm that performance was significantly above chance for participants in both training conditions (Determiner-Suffix, after three blocks of training: $t(28)= 6.28$, $p<.001$; after six blocks of training: $t(28)= 10.10$, $p<.001$; Suffix-Only, after three blocks of training: $t(30)= 17.42$, $p<.001$; after six blocks of training: $t(30)= 14.98$, $p<.001$; after three blocks of training: $M_{Determiner-Suffix}= .71$, $M_{Suffix Only}= .86$; after six blocks of training: $M_{Determiner-Suffix}= .80$, $M_{Suffix Only}= .88$).

Figure 34. Accuracy (proportion correct) for the 2AFC task for participants in the determiner-suffix and suffix only conditions after three and six blocks of training.

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A mixed-effects logistic regression was used to investigate the effects of training condition and length of training on accuracy during the 2AFC task. As shown in Table 46 there were no significant effects for training condition or length of training in the model. Additionally, there was no significant interaction between training condition and length of training.

Table 46. Regression coefficients for the fixed effects with accuracy as the binary outcome variable in the 2AFC task.

	Estimate	Std. Error	z-value	p-value
Training Condition	.920	.662	1.389	.165
Length of Training	.462	.618	.748	.455
Training Condition X Length of Training	-.294	.979	-.301	.763

No random effects included in the maximal model

Taken together with the above chance performance in both conditions at both points in time, this shows that participants in both training conditions were able to learn the meaning of trained words after three blocks of training. Further training did not lead to improvements in participants' learning of word meaning and training condition had no effect on learning of word meaning.

Grammatical generalisation

Phonological form generalisation

The extent to which participants could generalise the distributional-phonological cues from training to novel words was measured after six blocks of training in both conditions. A' scores were calculated to measure the level of generalisation, with a' scores above 0.5 taken as evidence that participants could generalise determiner-suffix pairings to novel items.

Figure 35 illustrates participants' ability to generalise associations between the two phonological-distributional cues from training to novel words in both training conditions after six blocks of training. One sample t-tests confirm that participants in both training conditions had a' scores significantly above 0.5 after training was complete (Determiner-Suffix: $t(28)= 2.11$, $p= .022$; Suffix Only: $t(30)= 3.31$, $p= .001$; A' scores: $M_{Determiner-Suffix}= .58$, $M_{Suffix Only}= .63$).
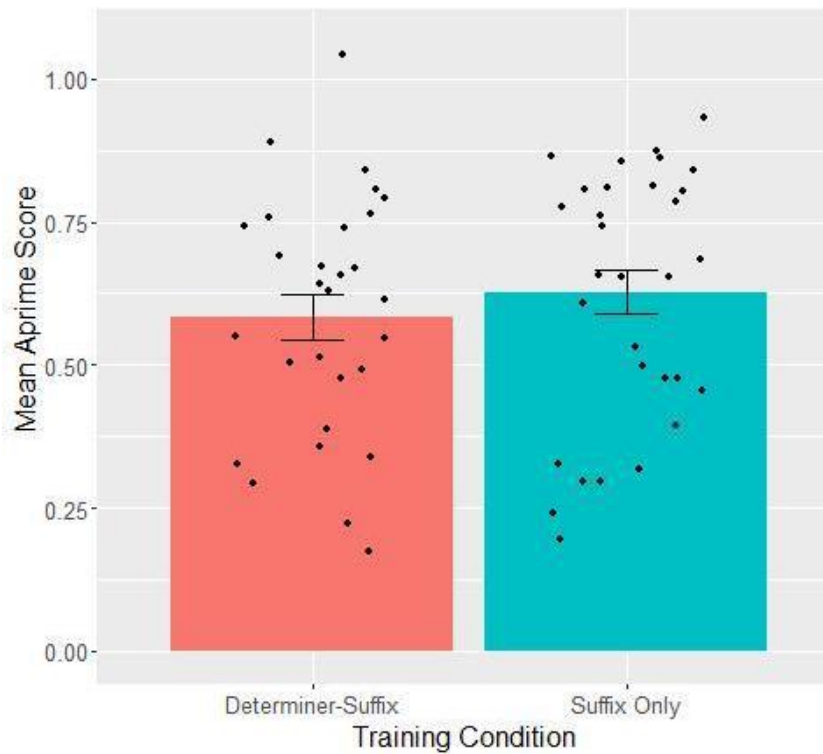
Figure 35. A' score on the phonological form generalisation task for participants in the determiner-suffix and suffix only conditions after training.

A linear regression was used to investigate the effect of training condition on a' score during the phonological form generalisation task. As shown in Table 47 training condition had no significant effect on a' score in the model.

Table 47. Regression coefficients for the fixed effects with a' score as the outcome variable in the phonological form generalisation task.

	Estimate	Std. Error	t-value	p-value
Training Condition	.043	.055	.782	.437

No random effects included in the maximal model

Taken together these results show that participants in both conditions were able to generalize the association between determiners and suffixes after six blocks of training. While participants were able to generalize associations between the two phonological distributional cues in this experiment, the non-significant effect of training condition in the model indicates that this is not due to the manipulation of determiner availability during training.

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Suffix generalisation

Participants' learning of the association between suffix and semantics present during training and their ability to apply it to novel items was tested after three and six blocks of training in both the determiner-suffix and suffix only training conditions. As in the generalisation tasks above, a' scores were calculated to index the level of generalisation with a' scores above 0.5 being taken as evidence that participants were able to generalise an association to novel items.

Figure 36 illustrates the extent to which participants could generalise suffix-semantic associations to novel items after three and six blocks of training. One sample t-tests confirm that a' score was significantly above 0.5 for participants in the suffix only condition after three and six blocks of training. A' scores for participants in the determiner-suffix condition were not significantly above 0.5 at either point in time (Determiner-Suffix, after three blocks of training: $t(28) = -1.37$, $p = .910$; after six blocks of training: $t(28) = -.13$, $p = .549$; Suffix Only, after three blocks of training: $t(30) = 3.75$, $p < .001$; after six blocks of training: $t(30) = 2.43$, $p = .011$; after three blocks of training: $M_{Determiner-Suffix} = .44$, $M_{Suffix Only} = .67$; after six blocks of training: $M_{Determiner-Suffix} = .49$, $M_{Suffix Only} = .63$).

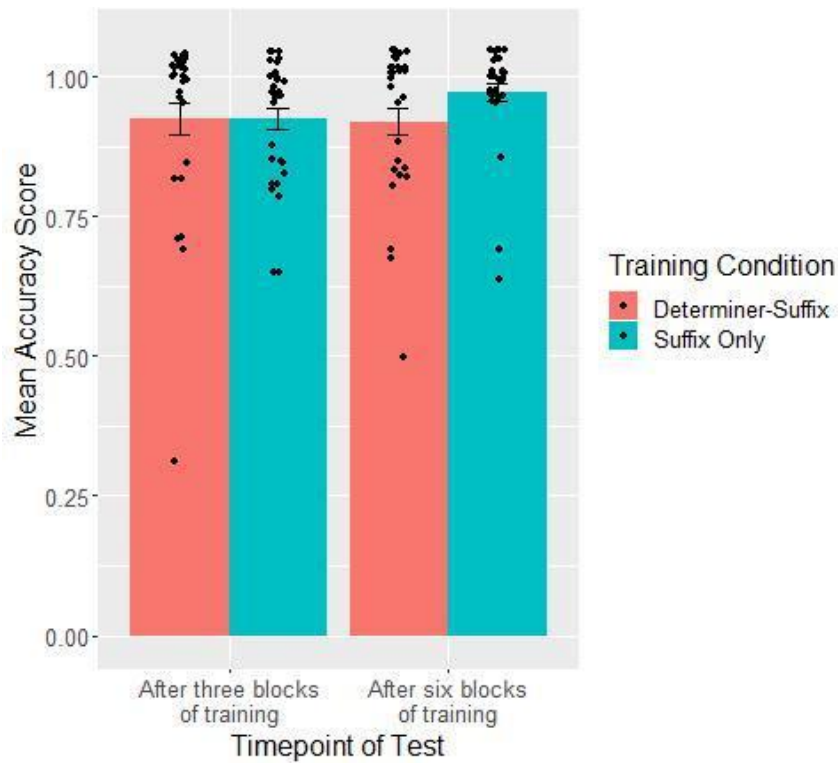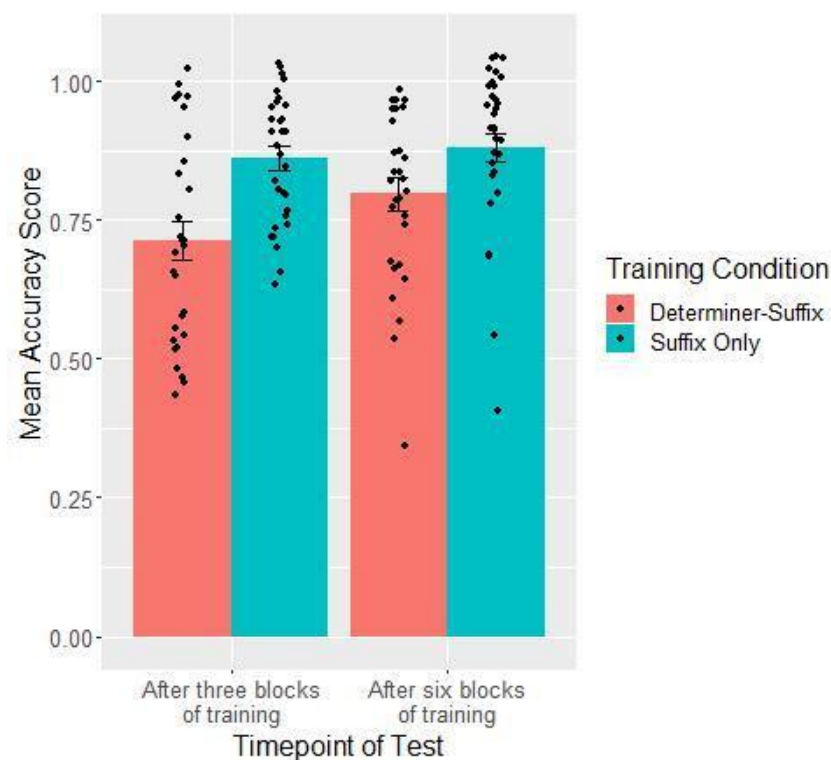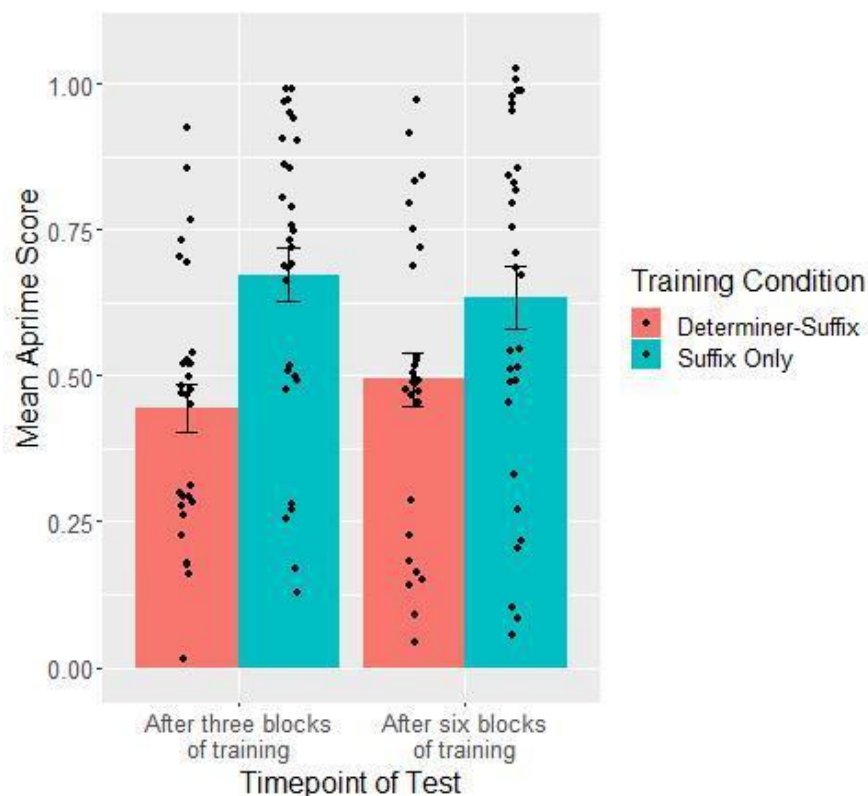*Figure 36. Performance on the suffix generalisation task for participants in the determiner-suffix and suffix only training conditions after three and six blocks of training*

A linear mixed-effects regression was used to investigate the effects of training condition and length of training on a' score during the suffix generalisation task. As shown in Table 48 participants in the suffix only condition showed significantly greater a' scores for the suffix generalisation task than participants in the determiner-suffix condition. There was no significant effect of length of training on a' score during the suffix generalisation task and there was no significant interaction between training condition and length of training.

Table 48. Regression coefficients for the fixed effects with accuracy as the outcome variable in the suffix generalisation task.

	Estimate	Std. Error	z-value	p-value
Training Condition	.139	.067	2.078	.037
Length of Training	-.050	.057	.857	.392
Training Condition X Length of Training	.089	.081	1.108	.268

Random effects included in the model: intercept by participants.

Taken together with the above chance performance for the suffix only condition at both timepoints, this shows that participants trained on a language with only the suffix for the first half of training were able to apply the associations between the suffix and animacy to novel pseudowords. This difference between training conditions was not affected by length of training meaning the additional exposures and the introduction of the determiner did not affect participants' ability to generalize the suffix-semantic associations.

Participants trained with the determiner and suffix present throughout the training language were not able to generalize the suffix-semantic associations present in the language after three blocks of training. An additional three blocks of training did not affect their ability to generalize suffix-semantic associations.

Determiner generalisation

Participants' ability to generalize the determiner-semantic associations was tested after training was complete in the determiner-suffix and suffix only training conditions. A' scores were calculated to index the level of generalisation with a' scores above 0.5 being taken as evidence that participants were able to generalise an association to novel items.

Figure 37 illustrates the extent to which participants could generalise semantic associations for the determiner to novel items. One sample t-tests confirm that mean a' score was significantly above 0.5 for participants in the suffix only training condition. Participants in the determiner-suffix training condition did not score significantly above chance although the p-value was close to borderline (p= .051) (Determiner-Suffix: t(28)= 1.69, p= .051; Suffix Only: t(30)= 1.78, p= .043; A' scores: $M_{Determiner-Suffix}$= .60, $M_{Suffix Only}$= .59).
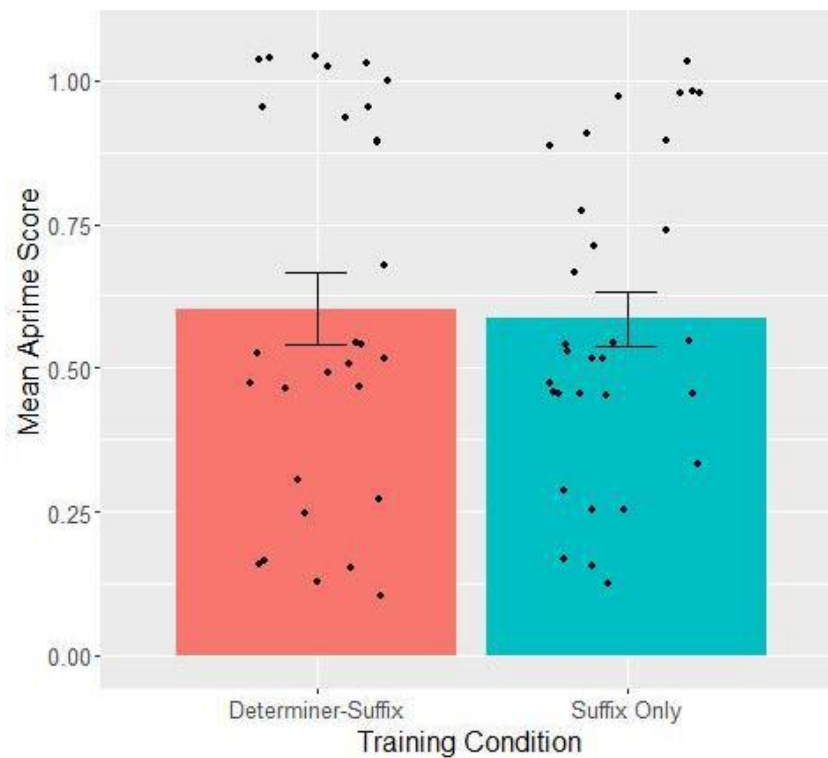
Figure 37. A' score on the determiner generalisation task for participants in the determiner-suffix and suffix only conditions.

A linear regression was used to investigate the effect of training condition on a' score during the determiner generalisation task. As shown in Table 49, training condition had no significant effect on a' score in the model.

Table 49. Regression coefficients for the fixed effects with a' score as the outcome variable in the determiner generalisation task.

	Estimate	Std. Error	t-value	p-value
Training Condition	-.018	.077	-.234	.816

No random effects included in the maximal model

Taken together with the comparisons between a' scores and 0.5, participants' ability to generalize determiner-semantic associations from training to novel languages was not affected by training participants with only the suffix for the first half of training. Based on the small difference between each of the training conditions and the critical value it is inconclusive whether participants were generally able to generalize the determiner to novel items.

Determiner-suffix generalisation

Participants' ability to generalize associations between semantics and determiner-suffix pairs to novel items was tested after training was complete in the determiner-suffix and suffix only training conditions. A' scores were calculated to index the level of generalisation with a' scores above 0.5 being taken as evidence that participants were able to generalise an association to novel items.

Figure 38 illustrates the extent to which participants could generalise semantic associations for the determiner-suffix pairs to novel items. One sample t-tests confirm that a' score was significantly above 0.5 for participants in both the determiner-suffix and the suffix only training conditions (Determiner-Suffix: $t(28)= 3.64$, $p< .001$; Suffix Only: $t(30)= 5.06$, $p< .001$; A' scores: $M_{Determiner-Suffix}= .70$, $M_{Suffix Only}= .75$).
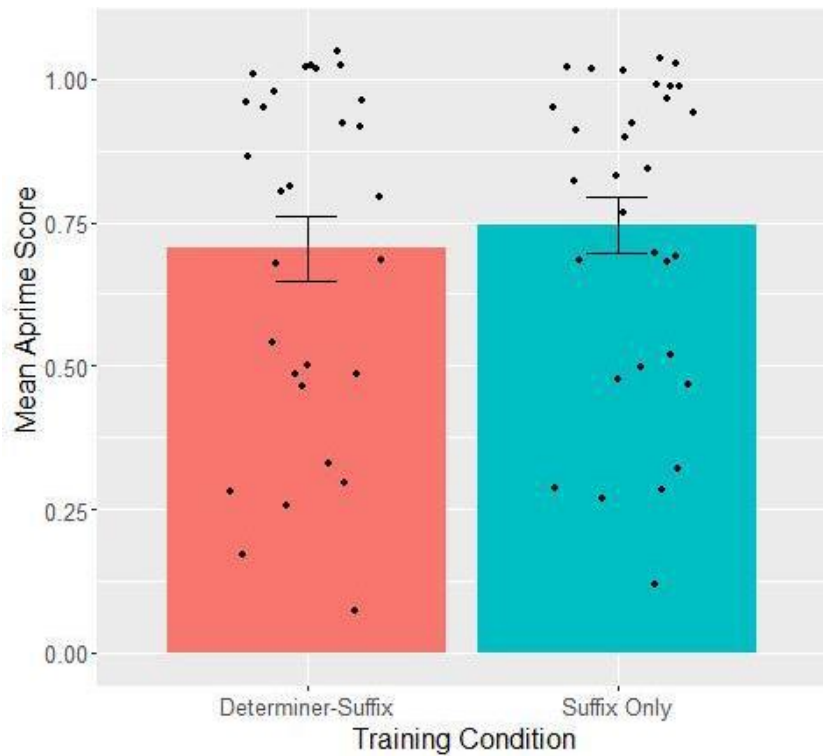
Figure 38. A' score on the determiner-suffix generalisation task for participants in the determiner-suffix and suffix only conditions.

A linear regression was used to investigate the effect of training condition on a' score during the determiner-suffix generalisation task. As shown in Table 50, training conditions had no significant effect on a' score in the model.

Table 50. Regression coefficients for the fixed effects with a' score as the outcome variable in the determiner-suffix generalisation task.

	Estimate	Std. Error	t-value	p-value
Training Condition	.041	.074	.556	.580

No random effects included in the maximal model

Taken together with the comparisons between a' scores and 0.5, participants' ability to generalize associations between semantics and determiner-suffix pairs was not affected by training participants with only the suffix for the first half of training. Participants in both training conditions were able to generalize the associations between determiner-suffix pairing and word meaning to novel words.

Explicit awareness of grammatical cues

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Explicit awareness was assessed after participants had completed both training and testing. It was scored based on individual awareness of determiner forms, determiner semantics, suffix forms, suffix semantics and determiner-suffix pairings.

Figure 39 illustrates the extent to which participants were able to explicitly identify the phonological forms, semantic associations and determiner-suffix pairings in the training language. Participants in the determiner-suffix training condition showed some awareness of the determiner and its semantic associations but little evidence that they could explicitly identify the suffixes or their associations with semantics and the determiner. Participants in the suffix only training condition showed some awareness of the determiner and its semantic associations and compared to the determiner-suffix training condition showed much more awareness of the suffix and its semantic associations in the training language.
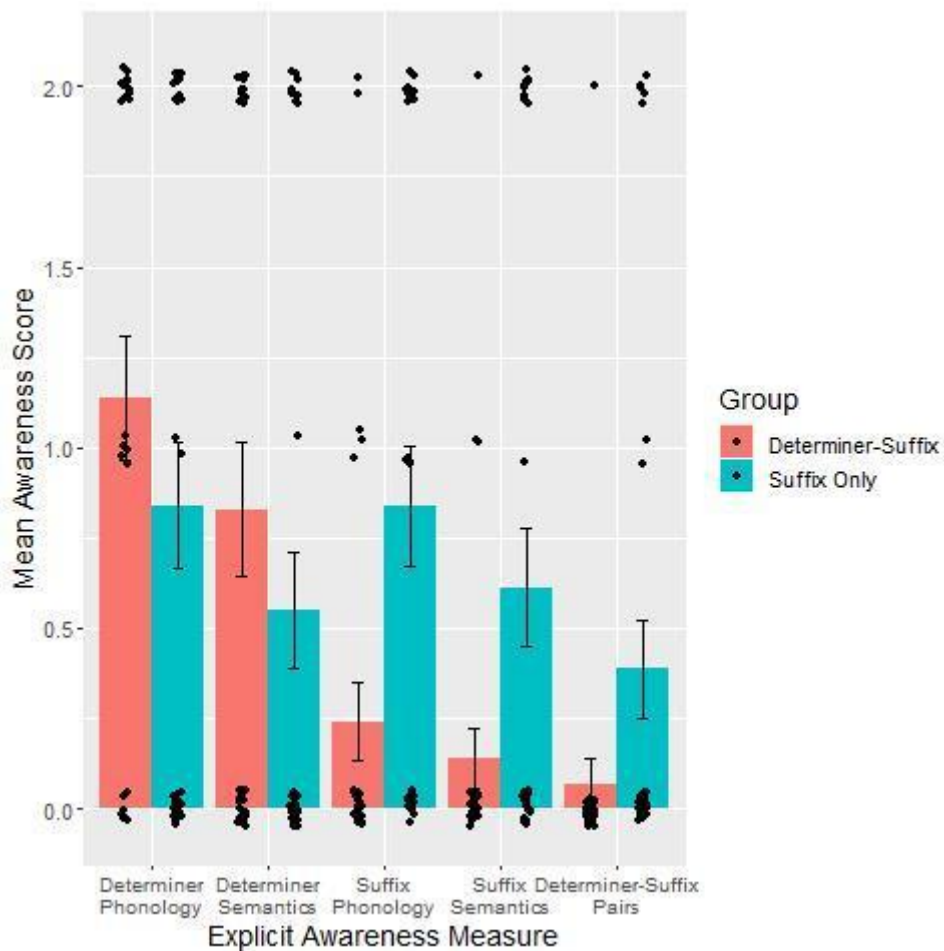
Figure 39. Mean explicit awareness scores for participants in the determiner-suffix and suffix only conditions.

As shown in Table 51 participants trained in the suffix only condition showed significantly better awareness of suffix phonology and semantics than participants trained in the determiner-suffix condition. They also showed greater awareness of the association between determiners and suffixes in the training language. There were no other significant effects of training condition on the other measures used to explore explicit awareness without phonological cue prompts.

Table 51. Linear regressions investigating training condition effects for each measure of explicit awareness.

Explicit Awareness Measure	Estimate	Std. Error	z-value	p-value
Determiner Phonology	-.300	.244	-1.227	.225
Determiner Semantics	-.279	.244	-1.143	.258
Suffix Phonology	.597	.202	2.955	.004
Suffix Semantics	.475	.188	2.523	.014
Determiner-Suffix Pairings	.318	.156	2.036	.046

No random effects included in the maximal models

Correlations between explicit awareness and generalisation

To investigate whether there was an association between explicit awareness and participants' ability to generalise semantic and phonological distributional cues several Pearson's correlations were conducted.

Correlations between phonological form generalisation after training was complete and explicit awareness of determiner forms, suffix forms and determiner-suffix pairings were carried out for participants in each training condition. As shown by Table 52, for participants in the determiner-suffix training condition there was a significant correlation between phonological form generalisation and explicit awareness of determiner-suffix pairings (r(27)= .372, p= .048). In addition to a correlation between phonological form generalisation and explicit awareness of determiner-suffix pairings (r(29)= .496, p= .005), there was also a significant correlation between phonological form generalisation and awareness of suffix phonology (r(29)= .496, p= .005) for participants in suffix only training condition.

Table 52. Pearson's correlations between explicit awareness measures and phonological form generalisation.

Training Condition	Correlation	Degrees of Freedom	r statistic	p-value
Determiner-Suffix Condition	Determiner phonology and phonological form generalisation	27	-.045	.813
	Suffix phonology and phonological form generalisation	27	.237	.215
	Determiner-suffix pairing and phonological form generalisation	27	.372	.048
Suffix Only Condition	Determiner phonology and phonological form generalisation	29	.246	.181
	Suffix phonology and phonological form generalisation	29	.410	.022
	Determiner-suffix pairing and phonological form generalisation	29	.496	.005

Correlations between suffix generalisation after training was complete and explicit awareness of suffix forms and suffix semantics were carried out for participants in each training condition. As shown by Table 53 there was a significant correlation between the ability to generalise the suffix to novel items and explicit awareness of suffix-semantic associations (r(29)= .434) for participants in the suffix only condition. For participants in the determiner-suffix condition there were no significant correlations between suffix generalisation and explicit awareness measures.

Table 53. Pearson's correlations between explicit awareness measures and suffix generalisation.

Training Condition	Correlation	Degrees of freedom	r statistic	p-value
Determiner-Suffix Condition	Suffix phonology and suffix generalisation	27	.282	.138

	Suffix semantics and suffix generalisation	27	.294	.121
Suffix Only Condition	Suffix phonology and suffix generalisation	29	.260	.158
	Suffix semantics and suffix generalisation	29	.434	.015

Correlations between determiner generalisation and explicit awareness of determiner forms and determiner semantics were carried out for participants in each training condition. Table 54 shows that for participants trained in the determiner-suffix condition, determiner generalisation was significantly correlated with explicit awareness of determiner phonology (r(27)= .554, p= .002) and determiner semantics (r(27)= .675, p<.001). For participants trained in the suffix only condition, there was a significant correlation between determiner generalisation and explicit awareness of determiner-semantics (r(29)= .440, p<.032).

Table 54. Pearson's correlations between explicit awareness measures and determiner generalisation

Training Condition	Correlation	Degrees of freedom	r statistic	p-value
Determiner-Suffix Condition	Determiner phonology and determiner generalisation	27	.554	.002
	Determiner semantics and determiner generalisation	27	.675	<.001
Suffix Only Condition	Determiner phonology and determiner generalisation	29	.165	.375
	Determiner semantics and determiner generalisation	29	.440	.032

Correlations between determiner-suffix generalisation and explicit awareness of determiner forms, determiner semantics, suffix forms, suffix semantics and determiner-suffix pairings were carried out for participants in each training condition. As shown by Table 55 in the determiner-suffix training

condition, determiner-suffix generalisation was significantly correlated with explicit awareness of determiner phonology (r(27)= .584, p<.001) and determiner semantics (r(27)= .788, p<.001). In the suffix only training condition, determiner-suffix generalisation was significantly correlated with explicit awareness of suffix phonology (r(29)= .410, p= .022) and suffix semantics (r(29)= .630, p<.001).

Table 55. Pearson's correlations between explicit awareness measures and determiner-suffix generalisation

Training Condition	Correlation	Degrees of Freedom	r statistic	p-value
Determiner-Suffix Condition	Determiner phonology and determiner-suffix generalisation	27	.584	<.001
	Determiner semantic and determiner-suffix generalisation	27	.788	<.001
	Suffix phonology and determiner-suffix generalisation	27	-.033	.864
	Suffix semantics and determiner-suffix generalisation	27	.193	.316
	Determiner-suffix pairing and determiner-suffix generalisation	27	.187	.331
Suffix Only Condition	Determiner phonology and determiner-suffix generalisation	29	.225	.223
	Determiner semantic and determiner-suffix generalisation	29	.255	.166
	Suffix phonology and determiner-suffix generalisation	29	.410	.022
	Suffix semantics and determiner-suffix generalisation	29	.630	<.001

Determiner-suffix pairing and determiner-suffix generalisation	29	.352	.052

In sum, the correlations between measures of explicit awareness and generalisation measures suggest that participants in the suffix only training condition made greater use of suffixes than participants in the determiner-suffix training condition. Notably for participants in the suffix only condition, awareness suffix phonology or suffix semantics was associated with performance on the phonological form generalisation and determiner-suffix generalisation tasks. In contrast participants in the determiner-suffix condition appear to have made more use of determiners, with awareness of determiner phonology and determiner semantics being associated with performance on the determiner-suffix generalisation task.

5.2.4 Discussion

Experiment 5 explored whether determiners and suffixes compete for relevance when both phonological-distributional cues are available in a language. Specifically, Experiment 5 investigated whether delaying the availability of determiners as a grammatical cue enhanced generalisation of suffix-semantic associations in the suffix-only training condition. Additionally, Experiment 5 investigated whether sequential presentation of suffixes before determiners would enable participants to learn both phonological-distributional cues and generalize the association between them.

Performance on the phonological form recognition and 2AFC tasks demonstrate that participants in both conditions were able to learn individual word forms and associate them with specific meanings after the first phase of training. Following this additional exposure to word forms and meanings in the second phase of training and the introduction of determiners in the suffix-only condition had no effect on participants' recognition of word forms and meanings. Mixed-effects logistic regressions demonstrate that omitting determiners for the first phase of training had no effect on participants' learning of word forms and meanings. Taken together these findings confirm that participants learned trained words and were able to associate them with specific semantic referents during training. Further these findings demonstrate that manipulating the availability of determiners over the course of training had no effect on learning of trained words.

Based on the competition model (Bates & MacWhinney, 1989; Culbertson et al., 2017) as well as the preference for determiners predicted by discriminative learning (Arnon & Ramscar, 2012; Havron & Arnon, 2021; Ramscar et al., 2010; Ramscar & Port, 2016) and the cohort model (Marslen-Wilson,

1987, 1988), the presence of determiners in the training language may interfere with participants' ability to learn suffixes. Experiment 5 examined the prediction that training participants without determiners would enable them to generalize suffix-semantic associations. This was tested by comparing the effects of omitting determiners for the first half of training on participants' ability to generalize suffix-semantic associations after one and two phases of training. The second suffix generalisation task was used to address whether participants would still be able to generalize suffix-semantic associations after a more competitive phonological-distributional cue (determiners) was introduced to the training language.

Comparisons against 0.5 showed that participants trained with only suffixes for the first phase were able to generalize suffix-semantic associations after the first and second phases of training. In contrast, participants trained with determiners and suffixes throughout were unable to generalize suffix-semantic associations. A linear mixed-effects regression confirmed that training participants with only suffixes during the first phase of training led to significantly higher performance on the suffix-generalisation tasks. These findings demonstrate that omitting the determiners during the first phase of training enhanced participants suffix-semantic generalisation and that this enhanced generalisation was not affected by introducing determiners later during training.

Based on blocking (Kamin, 1969), after participants have learned one cue they will block out subsequent cues if they are considered redundant. As determiners are more relevant as a predictor of word stem, it was predicted that training participants on suffixes first would not interfere with subsequent learning of determiners. This was tested by comparing determiner-semantic generalisation against chance in the suffix only condition and comparing determiner-semantic generalisation between the two training conditions.

Participants trained with only suffixes for the first phase of training were able to generalize determiner-semantic associations once determiners were introduced to the language. A linear regression found that training conditions had no significant effect on performance. This raises concerns regarding how well participants learned determiner-semantic associations as when compared against chance, participants in the determiner-suffix condition showed a borderline but nonsignificant (p= .051) difference. Overall, these findings suggest that learning suffixes first did not interfere with learning of determiners. However, results across conditions bring into question whether participants have learned determiner-semantic associations.

Based on the assumption that generalizing an association between two cues requires a learner to have some awareness of both cues, it was predicted that participants trained on suffixes before

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determiners would be able to learn both phonological-distributional cues and subsequently generalize the association between them. For this to be tested, participants in the suffix only condition would first need to demonstrate that they had learned determiners and suffixes during the determiner and suffix generalisation tasks. If participants trained in the suffix only condition met this prerequisite, then enhanced performance on the phonological form generalisation task would suggest the poor generalisation of determiner-suffix associations observed in previous studies was due to poor learning of suffixes.

As discussed, participants trained on only suffixes were able to generalize both suffix-semantic and determiner-semantic associations, performing significantly better on the suffix generalisation task than participants in the determiner-suffix condition. One-sample t-tests found that participants in both training conditions were able to generalize determiner-suffix associations but contrary to our prediction there was no significant effect of training on generalisation of determiner-suffix associations. These findings suggest that delaying the inclusion of determiners enabled participants to learn both affixes, but that learning both affixes was not what enabled participants' to generalize the associations between affixes in both training conditions.

Findings from the explicit awareness measures parallel findings from the generalisation tasks, suggesting that manipulation of the availability of determiners in the training language also affected which cues participants were able to explicitly identify after training was complete. Participants in the suffix only training condition also showed significantly greater explicit awareness of suffixes and their semantic associations compared to participants in the determiner-suffix condition. Suggesting that delaying the availability of determiners in the training language enhanced explicit awareness of suffixes and suffix semantic associations by the end of training.

Another notable finding in the analysis of explicit awareness is that training participants on only suffixes had a significant effect on participants' ability to identify determiner-suffix pairings during debriefing. This is particularly interesting as it offers some evidence that manipulating the availability of determiners had some effect on explicit awareness of determiner-suffix even if no effect was apparent for implicit knowledge in the phonological form generalisation task. One caveat to this is that only a few participants in the suffix only condition and a single participant in the simultaneous condition identified determiner-suffix pairs during debriefing. Meaning that the effect found was driven by a small subset of participants.

The findings of Experiment 5 support the competition model and to some extent blocking. The significant effect of training condition on the suffix generalisation tasks demonstrates that omitting

determiners for the first phase of training led to increased awareness of suffixes and their semantic associations. This suggests that when determiners and suffixes are presented together determiners outcompete suffixes for attention.

Despite showing increased awareness of suffixes, participants trained with only suffixes in the first phase of training showed no disadvantage when generalizing determiner-semantic associations after the second phase of training. In contrast, participants' trained with both affixes from the outset showed significantly poorer suffix-semantic generalisation. This is in line with blocking, suggesting that participants were able to learn determiners after acquiring suffixes but were unable to learn suffixes after acquiring determiners.

However, the evidence for blocking is not conclusive as while participants in the suffix only condition were able to learn determiners after suffixes participants in the determiner-suffix training condition did not demonstrate the ability to generalize associations for either affix. This leaves it unclear whether participants trained on determiners and suffixes from the first phase of training were able to learn either phonological-distributional cue. Additionally while significantly above 0.5, the effect size for the determiner generalisation task was still small in the suffix only condition.

Our findings are in line with discriminative learning and the cohort model demonstrating that when presented simultaneously determiners are favoured over suffixes. However, our findings do not address which factors drive cue preference. Previous literature identified early availability (Arnon & Ramscar, 2012; Culbertson et al., 2017; Havron & Arnon, 2021) and greater predictive value (Arnon & Ramscar, 2012; Havron & Arnon, 2021) as factors that determine cue preference. However, the current method does not allow us to confirm whether the factors identified by previous literature contribute to cue preference.

Our findings are inconclusive regarding whether competition between determiners and suffixes is related to participants' poor performance when generalizing associations between them. Training participants on only suffixes for the first phase of training affected whether participants could generalize suffix-semantic associations but not the association between determiners and suffixes. Findings from the explicit awareness measures suggest that suffix only training supported explicit awareness of suffixes, suffix-semantic associations and determiner-suffix associations, but these differences were driven by a small subset of participants.

One possible explanation is that the presence of semantics throughout training interfered with participants' ability to generalize associations between the phonological-distributional cues. As noted previously participants in Experiment 5 while above the critical value still performed poorly on

the phonological form generalisation task. Based on discriminative learning (Arnon & Ramscar, 2012; Havron & Arnon, 2021; Ramscar et al., 2010; Ramscar & Port, 2016), semantic cues should outcompete phonological-distributional cues for relevance. As such it is possible that while omitting determiners led to improved learning of suffixes, the presence of semantics led to participants favouring associations with semantic cues over the association between determiners and suffixes.

5.3 Experiment 6

5.3.1 Introduction

Experiment 5 demonstrates that there is competition between determiners and suffixes for relevance. It showed that learners' suffix generalisation benefitted from delaying the presentation of determiners. Additionally, as predicted by blocking (Kamin, 1969) learning the less favoured cue (suffixes) did not interfere with participants' ability to learn the more favoured cue (determiners) when it was added to the language. One issue left unaddressed by Experiment 5 is why learners have greater difficulty generalizing associations between determiners and suffixes. Despite demonstrating awareness of both determiners and suffixes during their respective generalisation tasks, participants in the suffix only condition showed no significant benefit in their ability to generalize associations between determiners and suffixes.

In line with blocking, Experiment 5 found that sequential presentation of the suffixes and determiners enabled participants to learn both cues and their semantic associations. However, Experiment 5 did not manipulate the introduction of semantic cues, which were present in both conditions throughout training. Experiment 6 addressed this by investigating whether sequential presentation of each phonological-distributional cue and the semantic cue can enable comprehensive learning of all of the cues available in the training language and the associations between them. In contrast to Experiment 5, Experiment 6 manipulated the availability of the semantic cue between training conditions in addition to manipulating the availability of determiners.

Participants in Experiment 6 were trained in either the simultaneous or the sequential training conditions. In both conditions training was split into three phases. For the simultaneous condition participants were trained with semantics present across all three phases of training. During the first phase of training participants heard a set of 24 pseudowords which each had a unique stem and one of two suffixes. From the second phase onwards each pseudoword acquired one of two determiners which were paired with their corresponding suffix. The simultaneous condition in Experiment 6

served as a comparison for the sequential condition while also replicating the suffix only training condition in Experiment 5.

In the sequential condition participants were trained without semantics for the first two phases of training. During the first phase of training participants in the sequential condition were trained on 24 pseudowords which each had a unique stem and one of two suffixes. During the second phase of training each pseudoword gained a determiner that matched its suffix. During the third phase of training semantics were added to the language. Pictures of animals and artefacts representing word meaning were associated with each pseudoword, and determiner-suffix pairings were associated with the animacy of each pseudoword meaning as in the simultaneous condition

Based on the competition model and discriminative learning the presence of semantics interferes with learning of phonological-distributional cues and the associations between them as it is the most relevant cue in the language. The competition model and discriminative learning also suggests that the presence of determiners interferes with learning of suffixes and their associations as determiners are the more relevant of the phonological-distributional cues. Based on blocking, participants will be able to learn more relevant cues after acquiring less relevant cues but will block out cues which are less relevant than those they have already learned.

This led to several predictions for how delaying the inclusion of semantics would affect the learning and generalisation of cue associations for participants learning suffixes and determiners sequentially. For participants in the simultaneous condition who would learn phonological-distributional cues sequentially with semantics present throughout, it was predicted that they would not be able to generalize semantic associations for suffixes and determiners. This is because knowledge of suffixes will not interfere with knowledge of determiners initially, but the presence of semantics throughout training will interfere with learning of associations between the two cues.

For participants in the sequential condition who would learn suffixes, determiners and semantics sequentially it was predicted that they would be able to learn associations between suffixes and determiners after determiners were introduced to the language and would learn the associations between both cues and semantics during the final phase of training. This is because training participants on the cues from least to most relevant would allow them to learn each cue and its associations without interference from more relevant cues.

Research questions

Replicating Experiment 5

1. Will participants trained with semantics from the outset be able to generalize suffix-semantic associations after training is complete?
2. Will participants trained with semantics from the outset be able to generalize determiner-semantic associations after training is complete?

Investigating the effect of semantics on sequential learning of determiner-suffix pairings

1. Will participants trained without semantics for the two phases of training be able to generalize suffix-semantic associations after training is complete?
   a. Will participants' training condition significantly affect their ability to generalize suffix-semantic associations?
2. Will participants trained without semantics for the first two phases of training be able to generalize determiner-semantic associations after training is complete?
   a. Will participants' training condition significantly affect their ability to generalize determiner-semantic associations?
3. Will participants trained without semantics be able to generalize determiner-suffix pairings after two phases of training?
4. Will participants trained without semantics for the first two phases of training be able to generalize determiner-suffix pairings after training is complete?
   a. Will participants trained without semantics for the first two phases of training be significantly more likely to generalize determiner-suffix pairings than participants who were trained with semantics throughout?

5.3.2 Methods

Participants

During recruitment, four participants were excluded from the study for not complying with instructions during training. The resulting sample was comprised of sixty-one monolingual, native English-speaking adults (33 males, 28 females; mean age = 27.66 range = 18-36) with no known language disorders. Participants had normal hearing and normal or corrected-to-normal vision. Participants were recruited from Prolific and participated in the study after providing informed consent. Each participant was paid £9.00 to take part in the study. The study was approved by the Ethics Committee at the Department of Psychology, University of York.

Participants were randomly allocated to one of two training conditions, for every participant allocated to the simultaneous condition one was assigned to the sequential condition. After

recruitment was complete, there were 31 participants in the simultaneous condition and 30 participants in the sequential training condition.

Materials

Language training set

Participants in both conditions were trained on a set of 24 pseudowords. Table 56 shows example word-picture pairs for each grammatical class by training condition and illustrates which cues were included over three phase of training.

In the simultaneous condition the training language matched the language used in the suffix only condition during Experiment 5. During the first phase of training pseudowords were composed of unique stems and a suffix (-*eem* or -*ool*). During the second phase of training a determiner (*tib-* or *ked-*) was added to the beginning of each word. The language in the simultaneous condition did not change between the second and third phases of training. Semantics were present across all three phases in the simultaneous condition.

In the sequential condition, the training language changed between each phase of training. During the first phase of training pseudowords were composed of unique stems and a suffix (-*eem* or -*ool*). During the second phase of training a determiner (t*ib-* or *ked-*) was added to the beginning of each word, meaning each pseudoword was composed of a determiner, stem and suffix. In contrast to the simultaneous condition, semantics were omitted from the first and second phases of training; instead of a picture of an animal or artefact a fixation cross remained in the middle of the screen to maintain visual attention. During the third phase of training semantics were introduced to the language in the sequential condition, as such the key difference between training conditions is the presence of semantics in the training language being delayed until the third phase of training in the sequential condition.

Table 56. Example stimuli for each training condition.

Training Condition	Stimuli	Simultaneous Condition		Sequential Condition	
		Animal Word	Artefact Word	Animal Word	Artefact Word
	Pseudoword	zeap-eem	cass-ool	zeap-eem	cass-ool

First Phase of Training	Picture	[duck]	[guitar]	+	+
Second Phase of Training	Pseudoword	tib-zeap-eem	ked-cass-ool	tib-zeap-eem	ked-cass-ool
	Picture	[duck]	[guitar]	+	+
Third Phase of Training	Pseudoword	tib-zeap-eem	ked-cass-ool	tib-zeap-eem	ked-cass-ool
	Picture	[duck]	[guitar]	[duck]	[guitar]

Generalisation sets

A total of 48 novel pseudowords were used across the generalisation tasks. Each phonological form generalisation task used 12 novel pseudowords, 6 which had determiner-suffix pairings consistent with the training set and 6 which had inconsistent determiner-suffix pairings. The three semantic generalisation tasks each used 8 novel pseudowords.

Procedure

As illustrated in Figure 40, participants in both conditions completed three phases of training. Each phase of training was comprised of three blocks of 24 trained words and after each block participants were allowed to take a break of up to five minutes. Participants were tested after the second and third phases of training were complete. The training and testing session lasted approximately 60 minutes. All training tasks and tests were presented using the platform Gorilla.

After the second phase of training participants completed a phonological form recognition task and a phonological form generalisation task which tested participants' learning of word forms and determiner-suffix pairings respectively. After the third phase of training participants completed a set of word-learning (phonological form recognition and 2AFC) and generalisation tasks (phonological form generalisation, determiner-only, suffix-only and determiner-suffix)

First phase of training	Second phase of training	Third phase of training

Training
Repetition Task
    3 Block of 24 trained pseudowords
	Training
	Repetition Task
	    3 Block of 24 trained pseudowords
	
	Testing
	Word Learning
	    Phonological Form Recognition Task
	
	Grammar Learning
	    Phonological Form Generalization Task
		Training
		Repetition and Word-Picture Matching Task
		    3 Block of 24 trained pseudowords
		
		Testing
		Word Leaning
		    Phonological Form Recognition Task
		    2AFC Task
		
		Grammar Learning
		    Phonological Form Generalization Task
		    Suffix Generalization Task
		    Determiner Generalization Task
		    Determiner-Suffix Generalization Task

Figure 40. Experiment Design and Tasks

Like in previous Experiments, explicit knowledge of the associations present in the language was assessed using two questions after the final set of tests. The responses for both questions were scored together for awareness of the determiners, determiner-semantic associations, the suffixes, suffix-semantic associations and determiner-suffix pairs to reflect the complexity of the regularities present in the language. For a more detailed breakdown of how each explicit awareness measure was scored see the general method section.

Data analyses

All analyses reported below were performed in R.

The same analyses used in previous experiments were conducted to investigate levels of word learning and generalisation for participants in each training condition at each point in time. For all models a maximal model that was able to converge was produced using the buildmer package.

In the analyses of the phonological form recognition task, The effects of training condition and length of training was investigated using a mixed-effects logistic regression with accuracy coded as a binary outcome measure. Training condition and length of training were fixed factors. Both training condition (simultaneous= 0, sequential= 1) and length of training (after two phases of training= 0, after three phases of training= 1) were coded as repeated contrasts. Random effects were included for both participants and test items.

For analyses of the 2AFC task, the effect of training condition was investigated using a logistic regression with accuracy coded as a binary outcome measure. Training condition was a fixed factor and was coded as a repeated contrast (simultaneous= 0, sequential= 1). Random effects were included for both participants and test items.

In the analyses of phonological form generalisation, the effects of training condition and length of training were investigated using a linear mixed-effects model with a' scores as the outcome measure. Training condition and length of training were coded as they were in the phonological form recognition task. Participants were included as a random effect.

For the three semantic generalisation tasks, the effect of training condition was investigated using a linear regression with a' scores as the outcome measure and training condition as the fixed effect.

In the analyses of explicit knowledge, the effect of training conditions on explicit knowledge of various associations present in the language was investigated using a series of linear regressions. Each model used participants' scores for an explicit awareness subtest as the outcome measure, training condition as the fixed effect and participants as a random effect. The models investigated the effect of training condition on explicit awareness of: i) determiner phonology, ii) determiner semantics, iii) suffix phonology, iv) suffix semantics and v) determiner-suffix pairs.

Following this Pearson's correlations were used to investigate whether there was a relationship between each generalisation measure at the end of training and relevant explicit awareness measures. For the phonological form generalisation task, we looked for correlations with:

1. Determiner phonology
2. Suffix phonology
3. Determiner-suffix pairs

For the determiner-suffix generalisation task we looked for correlations with:

1. Determiner phonology
2. Determiner semantics
3. Suffix phonology
4. Suffix semantics
5. Determiner-suffix pairs

For the determiner generalisation task we looked for correlations with:

1. Determiner phonology
2. Determiner semantics

For the final suffix generalisation task we looked for correlations with:

1. Suffix phonology
2. Suffix semantics

5.3.3 Results

<u>Word Learning</u>

Phonological form recognition was measured after six and nine blocks of training for participants in the simultaneous and sequential training conditions. To investigate whether participants in each condition had learned the word forms from training, one sample t-tests were used to compare the mean accuracy scores for familiar items against chance level (0.5).

Figure 41 illustrates the participants' recognition of word forms after six and nine blocks of training. One sample t-tests confirm that performance was significantly above chance for participants in both training conditions at both points in time (Simultaneous, after six blocks of training: $t(30)= 22.29$, $p<.001$; after nine blocks of training: $t(30)= 15.20$, $p<.001$; Sequential, after six blocks of training: $t(29)= 20.08$, $p<.001$; after nine blocks of training: $t(29)= 23.46$, $p<.001$; after six blocks of training: $M_{Simultaneous}= .94$, $M_{Sequential}= .94$; After nine blocks of training: $M_{Simultaneous}= .90$, $M_{Sequential}= .94$).
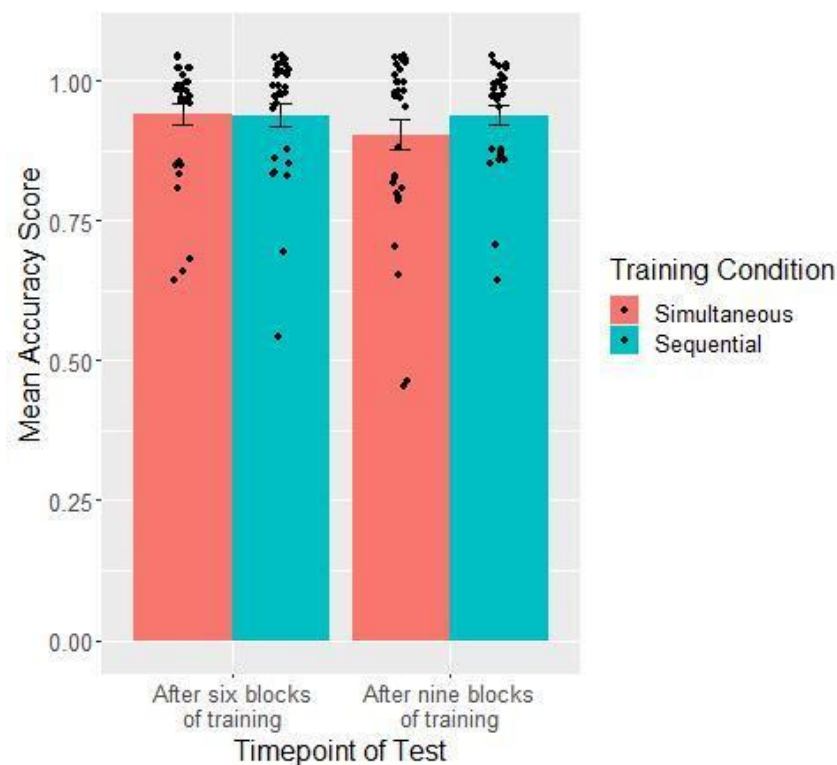
Figure 41. Accuracy (proportion correct) for the phonological form recognition task for participants in the simultaneous and sequential conditions after six and nine blocks of training.

A mixed-effects logistic regression was used to investigate the effects of training condition and length of training on accuracy during the phonological form recognition task. As shown in Table 57

there was no significant effect for training condition or length of training in the model. Additionally there was no significant interaction between training condition and length of training.

Table 57. Regression coefficients for the fixed effects with accuracy as the binary outcome variable in the phonological form recognition task.

	Estimate	Std. Error	z-value	p-value
Training Condition	.452	.324	1.395	.163
Length of Training	-.179	.511	-.350	.727
Training Condition X Length of Training	-.156	.353	-.442	.658

Random effects included in the model: intercept by items and participants, and slopes for length of training by participants.

Taken together these results show that participants were able to correctly recognise the trained word forms in both training conditions after six blocks of training. Further training did not lead to improvements in word form recognition and there was no effect of training condition on word form learning. Participants' performance was noticeably close to ceiling across training conditions and points in time.

Figure 42 illustrates the participants' learning of word meaning after training was complete. One sample t-tests confirm that performance was significantly above chance for participants in both training conditions (Simultaneous: $t(30)= 14.21$, $p<.001$; Sequential: $t(29)= 9.32$, $p<.001$; Mean Scores: $M_{Simultaneous}= .84$, $M_{Sequential}= .79$). This performance was comparable to the performance in Experiment 5.
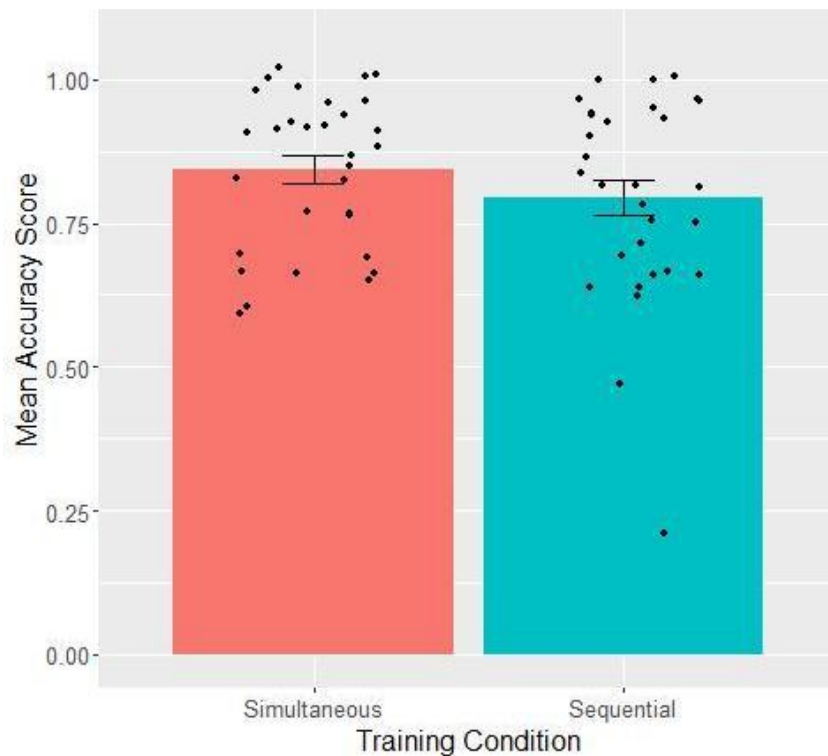
Figure 42. Accuracy (proportion correct) for the 2AFC task for participants in the simultaneous and sequential conditions.

A logistic regression was used to investigate the effect of training condition on accuracy during the 2AFC task. As shown in Table 58, there was no significant effect for training condition in the model.

Table 58. Regression coefficients for the fixed effects with accuracy as the binary outcome variable in the 2AFC task.

	Estimate	Std. Error	z-value	p-value
Group	-.401	.311	-1.288	.198

Random effects included in the model: intercept by items and participants.

Taken together with the above chance performance in both conditions, this shows that participants were able to learn the meaning of trained words regardless of whether the inclusion of semantics was delayed until the third phase of training.

Grammatical generalisation

Phonological form generalisation

The extent to which participants could generalise associations between phonological cues from training to novel words was measured after six and nine blocks of training in both conditions. A' scores were calculated to measure the level of generalisation, with a' scores above 0.5 taken as evidence that participants could generalise determiner-suffix pairs to novel items.

Figure 43 illustrates participants' ability to generalise phonological forms from training to novel words in both training conditions after six and nine blocks of training. One sample t-tests confirm that participants in the simultaneous condition had a' scores significantly above 0.5 after nine blocks of training. Participants in the sequential condition did not have a' scores that were significantly above 0.5 at either point in time (Simultaneous, after six blocks of training: t(30)= 1.56, p= .065; after nine blocks of training: t(30)= 1.70, p= .050; Sequential, after six blocks of training: t(29)= -0.19, p= .573; after nine blocks of training: t(29)= 0.73, p= .236; after six blocks of training: $M_{Simultaneous}$= .57, $M_{Sequential}$= .49; after nine blocks of training: $M_{Simultaneous}$= .57, $M_{Sequential}$= .53).
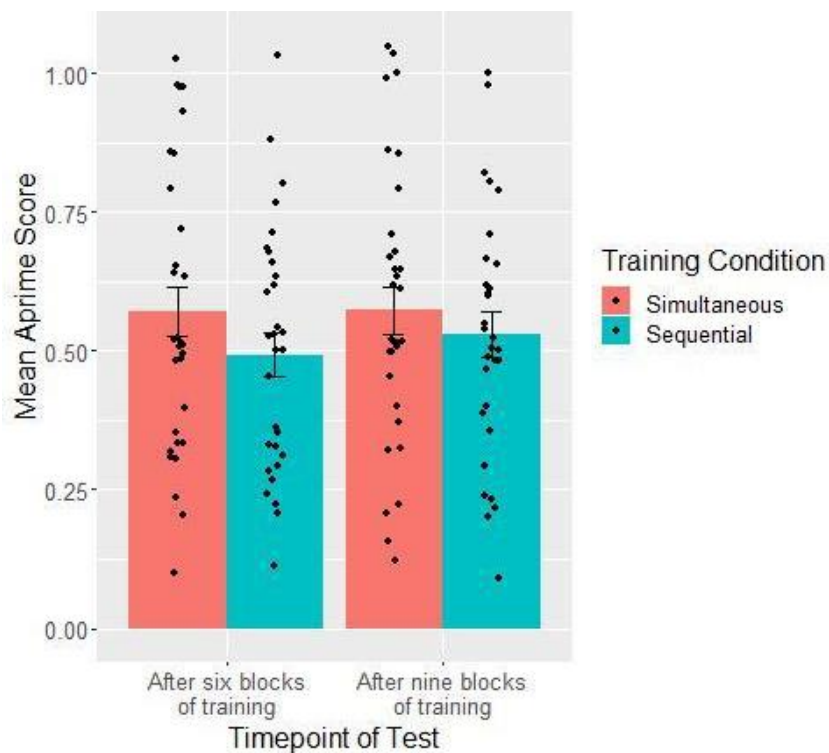
Figure 43. A' score on the phonological form generalisation task for participants in the simultaneous and sequential conditions after six and nine blocks of training.

A linear mixed-effects model was used to investigate the effects of training condition and length of training on a' scores during the phonological form generalisation task. As shown in Table 59, there were no significant effects for training condition or length of training in the model. Additionally there was no significant interaction between training condition and length of training .

Table 59. Regression coefficients for the fixed effects with a' score as the outcome variable in the phonological form generalisation task.

	Estimate	Std. Error	t-value	p-value
Group	-.078	.060	13.5	.437
Length of Training	.002	.051	.042	.967
Group X Length of Training	.035	.073	.479	.632

Random effects included in the model: intercept by participants.

Taken together these results show that participants were unable to generalize the association between the determiner and suffix after six blocks of training. After nine blocks of training participants in the simultaneous condition showed significantly above 0.5 but the difference was small and there was no significant group effect or interaction between group and length of training in the model. This suggests that participants did not show strong evidence of generalisation of the determiner-suffix pairs to novel words.

Suffix generalisation

Participants' learning of the association between suffixes and semantics present during training and their ability to apply it to novel items was tested after training was complete in both the simultaneous and sequential training conditions. A' scores were calculated to index the level of generalisation with a' scores above 0.5 being taken as evidence that participants were able to generalise an association to novel items.

Figure 44 illustrates the extent to which participants' could generalise suffix-semantic associations to novel items after training. One sample t-tests confirm that a' score was significantly above 0.5 for participants in the simultaneous condition after training was complete. However, mean a' score for participants in the sequential condition was not significantly above 0.5 (Simultaneous: $t(30)= 1.95$, $p= .030$; Sequential: $t(29)= 0.64$, $p= .267$; A' Scores: $M_{Simultaneous}= .61$, $M_{Sequential}= .53$).
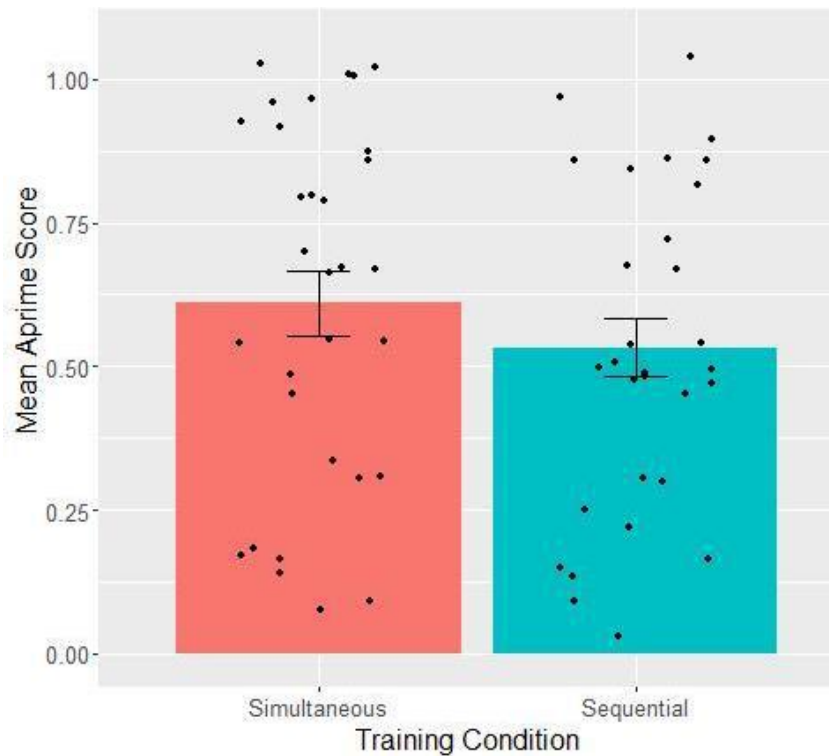
Figure 44. Performance on the Suffix Generalisation task for participants in the simultaneous and sequential training conditions.

A linear regression was used to investigate the effects of training condition on a' score during the suffix generalisation task. As shown in Table 60 there was no significant effect for training condition in the model.

Table 60. Regression coefficients for the fixed effects with accuracy as the outcome variable in the suffix generalisation task.

	Estimate	Std. Error	t-value	p-value
Group	-.078	.076	-1.024	.310

No random effects included in the maximal model.

Participants' performance in the simultaneous condition replicated the findings from the Suffix Only condition in Experiment 5 in that participants in this condition had a' scores significantly above the critical value of 0.5. However, generalisation levels in the current simultaneous condition were not high (a' = .61) and there was significant individual variation in both groups. As a result, no significant effect of training condition on suffix only generalisation was found.

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Determiner generalisation

Participants' ability to generalize the determiner-semantic associations to novel items was tested after training was complete in the simultaneous and sequential training conditions. A' scores were calculated to index the level of generalisation with a' scores above 0.5 being taken as evidence that participants were able to generalise an association to novel items.

Figure 45 illustrates the extent to which participants could generalise semantic associations for the determiner to novel items. One sample t-tests confirm that a' score was significantly above 0.5 for participants in the sequential training condition. Participants in the simultaneous training condition did not score significantly above 0.5 (Simultaneous: t(30)= 1.31, p= .101; Sequential: t(29)= 4.28, p<.001; A' scores: $M_{Simultaneous}$= .58, $M_{Sequential}$= .74).
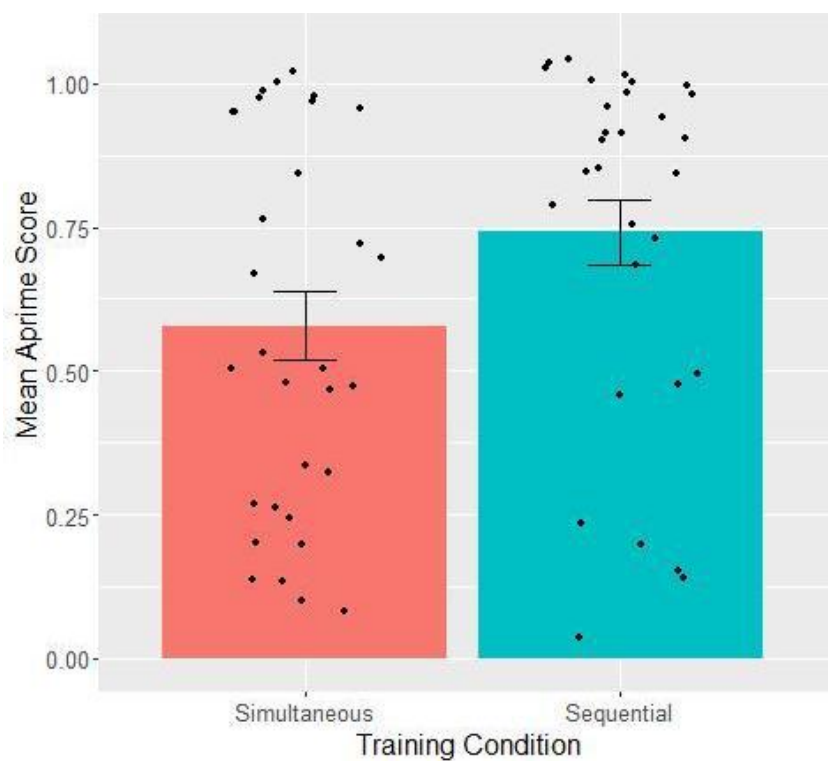
Figure 45. A' score on the determiner generalisation task for participants in the simultaneous and sequential training conditions.

A linear regression was used to investigate the effect of training condition on mean a' score during the determiner generalisation task. As shown in Table 61, there was no significant effect for training condition in the model.

Table 61. Regression coefficients for the fixed effects with a' score as the outcome variable in the determiner generalisation task.

	Estimate	Std. Error	z-value	p-value
Group	.163	.083	1.979	.053

No random effects included in the maximal model.

Taken together, there was evidence of generalisation in the determiner generalisation task for the sequential but not in the simultaneous condition in the analyses against the critical value of 0.5, but the difference between the groups when compared directly did not reach significance.

Determiner-suffix generalisation

Participants' ability to generalize associations between semantics and determiner-suffix pairs to novel items was tested after training was complete in the simultaneous and sequential training conditions. A' scores were calculated to index the level of generalisation with a' scores above 0.5 being taken as evidence that participants were able to generalise an association to novel items.

Figure 46 illustrates the extent to which participants could generalise semantic associations for the determiner-suffix pairs to novel items. One sample t-tests confirm that a' score was significantly above 0.5 for participants in both the simultaneous and the sequential conditions (Simultaneous: t(30)= 2.40, p= .011; Sequential: t(29)= 6.30, p< .001; A' scores: $M_{Simultaneous}$= .63, $M_{Sequential}$= .81).
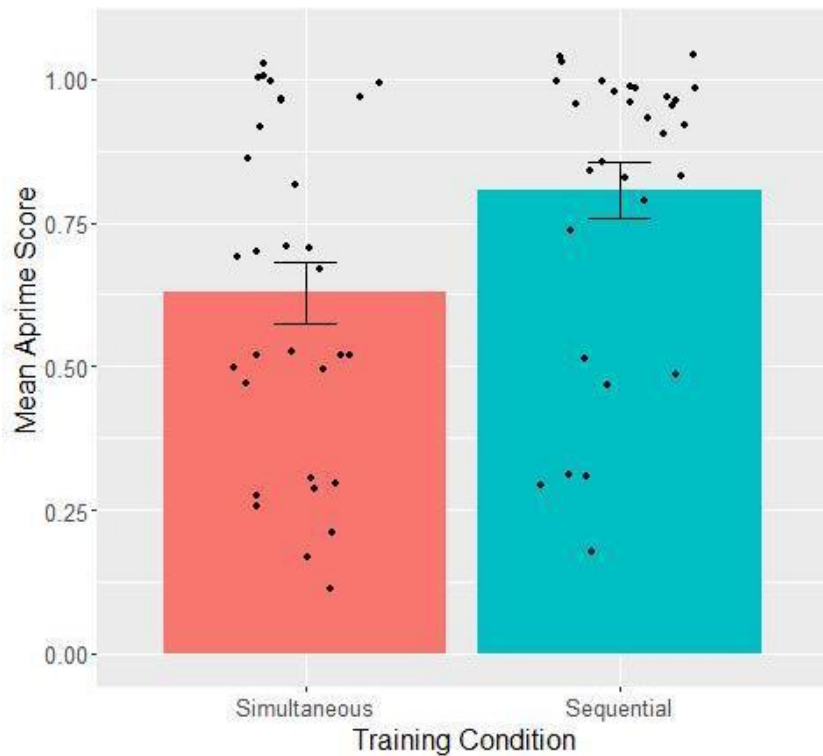
Figure 46. A' score on the determiner-suffix generalisation task for participants in the simultaneous and sequential training conditions.

A linear regression was used to investigate the effect of training condition on a' score during the determiner-suffix generalisation task. As shown in Table 62, participants in the sequential condition showed significantly greater a' scores for the determiner-suffix generalisation task than participants in the simultaneous condition.

Table 62. Regression coefficients for the fixed effects with a' score as the outcome variable in the determiner-suffix generalisation task.

	Estimate	Std. Error	z-value	p-value
Group	.177	.073	2.441	.018

No random effects included in the maximal model

Taken together with the comparisons between a' scores and 0.5, participants were able to generalize the association between semantics and determiner-suffix pairs in both conditions. However participants who were not presented with semantics until the third phase of training

showed a significant advantage in their ability to generalise the association between semantics and determiner-suffix pairs.

Explicit awareness of grammatical cues

Explicit awareness was assessed after participants had completed both training and testing. It was scored based on individual awareness of determiner forms, determiner semantics, suffix forms, suffix semantics and determiner-suffix pairs.

Figure 47 illustrates the extent to which participants were able to explicitly identify the phonological forms, semantic associations and pairing for determiners and suffixes in the training language. Across both training conditions the majority of participants showed little explicit awareness of determiner and suffix forms and their semantic associations in the language. However, participants in the simultaneous condition showed some awareness of the determiners and suffixes as well as their semantic associations. Participants in the sequential training condition also showed some awareness of the determiners and their semantic associations but compared to the simultaneous training condition showed less awareness of the semantic associations of the suffixes in the training language.
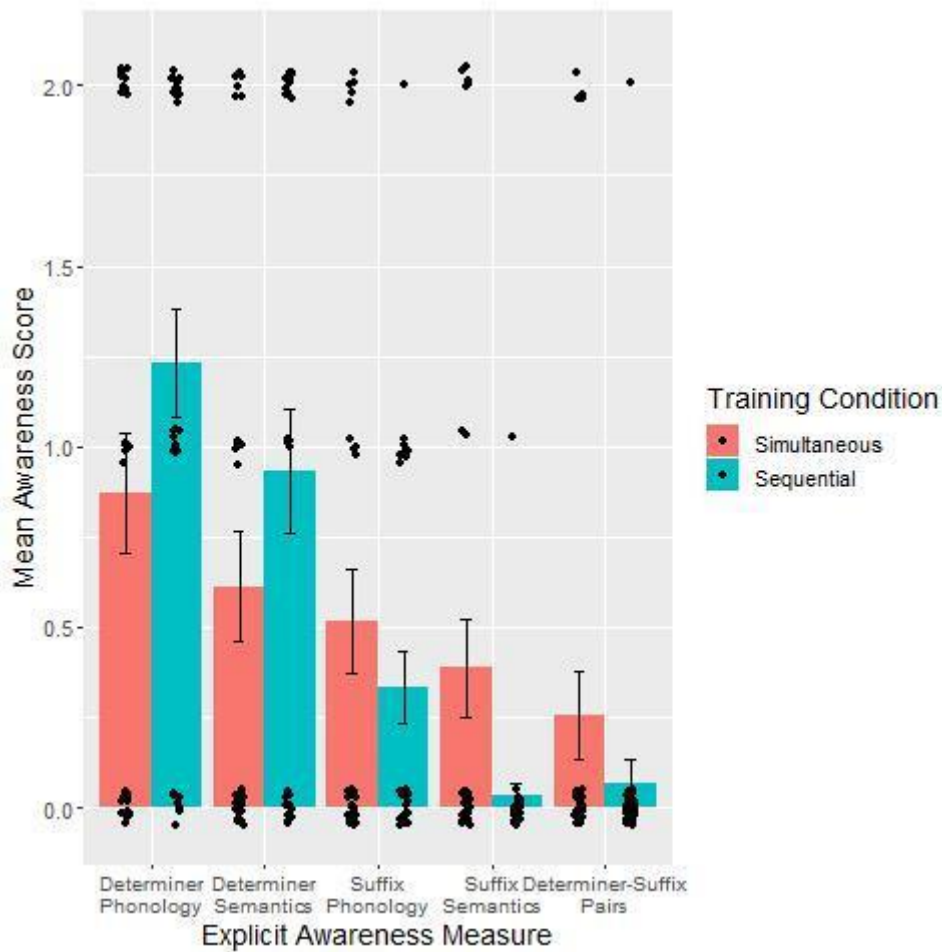
Figure 47. Mean explicit awareness scores for participants in the simultaneous and sequential training conditions.

As shown in Table 63 participants trained in the simultaneous condition showed significantly better awareness of suffix semantics than participants trained in the sequential condition. There were no other significant group effects for explicit awareness measures found in the other mixed-effects models.

Table 63. Linear regressions investigating training condition effects for each measure of explicit awareness.

Explicit Awareness Measure	Estimate	Std. Error	t-value	p-value
Determiner Forms	.362	.223	1.623	.110
Determiner Semantics	.320	.229	1.399	.167
Suffix Forms	-.183	.178	-1.029	.308

Suffix Semantics	-.354	.143	-2.479	.016
Determiner-Suffix Pairs	-.191	.141	-1.361	.179

No random effects included in the maximal models

Correlations between explicit awareness and generalisation

To investigate whether there was an association between explicit awareness and participants' ability to generalise semantic and phonological distributional cues several Pearson's correlations were conducted.

Correlations between phonological form generalisation after training was complete and explicit awareness of determiner forms, suffix forms and determiner-suffix pairs were carried out for participants in each training condition. As shown by Table 64 for participants in the simultaneous condition there were significant correlations between phonological form generalisation and explicit awareness of determiner forms (r(29)= .531, p= .002), suffix forms (r(29)= .710, p<.001) and determiner-suffix pairs (r(29)= .662, p<.001). For participants in the sequential training condition the only significant correlation was between phonological form generalisation and awareness of determiner-suffix pairs (r(28)= .362, p= .049).

Table 64. Pearson's correlations between explicit awareness measures and phonological form generalisation.

Training Condition	Correlation	Degrees of Freedom	r statistic	p-value
Simultaneous Condition	Determiner forms and phonological form generalisation	29	.531	.002
	Suffix forms and phonological form generalisation	29	.710	<.001
	Determiner-suffix pairs and phonological form generalisation	29	.662	<.001
Sequential Condition	Determiner forms and phonological form generalisation	28	.030	.875

		28	.004	.982
	Suffix forms and phonological form generalisation	28	.004	.982
	Determiner-suffix pairs and phonological form generalisation	28	.362	.049

Correlations between suffix generalisation and explicit awareness of suffix forms and suffix semantics were carried out for participants in each training condition. Table 65 shows that for participants in the simultaneous condition there were significant correlations between participants' ability to generalise the suffix to novel items and their explicit awareness of suffix forms (r(29)= .562, p= .001) and suffix semantics (r(29)= .514, p= .003). For participants in the sequential condition there were no significant correlations between their ability to generalise the suffix and explicit awareness measures.

Table 65. Pearson's correlations between explicit awareness measures and suffix generalisation.

Training Condition	Correlation	Degrees of freedom	r statistic	p-value
Simultaneous Condition	Suffix forms and suffix generalisation	29	.562	.001
	Suffix semantics and suffix generalisation	29	.514	.003
Sequential Condition	Suffix forms and suffix generalisation	28	.153	.420
	Suffix semantics and suffix generalisation	28	.317	.087

Correlations between determiner generalisation and explicit awareness of determiner forms and determiner semantics were carried out for participants in each training condition. Table 66 shows that for participants trained in the simultaneous condition, determiner generalisation was significantly correlated with explicit awareness of determiner forms (r(29)= .504, p= .004) and determiner semantics (r(29)= .587, p<.001). For participants trained in the sequential condition,

determiner generalisation was significantly correlated with explicit awareness of determiner forms (r(29)= .680, p<.001) and determiner semantics (r(29)= .590, p<.001).

Table 66. Pearson's correlations between explicit awareness measures and determiner generalisation.

Training Condition	Correlation	Degrees of freedom	r statistic	p-value
Simultaneous Condition	Determiner forms and determiner generalisation	29	.504	.004
	Determiner semantics and determiner generalisation	29	.587	<.001
Sequential Condition	Determiner forms and determiner generalisation	28	.680	<.001
	Determiner semantics and determiner generalisation	28	.590	<.001

Correlations between determiner-suffix generalisation and explicit awareness of determiner forms, determiner semantics, suffix forms, suffix semantics and determiner-suffix pairs for participants in each training condition. As shown by Table 67 in the simultaneous condition determiner-suffix generalisation was significantly correlated with explicit awareness of determiner forms (r(29)= .541, p= .002), determiner semantics associations (r(29)= .700, p<.001), suffix forms (r(29)= .589, p<.001), suffix semantics (r(29)= .610, p<.001) and determiner-suffix pairs (r(29)= .485, p= .006). In the sequential training condition, determiner-suffix generalisation was significantly correlated with explicit awareness of determiner forms (r(28)= .578, p<.001) and determiner semantics (r(28)= .637, p<.001).

Table 67. Pearson's correlations between explicit awareness measures and determiner-suffix generalisation.

Training Condition	Correlation	Degrees of Freedom	r statistic	p-value
Simultaneous Condition	Determiner forms and determiner-suffix generalisation	29	.541	.002

	Determiner semantics and determiner-suffix generalisation	29	.700	<.001
	Suffix forms and determiner-suffix generalisation	29	.589	<.001
	Suffix semantics and determiner-suffix generalisation	29	.610	<.001
	Determiner-suffix pairing and determiner-suffix generalisation	29	.485	.006
Sequential Condition	Determiner forms and determiner-suffix generalisation	28	.578	<.001
	Determiner semantics and determiner-suffix generalisation	28	.637	<.001
	Suffix forms and determiner-suffix generalisation	28	-.035	.856
	Suffix semantics and determiner-suffix generalisation	28	.093	.625
	Determiner-suffix pairing and determiner-suffix generalisation	28	.093	.625

In sum, correlations between explicit awareness measures and performance on the generalisation tasks suggest that participants in the simultaneous condition may have made better use of suffixes than participants in the sequential condition. In both training conditions, determiner phonology and determiner semantics were correlated with performance on the determiner and determiner--suffix generalisation tasks. However, suffix phonology and suffix semantics were only correlated with performance on the suffix and determiner-suffix generalisation tasks in the simultaneous condition.

5.3.4 Discussion

Experiment 6 explored whether semantic cues compete with phonological-distributional cues when both are available in a language and whether staggering the presentation of cues such that the least relevant cues are available before more competitive cues would enable participants to learn and

generalize associations between all three grammatical cues. Experiment 6 specifically addressed whether delaying the inclusion of semantics in the training language would enable participants to generalize determiner-suffix associations when they had the opportunity to learn suffixes before determiners.

In artificial language learning studies pseudowords presented alongside semantics are heard after participants have already seen a picture representing that word's meaning. If both cues are available throughout training then learners would encounter semantic cues first (Arnon & Ramscar, 2012; Culbertson et al., 2017; Havron & Arnon, 2021; Ramscar et al., 2010) and phonological-distributional cues second. When evaluating semantic cues as a predictor, learners will be able to use the word's meaning to predict the upcoming word stem (Arnon & Ramscar, 2012; Havron & Arnon 2021; Ramscar et al., 2010). In contrast, determiners, the first available phonological-distributional cue, would be heard after learners have seen the semantic cue and would be redundant as a predictor of word stems as participants could perfectly predict upcoming word stems using just semantics. This leads to semantic cues outcompeting both phonological-distributional cues for the learners' attention.

When applying the competition model to the two phonological-distributional cues in the training language, determiners would similarly be favoured over suffixes. Determiners are available earlier than suffixes in each word and can be used to reduce uncertainty when predicting word stems. In contrast, suffixes are the last cue available in each word and cannot be used to make predictions about word stems. Based on discriminative learning and the cohort model (Marslen-Wilson, 1987, 1988) this would lead participants to attend to determiners more than they do suffixes when both are available.

Taken together these comparisons suggest a hierarchy of grammatical cues. When all three cues are available during training, animacy of word meaning is at the top of this hierarchy, determiners are below animacy and suffixes are below both animacy and determiners. Blocking (Kamin, 1969), a component of discriminative learning further argues that as learners begin to acquire grammatical cues, unlearned cues which only provide redundant information will be blocked out.

Experiment 6 investigated whether sequential presentation of each phonological-distributional cue and the semantic cue can enable comprehensive learning of grammatical gender-like classes. This was done by comparing participants' ability to generalize associations between cues between two training conditions. The simultaneous condition replicated the suffix only condition in Experiment 5. Like in the suffix only condition participants were trained sequentially on suffixes and determiners

but semantics were present throughout. In the sequential condition participants were trained in three phases. In the first phase suffixes were the only grammatical cue available in the language. Determiners and semantics were then introduced to the language during the second and third phases of training respectively.

Based on the competition model, omitting the most relevant cues during training should enable participants to learn other cues which would normally be outcompeted, and based on blocking acquiring the least relevant cues should not interfere with subsequent learning of more relevant cues. As such, Experiment 6 first examined the prediction that like in Experiment 5 participants would be able to to learn suffixes and later generalize their semantic associations after being trained without determiners for the first phase of training. This was tested by comparing participants' performance on the suffix generalisation task against 0.5 in both training conditions.

While participants in the simultaneous condition were able to generalize suffix-semantic associations after training was complete, participants in the sequential condition were unable to despite also being exposed to suffixes without determiners for the first phase of training. A linear regression found no effect of training condition on suffix-semantic generalisation, meaning that the difference between conditions was not significant. Findings from the explicit awareness measures lend more insight into group differences. While there was no significant difference in participants' ability to identify suffixes between training conditions, participants trained without semantics for the first two phases of training were significantly worse at identifying suffix-semantic associations. Taken together these findings suggest that omitting semantics for the first two phases of training interfered with learning of suffix-semantic associations but not learning of the two suffixes. This suggests that participants' learning of suffix-semantic associations in the simultaneous condition was supported by semantics being present during their initial exposure to the language. As such while the difference was non-significant in the generalisation task, the direction of the difference and findings from the explicit awareness measures suggest that learning suffixes before semantics were introduced prevented participants from associating the suffixes with semantics.

Experiment 6 also examined the prediction that, like in Experiment 5, knowledge of the suffixes would not interfere with subsequent learning of determiners. This was tested by comparing participants' performance on the determiner generalisation task against 0.5 in both training conditions.

Comparisons against 0.5 showed that participants in the simultaneous condition were unable to generalize determiner-semantic associations after training while participants in the sequential

condition were. A linear regression found that training conditions had no significant effect on generalisation of determiner-semantic associations. Comparisons of participants' explicit knowledge of the determiners after training similarly shows no significant effect of training conditions on participants' knowledge of determiners and their semantic associations. While there is no significant effect of training condition, the direction of the difference suggests that delaying the inclusion of semantics until after determiners were introduced to the language may have led participants to associate determiner-semantic associations successfully in the sequential condition. Taken together with the successful generalisation of suffix-semantic association in the simultaneous condition this raises the possibility that learners more successfully generalize the associations between semantics and whichever phonological-distributional cue was most relevant at the time semantics were introduced.

Unique to Experiment 6 was the prediction that training participants on each cue sequentially beginning with suffixes before introducing determiners and then semantic cues would enable participants to learn and generalize the association between the two least relevant cues: determiners and suffixes. This was tested by comparing phonological form generalisation between participants trained in the simultaneous and sequential conditions.

In contrast to our predictions, training participants sequentially on suffixes and determiners before semantics were introduced did not enable learning of determiner-suffix associations. There was no significant effect of training conditions on participants' ability to generalize associations between determiners and suffixes nor was there any interaction between training condition and length of training. This contradicts the competition model, demonstrating that the presence of semantics which should outcompete both phonological-distributional cues does not interfere with learning of determiner-suffix associations. These findings suggest that contrary to the competition model and discriminative learning semantic and phonological-distributional cues do not compete for prioritisation by the learner.

Participants' ability to generalize associations between determiner-suffix pairs and semantic cues was also tested at the end of training, although specific predictions were not made regarding this test it does lend some more insight into which cues participants in each condition are using. Participants in both conditions were able to generalize the association between determiner-suffix pairs and the animacy of each word's meaning based on comparisons against 0.5. However, when correlating their explicit awareness of different cues and associations with their performance on the determiner-suffix generalisation task, participants in the simultaneous condition showed significant correlations for explicit awareness of both phonological-distributional cues and all of their

associations. In contrast participants in the sequential condition only showed significant correlations for awareness of determiners and their semantic associations. This suggests that while participants in the simultaneous condition were able to employ both phonological-distributional cues to discriminate against ungrammatical items, participants in the sequential condition were only able to use determiners to decide whether an item was grammatical.

Overall the findings in the simultaneous condition successfully replicated the key finding in Experiment 5: namely, that training participants on a language with only suffixes and semantics enabled learners to learn the suffixes and their semantic associations. In relation to blocking there is no evidence that training participants on suffixes and their semantic associations first interfered with learning of determiners and determiner-semantic associations. However, in both Experiment 5 and 6 the ability to generalize determiner-semantic associations bordered on non-significance leaving it inconclusive whether participants trained sequentially on suffixes before determiners were able to learn determiner-semantic associations.

Comparisons between training conditions in Experiment 6 suggest a more complicated picture of competition between semantic and phonological-distributional cues than the hierarchy derived from the competition model and discriminative learning. Rather than the presence of more relevant cues interfering with learning of less relevant cues these results suggest that the phonological-distributional cues may compete with each other to be associated with semantics.

5.4 Discussion

Experiments 5 and 6 aimed to address whether phonological-distributional cues compete with each other for relevance during language acquisition and whether learners can acquire multiple competing cues when those cues are presented sequentially from least to most relevant. The question of whether phonological-distribution competes with each other is addressed primarily by Experiment 5 however Experiment 6 lends some additional insights into the relationship between cues.

5.4.1 Competition between phonological-distributional cues

Based on the competition model (Bates & MacWhinney, 1989; Culbertson et al., 2017) and discriminative learning (Arnon & Ramscar, 2012; Havron & Arnon, 2021; Ramscar et al., 2010; Ramscar & Port, 2016) when determiners and suffixes are both available as cues during word learning, participants would favour determiners as they are available earlier in each word and can be used to narrow down candidates for the word's stem. The cohort model lends further support to

this, establishing that learners use sounds from the beginning of a word to recognise words faster than would otherwise be possible (Marslen-Wilson, 1987, 1988).

In addition to theoretical background, previous studies have found that participants were able to generalize suffix-semantic association when trained on a language which had suffixes and semantic cues but no determiners (Tamminen et al., 2015; Vujović et al., 2021). While this can be contrasted against our previous experiments in which participants were unable to generalize suffix-semantic associations in a language with determiners, suffixes and semantic cues, how the presence of the determiner affects suffix learning between otherwise equivalent conditions has not been addressed.

In answer to these predictions, participants in experiment 5 trained with only suffixes and semantic cues were able to generalize suffix-semantic associations where participants in our previous experiments were unable to. Further, they showed a significant advantage over participants in training with determiners, suffixes and semantic cues throughout training, and this advantage remained even when participants trained with suffixes and semantics were taught determiners in the second phase of training. This suggests that as predicted by the competition model, discriminative learning and the cohort model the presence of determiners during learners' initial exposure to the language does interfere with their ability to learn suffixes. These findings align with previous literature (Tamminen et al., 2015; Vujović et al., 2021) which suggested that participants could generalize suffix-semantic associations in languages without determiners. This underlines the need to consider each phonological-distributional cue a separate marker in the language when evaluating how learners use cues.

One aspect of discriminative learning which was unanswered by our findings is whether learning suffixes, the least relevant cue in the training language, interfered with subsequent learning of determiners. Based on blocking (Kamin, 1969), a component of discriminative learning, learning cues which are more relevant as predictors of word stems will interfere with learning of less relevant cues. According to blocking, less relevant cues such as suffixes will not interfere with learning of more relevant cues such as determiners. In our experiment training participants on suffixes before determiners had no significant effect on whether participants generalised determiner-semantic associations in the language. However, comparisons against 0.5 were borderline leaving it unclear whether participants successfully learned determiner-semantic associations in either condition.

One discrepancy that needs to be addressed between our findings and the literature is how participants in previous studies were able to learn and generalize associations between determiners and suffixes when learning a language without semantic cues. If as our findings suggest, determiners

are learned first based on their earlier presence in words and acquisition of determiners then interferes with subsequent learning of suffixes, it raises the question of how were participants able to generalize the association between both cues when learning a language with determiners and suffixes. One possible explanation for this is that the studies investigating non-adjacent dependencies trained participants using speech streams rather than individually presenting each word. One way in which suffixes can be used to make predictions in natural languages is by associating them with subsequent speech. In our artificial language learning paradigm the language is taught as individual pseudowords paired with their meanings which may have led to suffixes being devalued by our design.

While experiment 5 did not demonstrate that poor suffix learning was responsible for participants not being able to generalize associations between the two phonological-distributional cues, it presents a clear picture of determiners and suffixes competing for attention as outlined in the competition model. While the specifics of which properties lead to greater success in this competition were not specifically addressed in our methods, the preference displayed for determiners when presented together matches the properties of availability and predictive validity suggested by discriminative learning and the cohort model.

A key limitation to consider when evaluating the results of experiment 5 is that across conditions semantic cues were consistently available. As such, while the findings of experiment 5 suggest that competition does occur between determiners and suffixes, the presence of semantic cues in the background of this competition is not evaluated. This leaves it unclear whether the presence of semantics and semantic cues has any influence over the competition between determiners and suffixes. One possibility raised at the end of experiment 5 was that participants' inability to generalize associations between determiners and suffixes in the suffix only condition was because of the presence of semantics. The presence of semantic cues as the most relevant cue available in the training language, could have led participants to prioritise associations with the semantic cue over the association between the phonological-distributional cues.

5.4.2 Competition between semantic and phonological-distributional cues

When semantic cues are included alongside phonological-distributional cues in a language, the competition model and discriminative learning argue that the semantic cue would be favoured over both phonological-distributional cues as semantic cues are seen before participants have heard any other cues in the language (Arnon & Ramscar, 2012; Culbertson et al., 2017; Havron & Arnon, 2021)

and can be used to predict the upcoming word by associating a specific word meaning with the upcoming word (Arnon & Ramscar, 2012; Havron & Arnon, 2021).

When considering semantic cues alongside determiners and suffixes as two separate phonological-distributional cues, the competition model and discriminative learning can be used to suggest a hierarchy of cues with semantics at the top followed by determiners and then suffixes. In language learning this would lead to learners learning semantic cues and associating the first phonological-distributional cue learned with semantics. As determiners are above suffixes in this hierarchy, presenting all three cues simultaneously will lead to participants associating the more relevant cues in the language with each other, learning the determiner-semantic associations, but following this they will block out suffixes as a redundant cue. If participants are trained on suffixes before determiners, this would lead to participants associating both cues with semantics, as suffixes wouldn't interfere with learning of determiners. But they would not associate the phonological-cues with each other as learners would prioritise associations with the semantic cue. This paints a simple view of cue competition in which all cues in the language compete with each based only on their availability and value as a predictor.

Previous literature which has measured learning of semantic and phonological-distributional cues separately supports the notion that semantic cues interfere with learning of phonological-distributional cues in the language. These studies have found that participants were able to generalize semantic associations in the language but failed to generalize the association between phonological-distributional cues (Hickey, 2022; Mirković et al., 2021; Vujović et al., 2021). Contrasting this, in studies measuring only the learning of only phonological-distributional cues, participants were able to generalize the phonological-distributional associations in the language (Frigo & McDonald, 1998; Gomez, 2002; Vuong et al., 2016). Taken together these provide evidence in the literature that the presence of semantic cues in language can interfere with learning of associations between phonological-distributional cues.

Experiment 5 has further demonstrated that when trained on suffixes before determiners participants displayed an advantage when generalizing suffix-semantic associations. These findings support the notion of cues competing for relevance with a hierarchy of cues where after learning the most relevant cues in a language participants block out less relevant cues.

Experiment 6 attempted to expand the competition demonstrated in experiment 5 by investigating whether the presence of semantic cues from the outset of training interferes with learning of associations between suffixes and determiners. Like in experiment 5 participants were trained on

suffixes before determiners were introduced, however experiment 6 then investigated how delaying the presence of semantics until a third phase of training affected learning of both phonological-distributional cues and their associations. Based on the competition model and discriminative learning it was predicted that the absence of semantic cues would enable participants to learn both phonological-distributional cues and the associations between them, following this it was predicted that when semantics were introduced participants would be able to learn the more relevant associations between semantic and phonological-distributional cues.

In contrast to our predictions, experiment 6 found that delaying the inclusion of semantic cues didn't enable participants to generalize the association between phonological-distributional cues. While there was no significant effect of training conditions on suffix generalisation, the direction of the difference between conditions instead suggests that, if anything, omitting semantics from the first two phases of training negatively affected generalisation of suffix-semantic associations. The difference while non-significant is in line with results from the explicit awareness measures which found participants were worse at identifying suffix-semantic pairings after training. There was a borderline significant effect (p= .053) of training condition on the determiner generalisation task which suggests that omitting semantics until the third phase of training supported generalisation of determiner-semantic associations.

These results contradict the competition model and discriminative learning, finding that presenting the less relevant phonological-distributional cues before semantics did not benefit participants learning of the phonological-distributional cues or their associations. In addition to semantics not interfering with learning of phonological-distributional cues, these findings also complicated the relationship between determiners and suffixes. If the two cues were competing only with each other based on their availability and predictive value then omitting semantics should not have benefitted learning of determiners to the exclusion of suffixes.

In experiment 6 participants showed a borderline significant advantage in the determiner-semantic generalisation when determiners were present during their first exposure to semantics. When only suffixes were available during their initial exposure to semantics, participants showed a non-significant advantage in the suffix-semantic generalisation. This raises the possibility that rather than all three cues competing equally both phonological-distributional cues compete with each other to be associated with semantics.

While this cannot be explained using the competition model or discriminative learning, it is in line with the semantic binding hypothesis (Patterson et al., 1994). The semantic binding hypothesis was

devised to explain why participants showed an advantage when recalling known words over novel pseudowords. In contrast to the competition model the semantic binding hypothesis argues that semantic representations for words support learners' recall of phonological-distributional properties in the language. According to the semantic binding hypothesis, familiar words can be recalled more easily because participants take advantage of associations between different sounds in the word to recall it more accurately. These phonological associations are in turn supported by semantics which co-occur with phonology during both learning and recall.

Savill et al. (2017) provides evidence that the presence of semantics supports recall of word phonology using an immediate serial recall task. During their study participants were trained on two sets of items; pseudowords paired with semantically-trained artefacts and pseudowords with no associated meaning. Participants' ability to repeat back sets of four words was used to test whether the presence of semantic referents for each word affected immediate recall. They found that participants were able to accurately recall pseudowords paired with semantically-trained artefacts significantly more often than pseudowords with no associated meaning during the task. Studies conducted by Savill and others have similarly found a benefit of semantic associations for immediate word recall (Savill et al., 2015, 2018) and word learning (Pomper & Saffran, 2018).

Reframing our findings through the semantic binding hypothesis, the presence of semantics supports recall of phonological forms. As such when participants were trained with only suffixes and semantics, participants learned suffixes better because they were able to associate them with semantics. From this perspective the presence of determiners still interferes with suffix learning, but rather than the two cues competing for relevance on their own they are competing to be associated with semantics. As such in experiment 6 delaying the inclusion of semantics benefitted learning of determiner-semantic associations because determiners were available during participants initial exposure to semantics.

Chapter 6. General Discussion

Across six experiments we addressed how the presence of semantic cues affects learners' perception of phonological-distributional cues when both are available in a language. More specifically, we used an artificial language learning paradigm to investigate whether learners favour semantic cues and subsequently block out associations between phonological-distributional cues when generalizing a novel grammar. In experiments 1 and 2 we were able to demonstrate that participants acquire individual word forms and meanings but found that their ability to learn

semantic cues was relatively poor compared with previous findings (Hickey, 2022; Mirković et al., 2021). In experiments 3 and 4 we found that omitting semantic cues or even omitting semantics entirely did not enhance participants' generalisation of phonological-distributional cues. Finally in experiments 5 and 6 we were able to demonstrate that phonological-distributional cues in our artificial language may compete with each for relevance and that this competition may determine which cues are associated with semantic cues.

Before experiment 1 a power analysis was conducted for sample size estimation based on data from Mirković et al. (2021). As the experiment did not compare participants in the same training conditions as were used in this thesis, the power analysis instead calculated the number of participants needed to find significant evidence of phonological form generalization with a significance criterion of $\alpha= .05$ and a power of .80. The phonological form generalization test was prioritized in the power analysis because it was important to each experiment's predictions and is the generalization test that participants have historically had the poorest performance on (Hickey, 2022; Mirković et al., 2021).

This power analysis confirmed that at least 29 participants per group was sufficient to find significant evidence of phonological form generalization. Based on this we can be confident that participants' inability to generalize associations between determiners and suffixes observed across multiple experiments is representative of performance within the population rather than being an indicator of an insufficient sample size.

6.1 Learning of trained words

Previous language learning studies have consistently found that participants are able to learn individual words and when semantics are present to associate those words with their individual meanings (Hickey, 2022; Mirković et al., 2021). Based on this we predicted that participants would be able to recognise words forms and meanings across our experiments.

As we had predicted participants were able to recognise familiar words during phonological form recognition tasks and were able to select trained word's meanings when contrasted against a foil picture used for a different word in the training language. Across our experiments participants were able to learn word forms very quickly. For example, in experiments 1 and 2 participants were able to recognise word forms after a single exposure to the training language. Following this a further two exposures to the training language enhanced word form recognition but in experiment 2 increasing

the number of exposures to the language from three to nine did not significantly increase performance on the phonological form recognition task.

Similarly, participants demonstrated that they were able to select word meanings after as few as three exposures to the training language in experiments 1 and 2. Notably in experiment 2 increasing the number of exposures to the language from three to nine enhanced recognition of word meanings during the 2AFC tasks, suggesting that participants learned trained words faster than they learned to associate them with their meanings.

Experiments 3 and 4 primarily addressed how the presence of semantics separate from semantic cues affected learning of phonological-distributional cues. However, as part of this we compared how the presence of semantics in the training language affected learning of word forms. In experiments 1 and 2 we had already established that participants could learn word forms from a single exposure to the training language without semantic cues. However, when evaluating how the presence of semantics could affect learning of word forms, the semantic binding hypothesis (Patterson et al., 1994; Pomper & Saffran, 2018; Savill et al., 2015, 2018) suggested that as words and their meanings co-occur during language acquisition and recall, learners associate meaning with co-occurring sounds within words to support recollection of word forms. In experiments 3 and 4 participants demonstrated word recognition across training conditions, however, the presence of semantics during training had no effect on performance in the phonological form recognition task. This contradicts the findings of the semantic binding hypothesis suggesting that participants' ability to recall words did not benefit from associating those words with specific meanings during training.

Alongside the phonological form recognition task experiment 4 also included a speeded shadowing task as an alternate measure of word form learning. Notably the findings from the speeded shadowing task support the semantic binding hypothesis, demonstrating that participants repeated back trained words significantly faster than novel words when they had been with word forms and semantics. Taken together the findings from experiments 3 and 4 suggest that while the presence of semantics may enhance learning of word forms, this is not captured by the phonological form recognition task where participants' performance is consistently close to ceiling.

When considering participants learning of trained words during this experiment, the use of the repetition task during training has some implications for word learning. The production effect is a well-established phenomenon wherein being made to pronounce a word aloud enhances memory of that word. Multiple explanations have been proposed to explain why production would enhance

word learning, one is that production gives participants additional exposure to the word, another is that vocalizing a word requires more engagement than just passive listening and a third explanation is that production provides an opportunity to practice retrieving the word from memory (Hopman & MacDonald, 2018; Karpicke & Roediger, 2008). Based on this effect the use of a repetition task during training may have enhanced performance on measures of word learning compared to studies which only required participants to listen to and make decisions about the training language.

Mirković et al. (2021) demonstrates that introducing production during the artificial language learning paradigm not only enhances learning of word forms but also enhances learning and generalization of semantic associations in a language. This was demonstrated by comparing performance on measures of word learning and generalization between their second and third experiments. In both experiments, participants were trained on a set of 24 pseudowords by listening to each word and completing a word-picture matching task. The experiments differed from each other in the number of exposures to the language and the presence of a production element. In the second experiment there were nine blocks of training with no production element, in contrast the third experiment included only two blocks of training but required participants to repeat back each word during training.

In line with the production effect Mirković et al. (2021) found that participants demonstrated similar levels of word learning despite having fewer exposures to the language when made to repeat words during training. This suggests that the inclusion of a production element during training compensated for the fewer exposures to the training language. They also found that participants were able to generalize suffix-semantic associations when they were trained with a production element but not when given more exposures without a production element. Based on these findings the inclusion of a repetition task during training across our experiments may have enhanced performance on measures of word learning and generalization of semantic associations.

While the literature supports the notion that production can enhances word learning in the short-term, evidence from Kapnoula & Samuel (2022) complicates this by suggesting that over longer periods of training production may instead interfere with the quality of lexical representations developed during training. They found that after 12 exposures to a set of 8 novel words, participants trained by passively observing the stimuli reacted significantly faster when associating words with a semantic referent than participants required to produce words during training. One explanation offered for this finding is that requiring participants to immediately repeat back a word requires attentional resources to be allocated to production which could otherwise be used for encoding.

From this perspective production itself is not the issue, instead immediate production is a missed opportunity to use attentional resources to encode the word while listening to it.

Accepting this explanation, the combination of repetition and word picture matching tasks in experiments 3-6 and during the third experiment in Mirković et al. (2021) may have allowed participants to benefit from the production effect while also having the opportunity to encode the word without repeating it during the word-picture matching task.

6.2 Generalisation of semantic associations in the language

In previous artificial language learning studies, participants demonstrated learning of semantic cues by generalizing semantic associations from the training language to novel words (Hickey, 2022; Mirković et al., 2021). Across our experiments participants have likewise been able to generalize semantic associations to determiners-suffix pairs. This suggests that during language learning participants recognised that the meanings assigned to trained words in the artificial language were either animals or artefacts and that participants were able to associate the animacy of word meanings with determiner-suffix when encountering novel words. However, this finding doesn't address which phonological-distributional cues participants learned and whether they were able to associate each phonological-distributional cue with animacy.

To address this our experiments tested whether participants were able to generalize associations between semantic cues and individual phonological-distributional cues using two separate semantic generalisation tasks. These tasks addressed whether learners were able to associate animacy of word meanings with determiners or suffixes individually, allowing us to examine which cues participants were able to acquire by assessing whether they could associate them when encountering novel words. Our experiments generally found that participants endorsed novel words which had consistent determiner-semantic pairings over inconsistent words. However, unlike performance on the determiner–suffix generalisation task, there were multiple instances across our experiments where participants in specific training conditions were unable to generalize determiner-semantic associations. Overall findings from our experiment suggest that learners can acquire determiners during language acquisition and associate them with semantic cues such as animacy.

While our experiments found that learners could associate determiners with semantic cues, in experiments 1-4 we found that participants were unable to generalize associations between animacy of word meanings and suffixes to novel words. In experiment 5 we addressed this by investigating competition between phonological-distributional cues, finding that delaying the inclusion of

determiners in the language enabled participants to generalize suffix-semantic associations to novel words. When considering this alongside findings from explicit awareness measures which showed participants were for the most part unable to identify suffixes in the training language, these findings suggest that the poorer suffix-semantic generalisation observed in our experiments could be attributed to poorer learning of suffixes.

Overall, across our experiments participants demonstrated that they were able to learn semantic cues and generalize associations with semantic cues to novel words. This aligns with previous literature which similarly found that participants were generally capable of associating semantic and phonological-distributional cues in an artificial language (Hickey, 2022; Mirković et al., 2021).

6.3 Competition between phonological-distributional cues

Over the course of experiments 1-4 we observed that participants were unable to associate determiners and suffixes with each other in the phonological form generalisation task, nor were they able to generalize suffix-semantic associations in the suffix generalisation task. In experiment 5 this led to us investigating whether determiners and suffixes compete with each other for relevance as outlined by the competition model (Bates & MacWhinney, 1989; Culbertson et al., 2017) and discriminative learning (Arnon & Ramscar, 2012; Havron & Arnon, 2021; Ramscar et al., 2010; Ramscar & Port, 2016). Based on the competition model and discriminative learning when cues are in competition with each other, learners will favour cues which are available earlier (Arnon & Ramscar, 2012; Culbertson et al., 2017; Havron & Arnon, 2021; Ramscar et al., 2010) or can be used to predict the upcoming word (Arnon & Ramscar, 2012; Havron & Arnon, 2021; Ramscar et al., 2010). After participants learn a favoured cue, competing cues are then compared against the already learned cue and are blocked out if they do not provide additional predictive value (Kamin, 1969).

When applied to determiners and suffixes as two separate phonological-distributional cues we observed that determiners, due to their placement at the beginning of words, were heard before suffixes and could be used to narrow down the number of candidates when predicting upcoming word stems. In contrast, suffixes could not be used to make predictions as each pseudoword in the training language was presented in isolation with presentation order randomised during training.

Based on this, experiment 5 investigated whether delaying the inclusion of determiners until the latter half of training would enable participants to learn suffixes and subsequently generalize suffix-semantic associations to novel words. In line with the competition model and discriminative learning

experiment 5 showed that omitting determiners from the first half of training enhanced suffix-semantic generalisation. When taking together with our previous experiments, these findings suggest that when both determiners and suffixes are available in a language, determiners interfere with learning of suffixes, but when participants are trained without determiners they are able to learn suffixes and associate them with semantic cues. In line with discriminative learning, acquiring suffixes in the first half of training did not come at the expense of participants' learning of determiners. This suggests that as outlined in discriminative learning participants can acquire multiple cues so long as cues learned after the first provide additional predictive value.

When discussing competition between determiners and suffixes in our artificial language learning paradigm one key limitation to consider is how training participants on individual word forms in our experiments may have devalued suffixes as a cue. In natural languages learners encounter novel words in the context of full sentences. Under these conditions determiners can be used to make inferences about the word they are attached to while suffixes can be used to make inferences about subsequent words. As suffixes cannot be used to make predictions when learning words individually this may have caused a preference for determiners over suffixes which would not occur when learning novel words in a sentential context. There is some evidence for this in the previous language learning studies which have found that participants were able to generalize associations between determiners and suffixes when learning novel words from either speech streams (Gomez, 2002; Vuong et al., 2016) or when contextualised as time specific greetings directed at different classes of people (Frigo & McDonald, 1998).

6.4 Competition between semantic and phonological-distributional cues

From the outset, we aimed to address how semantic cues interacted with phonological-distributional cues when both were available during language learning. Based on the competition model (Bates & MacWhinney, 1989; Culbertson et al., 2017) and discriminative learning (Arnon & Ramscar, 2012; Havron & Arnon, 2021; Ramscar et al., 2010; Ramscar & Port, 2016) we anticipated that when both cues were available in a language, semantic cues would outcompete phonological-distributional cues leading to poorer acquisition of phonological-distributional cues by the end of training. Discriminative learning suggested that semantic cues may be favoured because when learning word-picture pairs semantic cues are available before phonological-distributional cues (Arnon & Ramscar, 2012; Culbertson et al., 2017; Havron & Arnon, 2021; Ramscar et al., 2010) and can be used to predict upcoming word stems (Arnon & Ramscar, 2012; Havron & Arnon, 2021; Ramscar et al., 2010). In contrast, phonological-distributional cues can only narrow down the

number of possible candidate stems. Across experiments 1-4 it was predicted that omitting semantic cues from the training language may enhance learning of phonological-distributional cues and enable participants to generalize associations between phonological-distributional cues.

Experiments 1 and 2 were unable to address how the presence of semantics affected learning of phonological-distributional cues. However, experiments 3 and 4 both found that omitting semantics from the training language did not enhance learning of phonological-distributional cues. In experiment 4 the speeded shadowing task did find an effect of omitting semantics on participants' responses to pseudowords which had inconsistent phonological-distributional cues. However, the difference observed in the speeded shadowing task showed that participants trained with semantics responded faster to inconsistent items contradicting both the predicted effects of training and the congruency effect which the speeded shadowing task was based on. Following these experiments we observed that participants were not showing implicit or explicit awareness of suffixes in the suffix generalisation task and explicit awareness measures respectively. This raised the possibility that an effect of semantics could not be found because participants across conditions had not acquired implicit knowledge of suffixes required to generalize associations between phonological-distributional cues.

Experiments 5 addressed whether participants were unable to generalize phonological-distributional cues because they lacked prerequisite knowledge of suffixes required to associate them with determiners. However, while delaying the inclusion of determiners enabled participants to learn determiners and suffixes by the end of training, as shown by participants generalizing semantic associations to determiners and suffixes, participants were unable to generalize associations between phonological-distributional cues. This led to experiment 6 addressing whether competing cues could be organised into a hierarchy where acquiring more relevant cues interferes with subsequent learning of cues lower in the hierarchy.

Experiment 6 investigated whether training participants sequentially on suffixes before introducing, determiners and animacy of word meanings in the second and third phases of training respectively may enable participants to generalize associations between determiners and suffixes. It also replicated the findings of experiment 5 by testing participants trained on suffixes and animacy of word meanings before semantics were introduced. Contrary to the competition and discriminative delaying the inclusion of semantic cues did not enhance learning of phonological-distributional associations. In fact, participants across conditions were unable to generalize phonological-distributional associations. We did however find that the inclusion of semantic cues during training

may have affected which affixes participants associated with semantic cues. Participants trained on suffixes and animacy of word meaning in the first phase of training were able to generalize suffix-semantic associations by the end of training but not determiner-semantic associations which were available from the second phase of training onwards. In contrast, participants trained on only suffixes in the first phase of training before determiners and semantics were introduced were able to generalize determiner-semantic associations but not suffix-semantic associations. This finding in particular stands out as when semantics were delayed until the last phase of training, determiner-semantic and suffix-semantic associations could only be acquired in the third and final phase of training.

Taken together these findings suggest that participants may only have generalised whichever phonological-distributional cue was most relevant when semantics were introduced to the training language. This would explain why participants with only suffixes and animacy of word meaning as cues generalised suffix-semantic associations but participants trained with determiners and suffixes before semantics were introduced were only able to generalize determiner-semantic associations. In contrast to the competition model and discriminative learning this would suggest that rather than semantic cues competing with phonological-distributional cues, determiners and suffixes competed with each other to be associated with semantic cues.

When evaluating these conclusions it is important to emphasise that training condition had no significant effect on performance in either the determiner or suffix generalisation tasks. There was a borderline effect observed for the determiner generalisation task (p= .053) but it was ultimately non-significant. As such while the direction of the differences lends to our speculation the differences observed cannot be considered significant or meaningful. One contributing factor in our experiments which may have prevented us from observing significant differences in the semantic generalisation tasks was the limited number of stimuli used using testing. For example in experiment 6 each generalisation task only employed 8 test items, 4 which were consistent with the training language and 4 which were inconsistent. This was done primarily because our focus was on the phonological-form generalisation tasks, but given the direction of the differences observed, expanding on these tasks may lend us greater insight into how semantic cues interact with phonological-distributional cues in language.

6.5 Implicit and Explicit Mechanisms

Statistical learning is generally understood to be a process which occurs unconsciously, producing implicit representations which learners can use to make determinations about a language but which they are unable to verbalise (Aslin & Newport, 2012; Christiansen, 2019; Seidenberg & MacDonald, 2018). In the artificial language learning paradigm employed in the present study and previous literature (Hickey, 2022; Mirković et al., 2021), training on regularities in the language was implicit. Participants were taught via exposure to words and word-picture pairs with the instructions providing no information regarding the properties of the words or pictures. Instead, the word-picture matching task instructed participants to determine whether specific word-picture pairs went well together to avoid any implication that there was a grammatical regularity in the training language.

Despite the lack of explicit instruction, previous artificial language learning studies have demonstrated that when asked after training, a minority of participants were able to explicitly identify cues and their associations (Hickey, .2022; Mirković et al., 2021). Further, in several studies, participants' ability to outline associations in the training language was associated with their performance on implicit measures of grammar learning (Batterink et al., 2015, 2019; Mirković et al., 2021; Rebuschat & Williams, 2012). These findings contrast the understanding of statistical learning as an implicit mechanism.

Across our experiment participants' explicit knowledge of both phonological-distributional cues, their semantic associations, and their association with each other were measured after training and testing were complete. Like previous artificial language learning studies (Hickey, 2022; Mirković et al., 2021) a subset of participants were able to identify determiners by the end of training and verbalise how determiners were associated with the semantic cue present in the language. Expanding on this, across experiments 1-6 explicit awareness of determiners and determiner-semantic associations was correlated with performance on both the determiner and determiner-suffix generalisation tasks. Additionally, in experiments 5 & 6 when group manipulations enhanced performance on the suffix generalisation task, explicit awareness of suffixes and suffix-semantic associations were both significantly correlated with performance on the suffix generalisation task and the determiner-suffix generalisation task. In experiments 5 & 6 explicit awareness of determiner-suffix pairs was correlated with performance on the phonological form generalisation task.

These findings suggest that explicit awareness emerges in a subset of participants alongside implicit awareness during the artificial language learning paradigm. It also suggests that participants' ability to verbalise grammatical regularities from the artificial language was associated with their ability to generalize those associations to novel words during testing. In experiments 5 & 6, these findings are demonstrated for the suffix generalisation and phonological form generalisation tasks when implicit

awareness of suffixes was enhanced by group manipulations. However, based on these findings alone it is unclear what the direction of this relationship is leaving it uncertain whether greater implicit awareness results in explicit awareness or whether developing an explicit awareness of grammar during the course of learning enhanced implicit awareness.

6.6 Generalizability to participants with different language backgrounds

In this study we have demonstrated that when learning a novel grammar which mimics grammatical gender classes, monolingual English-speakers may be learning the first phonological-distributional cue they encounter alongside semantics but then blocking out the remaining phonological-distributional cue. When evaluating this finding it is worth considering to what extent if any these findings can be applied to participants with different language backgrounds. In this discussion, we have explained why phonological-distributional cues would compete for relevance using the competition model (Bates & MacWhinney, 1989, Culbertson et al., 2017) and discriminative learning (Arnon & Ramscar, 2012; Havron & Arnon, 2021; Ramscar et al., 2010; Ramscar & Port, 2016) so it is worth evaluating whether either theory suggests that previous language experience would affect cue competition.

Based on the competition model the pattern of competition between phonological-distributional cues observed in experiments 5 & 6 should be generalizable to participants across different language backgrounds. The competition model argues that redundant cues are available across different languages because they help to communicate word meaning and that when interpreting meaning, learners weigh cues based on their validity and predictive value (Bates & MacWhinney, 1989). From this perspective the learner's previous language background does not influence the availability, reliability, or predictive value of unfamiliar cues in a novel language and as such would not affect which cues participants learn and generalize.

Discriminative learning similarly suggests that language background would not affect cue competition. Discriminative learning explains language acquisition as an error-driven process in which learners form expectations while listening to early input which are then tested as they hear more of the language (Ramscar et al., 2010; Ramscar & Port 2016). Within this framework cues are valued based on how useful they are for predicting upcoming word sounds. As the present findings are based on a novel language, familiarity with similar cues in a different language would not help participants predict upcoming word stems or suffixes and as such language background would not affect cue preference according to discriminative learning.

While few studies have compared cue learning between participants from different language backgrounds, Lew-Williams & Fernald (2010) provides some evidence that may suggest familiarity with grammatical gender from a native language affects how well participants can make use of gendered determiners in their native language. As outlined in the literature review, their first experiment found that native Spanish speaking adults and children were able to use gendered determiners to identify the semantic referent of a target noun faster. In contrast native English speakers who had learned Spanish as a second language were unable to identify semantic referents faster when gendered determiners were available to exploit. While this provides evidence that language background can affect how well participants use determiners from their own language, evidence from their second experiment suggests that this finding does not apply to similar cues in unfamiliar languages.

In their second experiment Lew-Williams & Fernald (2010) found that when the determiner and target noun were unfamiliar, both native and non-native Spanish speakers used gendered determiners to identify semantic referents faster. Taken together, these findings suggest that the advantage native Spanish speakers showed when using determiners to predict upcoming words only applied to identifying words in their native language and that when using determiners to identify novel words previous experience with grammatical gender classes did not enhance performance.

Overall, the competition model and discriminative learning both suggest that the findings of this thesis are generalizable to participants from other language backgrounds. Additionally, evidence from Lew-Williams and Fernald (2010) suggests that familiarity with grammatical gender from a native language does not affect how well participants can use determiners in novel languages modelled on grammatical gender.

6.7 Overall conclusions

Overall, our findings demonstrate that phonological-distributional cues may compete with each other for relevance during language acquisition. We have also demonstrated that when learning words individually without the context of full sentences as is the case in the artificial language learning paradigm, participants seemed to favour determiners over suffixes. We have demonstrated this by showing that participants were able to generalize associations between determiners and semantic cues but were unable to generalize associations between suffixes and semantic cues. In our experiments we have not investigated how training participants on a language using constructed sentences may affect competition between determiners and suffixes. However, based on previous literature (Frigo & McDonald, 1998; Gomez, 2002; Vuong et al., 2016) and the predictive value of

cues outlined by discriminative learning (Arnon & Ramscar, 2012; Havron & Arnon, 2021; Ramscar et al., 2010), suffixes may be more relevant and thus more likely to be acquired when they can be used to predict subsequent words in a sentence. In future studies it would be useful to investigate whether training participants in a sentential context would affect learning of determiners and suffixes in a language.

In relation to how the presence of semantic cues affects learning of phonological-distributional cues, our findings clearly demonstrate that the presence of semantics and semantic cues do not interfere with learning of phonological distributional cues as predicted by the competition model and discriminative learning. Instead, based on findings in experiments 5 and 6, phonological-distributional cues may compete with each other, with the more relevant cue being associated with semantic cues. This dynamic is still underdeveloped in our experiments and would require more study to substantiate. A particular issue with our experiments is that due to our focus on participants' generalisation of associations between phonological-distributional cues the semantic generalisation tasks employed fewer test items which may have prevented us from observing differences between training conditions.

If later research were to address whether, as we have speculated, phonological-distributional cues compete with each other to be associated with semantic cues, a greater number of stimuli would be needed when testing generalisation of semantic associations. Our findings have also highlighted a limitation with using the artificial language learning task to address learning of individual cues, demonstrating that by assessing cue acquisition using participants' ability to associate cues with each other, it is difficult to reliably show when participants have acquired a specific cue during training.

In conclusion, my thesis has demonstrated that when there are multiple cues available in a training language, phonological-distributional cues may compete with each other for relevance as outlined by the competition model (Bates & MacWhinney, 1989; Culbertson et al., 2017) and discriminative learning (Arnon & Ramscar, 2012; Havron & Arnon, 2021; Ramscar et al., 2010; Ramscar & Port, 2016). However, in addressing whether semantic cues interfere with learning of phonological-distributional cues, our findings have clearly demonstrated that semantic cues do not interfere with learning of phonological-distributional cues and that instead participants may favour phonological-distributional cues based on which cue they are able to associate with semantic cues first.

Appendices

Table A1. Training items used across all experiments in Chapter 3, 4 and 5

Word	Picture	Experiment used
tib mofeem	dog	Chapter 3, 4 & 5
tib hormeem	sheep	Chapter 3, 4 & 5
tib doudeem	horse	Chapter 3, 4 & 5
tib shemeem	chicken	Chapter 3, 4 & 5
tib tercheem	parrot	Chapter 3, 4 & 5
tib gatcheem	snake	Chapter 3, 4 & 5
tib norneem	lion	Chapter 3, 4 & 5
tib flarneem	owl	Chapter 3, 4 & 5
tib vedeem	cow	Chapter 3, 4 & 5
tib zeapeem	duck	Chapter 3, 4 & 5
tib viffeem	tiger	Chapter 3, 4 & 5
tib phlaveem	squirrel	Chapter 3, 4 & 5
tib jerleem	crocodile	Chapter 4 & 5
tib ropeem	elephant	Chapter 4 & 5
tib morcheem	fox	Chapter 4 & 5
tib dupeem	mouse	Chapter 4 & 5
ked borchool	knife	Chapter 3, 4 & 5
ked roivool	toaster	Chapter 3, 4 & 5
ked snarool	tv	Chapter 3, 4 & 5
ked larshool	table	Chapter 3, 4 & 5
ked felchool	hairbrush	Chapter 3, 4 & 5
ked dranool	umbrella	Chapter 3, 4 & 5
ked pilmool	toothbrush	Chapter 3, 4 & 5
ked migool	box	Chapter 3, 4 & 5
ked tormool	window	Chapter 3, 4 & 5
ked jorool	lamp	Chapter 3, 4 & 5
ked shillool	ipod	Chapter 3, 4 & 5

ked cassool	guitar	Chapter 3, 4 & 5
ked vevool	pencil	Chapter 4 & 5
ked geshool	spoon	Chapter 4 & 5
ked gniddool	bed	Chapter 4 & 5
ked wilnool	clock	Chapter 4 & 5

Table A2. Novel items used in the phonological form recognition task in Chapter 3, 4 and 5

Word	Experiment used
tib blorcheem	Chapter 3
tib chebeem	Chapter 3
tib cherkeem	Chapter 3
tib chowtheem	Chapter 3
tib heefeem	Chapter 3
tib lupeem	Chapter 3
tib sarbeem	Chapter 3, 4 & 5
tib scoiffeem	Chapter 3, 4 & 5
tib dreteem	Chapter 3, 4 & 5
tib gorteem	Chapter 3, 4 & 5
tib zerfeem	Chapter 3, 4 & 5
tib zimbeem	Chapter 3, 4 & 5
ked bisool	Chapter 3
ked zurrool	Chapter 3
ked dowthoold	Chapter 3
ked furgool	Chapter 3
ked tremool	Chapter 3
ked zomool	Chapter 3
ked perrbool	Chapter 3, 4 & 5
ked plounool	Chapter 3, 4 & 5
ked shreelool	Chapter 3, 4 & 5

ked treggool	Chapter 3, 4 & 5
ked garrool	Chapter 3, 4 & 5
ked jurbool	Chapter 3, 4 & 5

Table A3. Phonological form generalisation task items in Chapter 3

Word	Consistency
tib pesseem	Consistent
tib goiteem	Consistent
tib jitool	Inconsistent
tib lerthool	Inconsistent
ked thrairool	Consistent
ked rutchool	Consistent
ked risheem	Inconsistent
ked narpeem	Inconsistent

Table A4. Phonological form generalisation task items in Chapter 4

Word	Consistency	Experiment used
tib chowtheem	Consistent	Experiment 3 & 4
tib heefeem	Consistent	Experiment 3 & 4
tib lupeem	Consistent	Experiment 3 & 4
tib blorcheem	Consistent	Experiment 3
tib chebeem	Consistent	Experiment 3
tib cherkeem	Consistent	Experiment 3
tib zeenool	Inconsistent	Experiment 4
tib bovsool	Inconsistent	Experiment 4
tib plixool	Inconsistent	Experiment 4
tib jitool	Inconsistent	Experiment 3
tib lerthool	Inconsistent	Experiment 3
tib spomool	Inconsistent	Experiment 3

tib scisool	Inconsistent	Experiment 3
tib shegool	Inconsistent	Experiment 3
tib malool	Inconsistent	Experiment 3
ked hylmbool	Consistent	Experiment 3 & 4
ked geechool	Consistent	Experiment 3 & 4
ked bisool	Consistent	Experiment 3 & 4
ked zurrool	Consistent	Experiment 3
ked dowthool	Consistent	Experiment 3
ked furgool	Consistent	Experiment 3
ked sorleem	Inconsistent	Experiment 4
ked whoveem	Inconsistent	Experiment 4
ked yealeem	Inconsistent	Experiment 4
ked risheem	Inconsistent	Experiment 3
ked narpeem	Inconsistent	Experiment 3
ked voapeem	Inconsistent	Experiment 3
ked dorgeem	Inconsistent	Experiment 3
ked hegeem	Inconsistent	Experiment 3
ked vugeem	Inconsistent	Experiment 3

Table A5. Phonological form generalisation task items in Chapter 5

Word	Consistency	Experiment used
tib cherkeem	Consistent	Experiment 6
tib fozzeem	Consistent	Experiment 6
tib blugeem	Consistent	Experiment 6
tib chowtheem	Consistent	Experiment 5 & 6
tib heefeem	Consistent	Experiment 5 & 6
tib lupeem	Consistent	Experiment 5 & 6
tib lerthool	Inconsistent	Experiment 6

tib spomool	Inconsistent	Experiment 6
tib scisool	Inconsistent	Experiment 6
tib zeenool	Inconsistent	Experiment 5 & 6
tib bovsool	Inconsistent	Experiment 5 & 6
tib plixool	Inconsistent	Experiment 5 & 6
ked blinool	Consistent	Experiment 6
ked furgool	Consistent	Experiment 6
ked teidool	Consistent	Experiment 6
ked hylmbool	Consistent	Experiment 5 & 6
ked geechool	Consistent	Experiment 5 & 6
ked bisool	Consistent	Experiment 5 & 6
ked hegeem	Inconsistent	Experiment 6
ked kugeem	Inconsistent	Experiment 6
ked voapeem	Inconsistent	Experiment 6
ked sorleem	Inconsistent	Experiment 5 & 6
ked whoveem	Inconsistent	Experiment 5 & 6
ked yealeem	Inconsistent	Experiment 5 & 6

Table A6. Determiner-suffix generalisation task items in Chapter 3

Word	Picture	Consistency	Experiments used
tib lekeem	rabbit	Consistent	Experiment 1 & 2
tib taseem	giraffe	Consistent	Experiment 1
tib darleem	bowl	Inconsistent	Experiment 1 & 2
tib bupeem	camera	Inconsistent	Experiment 1
ked rournool	glasses	Consistent	Experiment 1 & 2
ked tarbool	door	Consistent	Experiment 1
ked sirdool	pig	Inconsistent	Experiment 1 & 2
ked soidool	wolf	Inconsistent	Experiment 1

Table A7. Determiner-suffix generalisation task items in Chapter 4 and 5

Word	Picture	Consistency	Experiments used
tib morcheem	fox	Consistent	Chapter 4 & 5
tib chebeem	turtle	Consistent	Chapter 5
tib darleem	bowl	Inconsistent	Chapter 4 & 5
tib frapeem	football	Inconsistent	Chapter 5
ked gniddool	bed	Consistent	Chapter 4 & 5
ked dagsool	suitcase	Consistent	Chapter 5
ked sirdool	pig	Inconsistent	Chapter 4 & 5
ked noaxool	rhinoceros	Inconsistent	Chapter 5

Table A8. Determiner generalisation task items in Chapter 3

Word	Picture	Consistency	Experiments used
tib perneem	kangaroo	Consistent	Experiment 1 & 2
tib wholeem	monkey	Consistent	Experiment 1
tib grurmbool	button	Inconsistent	Experiment 1 & 2
tib malool	key	Inconsistent	Experiment 1
ked volmool	anchor	Consistent	Experiment 1 & 2
ked hylmbool	basket	Consistent	Experiment 1
ked henkeem	frog	Inconsistent	Experiment 1 & 2
ked vugeem	bird	Inconsistent	Experiment 1

Table A9. Determiner generalisation task items in Chapter 4 and 5

Word	Picture	Consistency	Experiments used
tib dupeem	mouse	Consistent	Chapter 4 & 5
tib blorcheem	raccoon	Consistent	Chapter 5
tib grurmbool	key	Inconsistent	Chapter 4 & 5
tib wethool	candle	Inconsistent	Chapter 5
ked wilnool	clock	Consistent	Chapter 4 & 5

ked quivool	refrigerator	Consistent	Chapter 5
ked henkeem	bird	Inconsistent	Chapter 4 & 5
ked gurgeem	skunk	Inconsistent	Chapter 5

Table A10. Suffix generalisation task items in Chapter 3

Word	Picture	Consistency	Experiments used
tib thileem	panda	Consistent	Experiment 1 & 2
tib vangeem	cat	Consistent	Experiment 1
tib senool	goat	Inconsistent	Experiment 1 & 2
tib shegool	camel	Inconsistent	Experiment 1
ked shubool	chair	Consistent	Experiment 1 & 2
ked geechool	book	Consistent	Experiment 1
ked chusheem	ruler	Inconsistent	Experiment 1 & 2
ked hegeem	computer	Inconsistent	Experiment 1

Table A11. Suffix generalisation task items in Chapter 4 and 5

Word	Picture	Consistency	Experiment used
tib perneem	kangaroo	Consistent	Experiment 3, 4, 5 & 6
tib yaigeem	leopard	Consistent	Experiment 5 & 6
tib cherkeem	snail	Consistent	Experiment 5
tib fozzeem	lobster	Consistent	Experiment 5
tib senool	goat	Inconsistent	Experiment 3, 4, 5 & 6
tib jitool	seahorse	Inconsistent	Experiment 5 & 6
tib lerthool	deer	Inconsistent	Experiment 5
tib spomool	fish	Inconsistent	Experiment 5
ked clarrool	table	Consistent	Experiment 3, 4, 5 & 6
ked zurrool	racket	Consistent	Experiment 5 & 6
ked blinool	baseball bat	Consistent	Experiment 5
ked furgool	axe	Consistent	Experiment 5

ked chusheem	ruler	Inconsistent	Experiment 3, 4, 5 & 6
ked dorgeem	bow	Inconsistent	Experiment 5 & 6
ked hegeem	pipe	Inconsistent	Experiment 5
ked kugeem	boot	Inconsistent	Experiment 5

Table A12. Novel items used in the speeded shadowing task

Word	Consistency
tib synleem	Consistent
tib yaigeem	Consistent
tib blugeem	Consistent
ked dagsool	Consistent
ked noldooll	Consistent
ked noaxool	Consistent
tib vebsool	Inconsistent
tib nennool	Inconsistent
tib wethool	Inconsistent
ked lowleem	Inconsistent
ked gurgeem	Inconsistent
ked kugeem	Inconsistent

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