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# Shape vs. colour biases during adult word learning are linked to language experience

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**ABSTRACT**
Children's acquisition of category labels can be facilitated by an attentional bias toward shape. Here, we provide evidence that attending to shape vs. colour impacts adult word learning differently depending on language experience. When learning novel words for objects that highlighted shape or colour similarities, an attentional bias toward the linguistically salient visual feature facilitated learning among bilinguals, but not among monolinguals. We propose that bilingual experience may enhance the ability to capitalise on linguistic commonalities among visually similar items (i.e. positive transfer). Additionally, analyses of errors revealed that the tendency to sort by shape vs. colour may reflect a more general predisposition toward abstract, categorical processing vs. concrete, featural processing. These findings highlight the complex interactions between language, attention, and perception, and contribute toward understanding how variation in linguistic experiences and attentional biases impact learning.

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## Introduction

Few English speakers are likely to have heard of an *amargasaurus* or an *andesite,* and yet fewer would have difficulty determining which is a dinosaur and which is a rock. Vocabulary acquisition is an incremental process whereby regularities in previously learned words can provide insight into the meanings of new words. For children acquiring English as their first language, objects' shapes are particularly salient and effective cues for how to generalise learned categorical labels to novel exemplars (i.e. a "shape bias"; Landau et al., 1988; Yoshida & Smith, 2005). Although attentional biases toward visual features are well documented in early childhood, it remains unclear whether they continue to influence word learning as linguistic systems become more complex and learners accumulate greater language experience. Here, we examine the relationship between attentional biases and adult word learning to determine whether individual differences in the salience of shape vs. colour cues, including those that may be linked to linguistic backgrounds, predict the ability to learn novel linguistic regularities and words.

Markman (1990) famously found that children operate on three assumptions as they encounter novel words: 1. The whole object assumption, which leads children to interpret a word as the label of a whole object and not its parts; 2. The mutual exclusivity assumption, which leads children to attach only one label to an object; and 3. The taxonomic assumption, which leads children to generalise categorical labels to objects of the same kind, instead of to objects that are thematically related. Among these, the finding that words are assumed to be categorical labels was expanded when later studies showed that shape was the preferred visual cue over material, texture, or size in how children and adults judge object categories (Landau et al., 1988; Yoshida & Smith, 2005). The acquisition of a shape bias has been shown to positively predict word learning in young children (Niese & Brackenbury, 2020; Samuelson, 2002; Smith et al., 2002), ostensibly because the words learned during early acquisition tend to be dominated by count nouns, which are more likely to be organised by shape than other features (Samuelson & Smith, 1999). Children with a shape bias also exhibit superior memory of visual objects' shapes and worse memory of colour and size compared to children without a shape bias (Vlach, 2016), suggesting that attentional biases toward shape when generalizing object labels predict subsequent retention of shape-related visual information.

Less understood is the extent to which attentional biases impact more complex word learning at later stages of development. While shape-based heuristics may be conducive to the acquisition of many count nouns learned early in development, referents with

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shared or similar labels learned at more advanced stages of acquisition sometimes, but not always, overlap in perceptual and semantic attributes other than shape (e.g. "bluejay," "blueberry," "blueprint"). Evidence suggests that children can override a shape bias when contextual information highlights alternative predictive features. For example, children generalise by non-shape attributes, such as texture, when they are made relevant (Graham et al., 2010), when contextual factors render non-shape properties more distinctive (Hammer & Diesendruck, 2005; Landau et al., 1992), or when arbitrary but predictive cues direct attention toward otherwise overlooked features (Luna & Sandhofer, 2021). Although this ability to disregard shape in favour of a more relevant property has been shown to increase with age (Golinkoff et al., 1995; Graham et al., 1999), relatively few studies have examined how attentional biases impact the acquisition of more complex linguistic regularities. In addition to words that refer to broad categories of referents (e.g. "dinosaur"), labels of subordinate exemplars often share some, but not all linguistic features with one another (e.g. "amargasaurus," "lambeosaurus"). To provide a more challenging and ecologically valid test of adult word learning, the present study examines whether predispositions toward grouping by shape vs. colour predict the ability to learn shape vs. colour-based linguistic regularities (i.e. morphemes) embedded *within* otherwise distinct labels.

A secondary goal is to examine whether the emergence and impact of attentional biases in adults is moderated by prior language experience. According to the attentional learning account (ALA) (Colunga & Smith, 2008; Samuelson & Horst, 2008), children's attentional biases develop as a result of sensitivity to statistical regularities in the environment which provide information regarding the most relevant properties. Consistent with this perspective, the strength of the shape bias has been shown to vary as a function of language experience. As English-speaking children are primarily exposed to shape-based categories (e.g. "ball," "dog") during early stages of language acquisition, perceptual and linguistic regularities make shape a salient cue for category membership. Notably, however, the tendency to generalise labels by shape does not develop until a child knows a sufficiently large number of nouns that could serve as a basis for learning the covariance between shape and category (Samuelson & Smith, 1999).

The strength of the shape bias has additionally been found to vary by children's experiences with different languages. For instance, Smith (1999) suggests that the typically robust shape bias observed among English-speaking children may be partly attributable to the fact that English syntax makes an obligatory distinction between count nouns (that tend to be organised by shape) and mass nouns (which are not organised by shape). Consistent with this proposal, the shape bias was diminished or even absent among children who speak languages that do not reliably distinguish between count and mass nouns (e.g. Japanese, Imai & Gentner, 1997; Korean, Gathercole & Min, 1997; Mandarin, Subrahmanyam & Chen, 2006; Spanish, Hahn & Cantrell, 2012). Moreover, bilingual children's shape biases can be modulated by language context: Spanish-English bilingual children exhibit a shape bias when tested in English, but not when tested in Spanish (Schonberg et al., 2020), suggesting that both past experience and current language context shape attentional tendencies. Colunga et al. (2009) found that Spanish-speaking children directed greater attention to objects' material relative to age-matched English-speakers, suggesting that a reduced attentional bias toward shape can be accompanied by the increased salience of other properties. Together, these findings strongly implicate the role of prior language experience in the development of attentional biases in children, which can subsequently bolster further acquisition of words and categories that are meaningfully delineated by the attended property.

## The present study

The goal of the present study was to determine the extent to which effects of attentional biases and language experience extend to adult word learning. Specifically, we examined whether predispositions toward sorting novel objects by shape vs. colour predict how well speakers of different languages learn partially overlapping labels that covary by either shape or colour. To increase task engagement, English monolinguals and English-Spanish bilinguals were asked to imagine that they had crash-landed on an alien planet and needed to remember their alien hosts' names to survive. Participants were presented with pictures of aliens that each shared a colour or a shape with a subset of other aliens. To obtain a measure of attentional bias, participants were asked to sort a first set of aliens into distinct social groups. Participants were then taught and tested on the names of a second set of aliens. Critically, each alien's name partially overlapped with that of two others in a way that reliably corresponded to the aliens' colour (e.g. three aliens with green heads named Bondil, Boncas, and Bonmet) or shape (e.g. three aliens with square heads named Bondil, Boncas, and Bonmet) in a between-subject design.

Based on prior literature suggesting that an attentional shape bias facilitates word learning (Niese & Brackenbury, 2020; Samuelson, 2002; Smith et al., 2002) and enhances memory for objects' shapes (Vlach, 2016), we may expect participants with a shape bias to exhibit superior learning when item shapes reliably correspond to linguistic features of their labels (e.g. when the names of all aliens with square heads began with "Bon"). We may likewise expect participants with an attentional colour bias to exhibit superior learning when item colours are reliably associated with linguistic features. The opposite prediction could be made, however, based on research showing that learning can be impeded by overlapping visual forms of referents (Ishii, 2013, 2015) and linguistic forms of labels (Kemp & McDonald, 2021; Laufer, 1988; Lian et al., 2004; Llach, 2015; Nation, 2000; Papagno & Vallar, 1992). To the extent that the challenge of distinguishing between similar-sounding labels is compounded when they highlight salient visual similarities, we may expect that participants who sorted by shape would have greater difficulty learning shape-biased names than participants who sorted by colour (and vice versa).

## Methods

### Participants

One hundred and forty-one participants were tested. Of these, 67 were English monolinguals who reported no second language experience and 74 were English-Spanish bilinguals who spoke English as a native language and acquired Spanish between the ages of 0 and 24 (50.1% before the age of 10). Using G*Power 3.1 (Faul et al., 2009), power analyses were performed to establish the sample size. Based on the effect size of $f^2 = .27$ (Ning et al., 2020), $\alpha = .05$, and power = .85, the minimum number of participants needed was $N = 55$.

Monolinguals and bilinguals did not differ from each other in gender, age, years of education, age of English acquisition, self-reported English proficiency (aggregated across speaking, understanding, reading on the LEAP-Q; Marian et al., 2007), English vocabulary (LexTALE; Lemhöfer & Broersma, 2012), non-verbal intelligence (Wechsler, 1999), or verbal working memory (Memory for Digits of the CTOPP; Wagner et al., 1999; all $p > .102$). See Table 1 for a summary of participants' demographic and language backgrounds. Informed consent was obtained from all participants, and the experimental protocol was approved by the Institutional Review Board (IRB) at Northwestern University (STU00209916).

**Table 1.** Demographic and language backgrounds of monolinguals and bilinguals.

| | Monolingual | Bilingual |
|---|---|---|
| *N* | 67 | 74 |
| Gender (% Female) | 53.7% | 43.2% |
| Age | 28.13 (4.27) | 27.09 (4.38) |
| Years of Education | 15.45 (2.52) | 15.05 (2.91) |
| English AoA (years) | 1.33 (1.30) | 1.28 (1.23) |
| Spanish AoA (years) | – | 8.49 (5.95) |
| English Self-Reported Proficiency (0–10) | 9.63 (0.70) | 9.66 (0.55) |
| Spanish Self-Reported Proficiency (0–10) | - | 6.37 (2.51) |
| English Vocabulary (LexTALE) | 87.84 (14.03) | 86.55 (12.58) |
| Spanish Vocabulary (LexTALE-Esp) | - | 52.04 (21.19) |
| Matrix Reasoning T Score (WASI) | 25.79 (3.27) | 24.77 (4.09) |
| Memory for Digits (CTOPP) | 14.37 (5.96) | 14.72 (5.34) |

### Materials

#### Alien pictures

A total of 24 alien figures were created, 12 in each of two sets, Set A and Set B (see Figure 1 for the alien figures). Within each set, 9 were experimental items and 3 were filler items. Each alien figure was created from 3 basic geometric shapes (e.g. square, circle, and triangle) and two black dots as eyes. Each experimental item had one primary color (red, blue, or green), one secondary color (yellow, magenta, or cyan), and one tertiary color (red + magenta, yellow + green, or blue + cyan) in its design based on the RGB color scale (Labrecque, 2020). To ensure that the two sets of aliens did not differ significantly in their appearances, the same geometric shapes and colors were used to construct the aliens across Sets A and B. Within each set, there were 3 color designs as well as 3 shape designs, so that each of the 9 experimental aliens had the same color design as two other aliens, and the same shape design as another two aliens.

#### Pseudoword names

Twelve pseudowords were created as names for the alien figures, which corresponded to either the shape or colour of the aliens' visual appearances. The 9 experimental items each consisted of two 3-letter syllables, with one shared root and one unique stem. The position of the shared root and unique stem in the pseudowords was counterbalanced, with half of the participants learning pseudoword names with the shared root at the onset of the word and half learning pseudoword names with the shared root at the end of the word. See Table 2.

All bigrams and biphones in the pseudowords were legal in both English and Spanish (CLEARPOND; Marian et al., 2012). Average bigram, biphone, and single letter frequencies were matched across groups and languages (between-condition t-tests $ps > .05$). This was done to ensure that all pseudowords had comparable levels of difficulty, and that nothing in the pseudowords themselves would unfairly advantage or

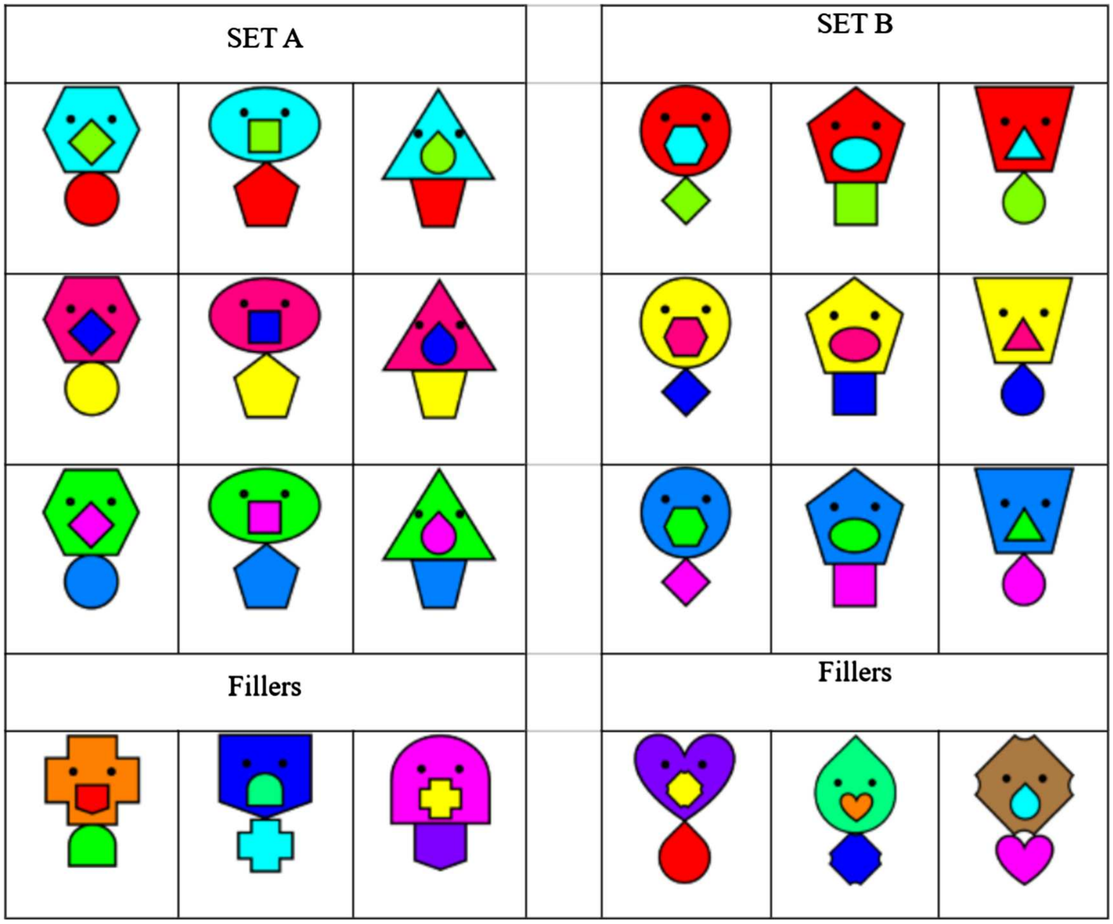


**Figure 1.** Alien figure sets A and B.

disadvantage either the English-speaking monolingual group or the English-Spanish bilingual group in word learning.

## *Procedure*

This study was administered online as a Qualtrics survey on the CloudResearch platform (formerly TurkPrime). The experiment consisted of an attentional bias test section and a name-learning section. In the attentional bias test section, participants were introduced to the study with the following instructions: "Imagine your spaceship has just crash-landed on an unfamiliar planet. You wake up and see aliens around you. In order to survive on this planet, you will have to interact with these aliens." Participants were shown one of the two sets of aliens (either Set A or Set B) and were instructed to sort the 9 experimental items into three distinct social groups based on their best guess by dragging and dropping each into one of three boxes.

During the name-learning section, participants learned the names of the remaining set of aliens with shared roots (i.e. phonological overlap) that either corresponded to the aliens' colours (colour-biased condition) or their shapes (shape-biased condition). In the colour-biased condition, alien figures that shared colour patterns also shared one syllable in their names. In the shape-biased condition, alien figures that shared shape patterns shared one syllable in their names.

Participants learned the pseudoword alien names in a three-step learning session (see Figure 2). In the first step, participants saw the alien figures and their names

**Table 2.** Pseudoword alien names with phonological overlap position counterbalanced.

| Onset Phonological Overlap | | | | Rime Phonological Overlap | | | |
|---|---|---|---|---|---|---|---|
| *Bon-* | *Bon*met | *Bon*cas | *Bon*dil | ***-bon*** | Met*bon* | Cas*bon* | Dil*bon* |
| *Las-* | *Las*nop | *Las*gec | *Las*bif | ***-las*** | Nop*las* | Gec*las* | Bif*las* |
| *Mep-* | *Mep*san | *Mep*lig | *Mep*tob | ***-mep*** | San*mep* | Lig*mep* | Tob*mep* |
| Fillers | Fimpud | Sucrow | Patfik | **Fillers** | Pudfim | Rowsuc | Fikpat |

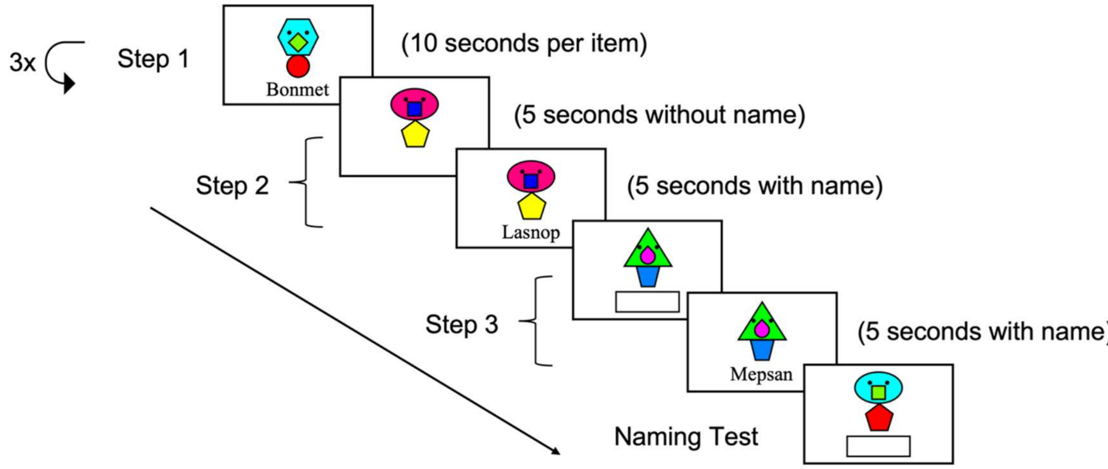


**Figure 2.** A schematic representation of the name-learning procedures.

on the screen one at a time, each for 10 s, and were instructed to memorise them. This step was repeated three times to ensure learning. According to the testing effect, acquisition of new information is facilitated by being tested on the material (Roediger & Karpicke, 2006). Using a dynamic testing paradigm in which feedback is given after the initial test (Grigorenko & Sternberg, 1998), in the next learning step, participants were shown the same 12 aliens one at a time, but their names appeared on the screen 5 s after the picture onset for a duration of 5 s. Participants were instructed to try to recall the alien's name in their head when each of the aliens first appeared, and then to compare their answer with the correct answer. In the third learning step, alien figures appeared on the screen without names one at a time, and participants were asked to type the alien's name in a box using the keyboard. After their response was submitted, the correct name appeared on the screen for 5 s. When all three learning steps were completed, participants were tested on their memory of the alien names. During the testing stage, participants saw alien figures without their names, and were asked to type the names, but no feedback was given after responses were submitted. The order of presentation of the aliens was switched in each step of the word learning and testing session.

After completing the two experimental sections, participants were given a battery of language and cognitive background tasks.

## Results

### Effects of language background on attentional bias

The effect of language background on attentional bias was first examined using a generalised linear model with sorting group as a binomial outcome variable (0 = grouped by colour, 1 = grouped by shape) and Language Group (monolingual, bilingual) as a fixed effect. Language Group was contrast coded and weighted by the number of participants to compare Monolinguals (−0.48) to Bilinguals (+0.52). Consistent with an attentional shape bias, a significant intercept term indicated that a greater proportion of participants sorted by shape (vs. colour) than would be expected by chance, *Estimate* = 0.48, *SE* = 0.17, $z = 2.75$, $p = .006$. The proportion of participants who sorted by shape did not significantly differ between English Monolinguals (61.2%) and English-Spanish Bilinguals (62.2%), *Estimate* = 0.04, *SE* = 0.35, $z = 0.12$, $p = .906$.

### Effects of language background and attentional bias on word learning

Separate generalised linear mixed effects models were designed to examine effects of language background and attentional bias on the successful acquisition of (1) shared roots (e.g. **Bon**dil, **Bon**cas; **Mep**lig, **Mep**san) and (2) unique stems (e.g. Bon**dil**, Bon**cas**; Mep**lig**, Mep**san**) of alien names. For each model, accuracy for each three-letter cluster was coded as a binomial outcome variable (0 = incorrect, 1 = correct). Fixed effects included Language Group (Monolinguals −0.48 vs. Bilinguals +0.52), Naming Condition (Colour-biased shared roots: −0.5 vs. Shape-biased shared roots: +0.5), and Bias Match between the naming condition and attentional bias (Mismatch, e.g. participants with a colour bias learning shape-biased names: −0.5 vs. Match, e.g. participants with a shape bias learning shape-biased names: +0.5). The models additionally included the maximal random effect structure, consisting of random intercepts for participant and set, as well as by-set random slopes for Language Group, Naming Condition, and Bias Match.

### *Shared roots*

Significant interactions emerged between Naming Condition and Group, *Estimate* = −2.39, *SE* = 0.84, *z* = −2.83, *p* = .005, as well as between Bias Match and Group, *Estimate* = 2.55, *SE* = 0.84, *z* = 3.04, *p* = .002. Follow-up tests by Naming Condition revealed that English monolinguals (*M* = 0.61, *SD* = 0.49) outperformed English-Spanish bilinguals (*M* = 0.53, *SD* = 0.50) when learning the shared roots of shape-biased names, *Estimate* = −1.33, *SE* = 0.64, *t*(1256) = −2.06, *p* = 0.039, while bilinguals (*M* = 0.66, *SD* = 0.47) outperformed monolinguals (*M* = 0.54, *SD* = 0.50) when learning colour-biased names, *Estimate* = 1.14, *SE* = 0.55, *t*(1256) = 2.06, *p* = .039.

Follow-up tests by Bias Match revealed that English-Spanish bilinguals learned the shared roots of alien names significantly better when there was a match between naming condition and attentional bias (e.g. shape-biased participants learning shape-biased names) than when there was a mismatch (e.g. colour-biased participants learning shape-biased names), *Estimate* = 1.49, *SE* = 0.60, *t*(1256) = 2.49, *p* = .013. In contrast, monolinguals showed a nonsignificant numerical tendency to learn shared roots better when there was a mismatch than a match between naming condition and attentional bias, *Estimate* = −1.13, *SE* = 0.6, *t*(1256) = −1.88, *p* = .059 (see Figure 3). Accuracy on filler items did not differ between monolinguals and bilinguals, *Estimate* = 0.36, *SE* = 0.12, *z* = 0.30, *p* = .766, suggesting that group differences were specific to items containing phonological-visual overlap rather than reflecting general differences in task engagement or learning ability.

### *Unique stems*

As was the case for the acquisition of shared roots, significant interactions emerged between Naming Condition and Group, *Estimate* = −2.39, *SE* = 0.88, *z* = −2.72, *p* = .007, as well as between Bias Match and Group, *Estimate* = 2.20, *SE* = 0.89, *z* = 2.52, *p* = .012. Follow-up tests by Naming Condition revealed that English monolinguals (*M* = 0.50, *SD* = 0.50) outperformed English-Spanish bilinguals (*M* = 0.42, *SD* = 0.50) when learning the unique stems of shape-biased names, *Estimate* = −1.48, *SE* = 0.67, *t*(1256) = −2.19, *p* = .029, while bilinguals (*M* = 0.49, *SD* = 0.50) showed a nonsignificant

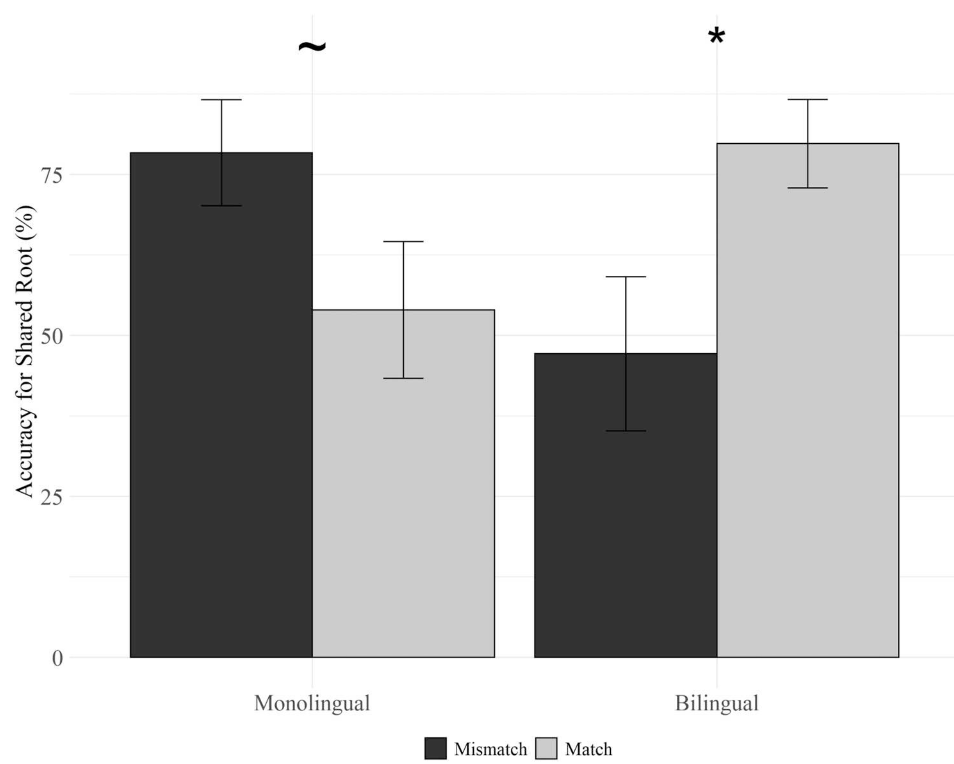


**Figure 3.** Mean accuracy for shared roots of names by Language Group and Bias Match. English monolinguals learned the shared roots of alien names marginally better when there was a mismatch between naming condition and the participant's attentional bias (dark gray; e.g. colour-biased participants learning shape-biased names) than when there was a match (light gray; e.g. shape-biased participants learning shape-biased names). In contrast, English-Spanish bilinguals learned shared roots significantly better when there was a match than a mismatch between naming condition and attentional bias. Error bars represent standard errors. *$p < .05$, ~$p < .06$.

numerical advantage over monolinguals ($M = 0.36$, $SD = 0.48$) when learning colour-biased names, *Estimate* = 1.06, $SE = 0.57$, $t(1256) = 1.85$, $p = .065$.

Follow-up tests by Bias Match revealed that English-Spanish bilinguals learned the unique stems of alien names significantly better when there was a match than a mismatch between naming condition and attentional bias, *Estimate* = 1.39, $SE = 0.62$, $t(1256) = 2.23$, $p = .026$, while accuracy for monolinguals did not significantly vary by match, *Estimate* = 0.93, $SE = 0.62$, $t(1256) = 1.5$, $p = .135$ (see Figure 4). In contrast to bilinguals who exhibited a match advantage in both the shape-biased (*Ms* = 0.48 for matched and 0.29 for mismatched conditions) and colour-biased (*Ms* = 0.57 and 0.43) naming conditions, a marginal three-way interaction between Group, Bias Match, and Naming Condition, *Estimate* = 3.13, $SE = 1.76$, $z = 1.77$, $p = .076$, revealed that the effect of Bias Match differed across Naming Conditions for monolinguals. Specifically, monolinguals learned shape-biased unique stems significantly better when there was a mismatch ($M = 0.71$, $SD = 0.46$) than a match ($M = 0.39$, $SD = 0.49$), *Estimate* = −2.21, $SE = 0.93$, $t(1256) = -2.38$, $p = .017$, but learned colour-biased unique stems comparably well when there was a match ($M = 0.39$, $SD = 0.49$) or a mismatch ($M = 0.33$, $SD = 0.47$), *Estimate* = 0.35, $SE = 0.83$, $t(1256) = 0.42$, $p = .678$.

## *Effects of language background and attentional bias on word learning errors*

In our final set of analyses, we investigated the impact of language experience and attentional bias in greater detail by examining whether there were systematic differences in the types of errors participants made during the name learning task. Each error for the shared and unique portions of alien names was first coded as one of three types of mistakes: (1) "swap," indicating that the shared or unique portion of a name was swapped for a different alien's name, (2) "partial," indicating that some, but not all letters of the shared or unique portions of names were correctly recalled, and (3) "wrong," indicating that the shared or unique portion was either left blank or was incorrect. Each participant's total number of errors per category was entered as a continuous outcome variable in a linear mixed effects model. Fixed effects included Language Group (monolingual vs. bilingual), Naming Condition (colour-biased vs. shape-biased), Bias Match (match vs. mismatch), Word Part (shared root vs. unique stem),

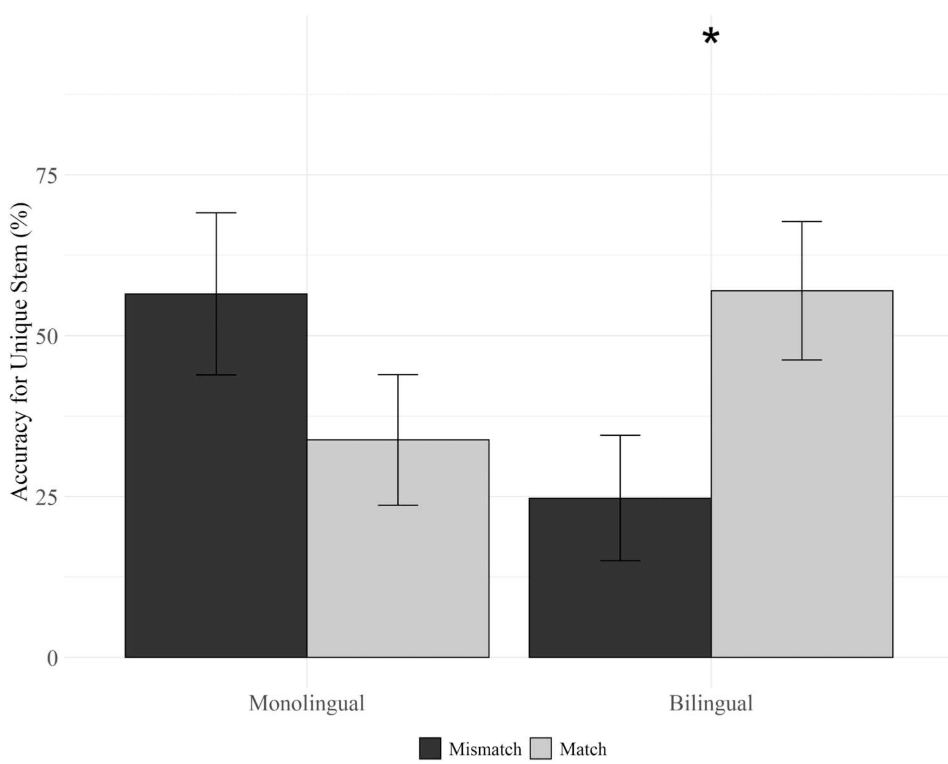


**Figure 4.** Mean accuracy for unique stems of names by Language Group and Bias Match. English-Spanish bilinguals learned the unique stems of alien names significantly better when there was a match between naming condition and the participant's attentional bias (light gray; e.g. shape-biased participants learning shape-biased names) than when there was a mismatch (dark gray; e.g. colour-biased participants learning shape-biased names). English monolinguals did not significantly vary by match. Error bars represent standard errors. *$p < .05$.

and Error Type (swap, partial, wrong), plus all interactions. The model additionally included a random intercept for participant and by-participant random slope for Word Part. Error Type was sum-coded to compare swap errors (Contrast 1) and partial errors (Contrast 2) to the grand mean. Significant effects of error were followed up with pairwise comparisons of each error type.

A significant main effect of the partial error contrast, *Estimate* = −0.38, *SE* = 0.08, $t(664.99) = -4.79$, $p < .001$, revealed that participants made significantly fewer partial errors ($M = 1.06$, $SD = 1.26$) compared to both swap errors ($M = 1.56$, $SD = 1.83$), *Estimate* = −0.51, *SE* = 0.14, $t(532) = -3.6$, $p < .001$, and incorrect responses ($M = 1.73$, $SD = 2.13$), *Estimate* = 0.66, *SE* = 0.14, $t(532) = 4.68$, $p < .001$. A significant interaction between the partial error contrast and Word Part, *Estimate* = −0.44, *SE* = 0.16, $t(665) = -2.73$, $p = .006$, revealed that while participants made comparable partial errors for the shared and unique parts of names, *Estimate* = −0.04, *SE* = 0.2, $t(598.46) = -0.19$, $p = .852$, they were significantly more likely to make both swap errors, *Estimate* = 0.47, *SE* = 0.2, $t(598.46) = 2.35$, $p = .019$, and incorrect responses, *Estimate* = −0.78, *SE* = 0.2, $t(598.46) = -3.93$, $p < .001$, for the unique than shared parts of names.

A significant interaction between Bias Match and the swap error contrast indicated that participants were significantly more likely to make swap errors when the naming condition mismatched ($M = 1.85$, $SD = 2.07$) vs. matched ($M = 1.32$, $SD = 1.58$) participants' attentional biases, *Estimate* = −0.52, *SE* = 0.24, $t(398.26) = -2.22$, $p = .027$. The likelihood of making partial and full errors did not vary by Bias Match, $p > .261$. Finally, a significant four-way interaction between Bias Match, Error Type, Naming Condition, and Group, *Estimate* = −1.46, *SE* = 0.65, $t(665) = -2.25$, $p = .025$, indicated that while bilinguals were generally more likely to swap names when there was a mismatch than a match (aggregated across naming conditions), *Estimate* = −1.20, *SE* = 0.33, $t(398.26) = -3.65$, $p < .001$, monolinguals were numerically, though not significantly, more likely to swap colour-biased names when there was a mismatch, *Estimate* = −0.76, *SE* = 0.46, $t(398.26) = -1.66$, $p = .098$, and significantly more likely to swap shape-biased names when there was a match, *Estimate* = 1.06, *SE* = 0.5, $t(398.26) = 2.14$, $p = .033$ (see Figure 5). In summary, the error analyses indicate that swap errors, reflecting confusion between competing referents, were the most sensitive to the interaction between attentional bias and naming condition. Bilinguals exhibited more swap errors when attentional and linguistic biases mismatched, whereas monolinguals with an attentional shape bias showed increased swap errors specifically when learning shape-biased names. These patterns suggest that bilinguals' performance was most affected by congruity between visual sorting tendencies and label structure, while monolinguals with a shape bias were more prone to within-category confusion when visual and phonological similarities aligned.

## Sensitivity analyses

To assess the robustness of the primary findings, we conducted a series of sensitivity analyses. Specifically, we re-estimated the primary models while controlling for (1) bilingual participants' language background, including proficiency and age of acquisition, and (2) stimulus characteristics, namely whether the manipulation occurred at the onset or rime of the words. These analyses tested whether the observed effects held under alternative model specifications that accounted for individual differences and item-level variation.

### Bilingual language background

To determine whether bilingual language background measures moderated the reported effects, we re-estimated each primary model for the English-dominant bilinguals while including mean-centered measures of Spanish proficiency and age of acquisition as additional fixed effects.

***Attentional bias.*** Supplemental analyses including only bilinguals revealed that attentional biases were not predicted by standardised measures of Spanish age of acquisition, *Estimate* = −0.40, *SE* = 0.30, $z = -1.34$, $p = .181$, Spanish proficiency, *Estimate* = −0.08, *SE* = 0.31, $z = -0.25$, $p = .801$, or their interaction, *Estimate* = −0.08, *SE* = 0.22, $z = -0.38$, $p = .703$. VIF scores indicated no issues of multicollinearity (all < 1.66).

***Word learning.*** Learning performance of shared roots was not predicted by Spanish age of acquisition, *Estimate* = 0.37, *SE* = 0.41, $z = 0.90$, $p = .366$, Spanish proficiency, *Estimate* = 0.49, *SE* = 0.47, $z = 1.06$, $p = .289$, or any two-way interactions with Naming Condition or Bias Match (all $ps \geq .268$). Although the three-way interaction between Naming Condition, Bias Match, and Spanish proficiency was dropped due to possible issues with multicollinearity (VIF = 6.88), there was no evidence of a three-way interaction with Spanish age of acquisition, *Estimate* = 1.87, *SE* = 1.82, $z = 1.03$, $p = .305$ (remaining VIFs < 2.2).

Likewise, learning performance of unique stems was not predicted by Spanish age of acquisition, *Estimate* =

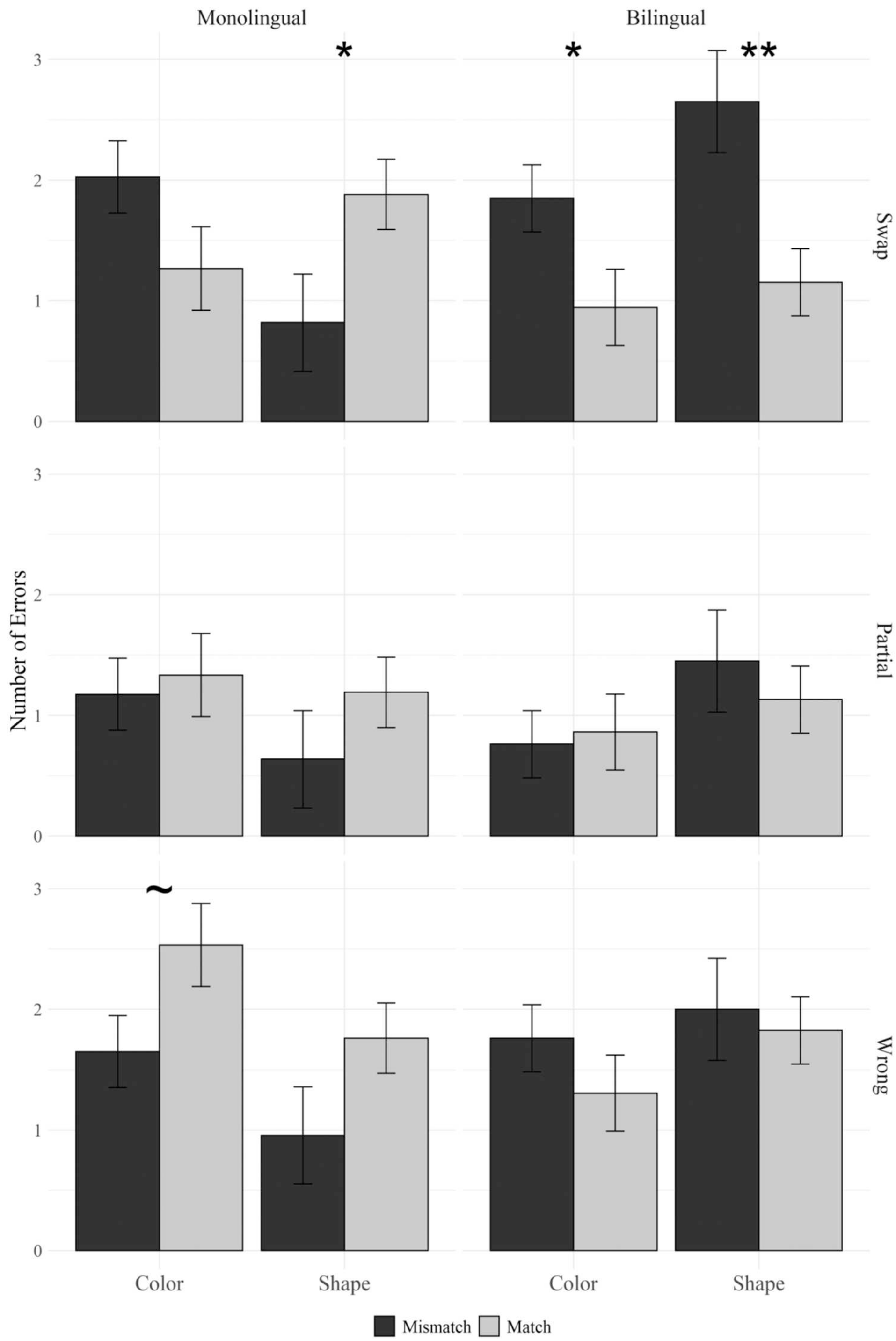


**Figure 5.** Mean number of swap errors, partial errors, and wrong responses by Language Group, Naming Condition, and Bias Match. English-Spanish bilinguals made significantly more swap errors when there was a mismatch (dark gray) compared to match (light gray) between naming condition and attentional bias. English monolinguals made significantly more swap errors for shape-biased names when there was a match (i.e. an attentional shape bias) than mismatch (i.e. an attentional colour bias). Error bars represent standard errors. $^{**}p < .01$, $^{*}p < .05$, $\sim p < .06$.

0.29, $SE = 0.44$, $z = 0.66$, $p = .513$, Spanish proficiency, *Estimate* = −0.03, $SE = 0.48$, $z = -0.06$, $p = .956$, or any interactions with Naming Condition or Bias Match (all $ps \geq .346$; all VIFs < 1.97).

***Word learning errors.*** The prevalence of errors was not predicted by Spanish age of acquisition, *Estimate* = −0.14, $SE = 0.16$, $t = -0.88$, $p = .383$, Spanish proficiency, *Estimate* = −0.13, $SE = 0.19$, $t = -0.71$, $p = .482$, or any interactions with Naming Condition, Bias Match, or Word Part (all $ps \geq .213$; all VIFs $< 2.25$).

### *Overlap position*

To determine whether the position of the shared syllable influenced performance, we re-estimated each primary model including Overlap Position (onset vs. rime) as an additional fixed effect.

***Word learning.*** Including Overlap Position did not alter the pattern of results for the acquisition of shared roots. Significant interactions remained between Group and Naming Condition (*Estimate* = −2.36, *SE* = 0.84, $z = -2.81$, $p = .005$) and between Group and Bias Match (*Estimate* = 2.60, *SE* = 0.86, $z = 3.04$, $p = .002$). There was no main effect of Overlap Position and no interactions involving Overlap Position (all $ps \geq .271$).

Likewise, Overlap Position did not alter the pattern of results for the acquisition of unique stems. Significant interactions remained between Group and Naming Condition (*Estimate* = −2.35, *SE* = 0.86, $z = -2.74$, $p = .006$) and between Group and Bias Match (*Estimate* = 2.01, *SE* = 0.88, $z = 2.28$, $p = .023$). The marginal three-way interaction between Group, Bias Match, and Naming Condition reached significance in the updated model (*Estimate* = 3.77, *SE* = 1.77, $z = 2.13$, $p = .034$). No main effects or interactions involving Overlap Position were observed (all $ps \geq .09$).

***Word learning errors.*** Including Overlap Position produced a comparable pattern of results to the main analysis. All reported effects remained significant (all $ps < .05$). The only additional effect was a significant four-way interaction involving the swap error contrast, Naming Condition, Bias Match, and Overlap Position. Although none of the simple effects by Overlap Position reached significance, the effect of Bias Match was relatively more pronounced for colour- than shape-biased names, particularly when the shared syllable occurred at the rime rather than the onset of the word.

## Discussion

The goal of the present study was to investigate the relationship between word learning and attentional biases among monolingual and bilingual adults. Research on language learning indicates that both children and adults are more likely to generalise an object's label to other items with the same shape than to objects that share other characteristics such as colour, texture, or size. Among young children, an attentional bias toward visual shape positively predicts vocabulary acquisition (Smith et al., 2002), likely due to the fact that objects' shapes are often reliable indicators of linguistic categories in children's early vocabularies. Here, we extended the investigation to English monolingual and English-Spanish bilingual adults to examine whether (1) predispositions toward attending to shape vs. colour meaningfully impact more advanced and complex word learning and (2) whether effects of attentional biases on word learning are moderated by prior language experience.

We found that participants were more likely to categorise novel visual objects by shape than by colour. However, in contrast to developmental research suggesting that the shape bias is more pronounced for English monolingual children than Spanish monolingual children (Hahn & Cantrell, 2012), the magnitude of shape bias did not differ between English monolingual and English-Spanish bilingual adults. In other words, English speakers exhibited a comparable degree of shape bias regardless of whether an additional language was known. Of particular note, however, is that in addition to significant differences between the populations tested in the present study (English monolingual and English-Spanish bilingual adults) and those in Hahn and Cantrell's study (English monolingual and Spanish monolingual children), our measure of attentional bias reflected categorical judgments in a non-linguistic context. As noted, shape biases are typically observed when participants are taught the name of a novel object and are asked to determine which other objects the label is likely to apply to. In the present study, participants exhibited a shape bias when asked to sort unnamed alien figures into distinct social groups, suggesting that the predisposition to form shape-based categories is not limited to the linguistic domain. At the same time, the use of schematic alien figures raises the question of whether such stimuli might engage face-specific processing mechanisms.

Faces are known to recruit partially specialised neural systems and configural processing (Gauthier & Tarr, 2002; Kanwisher et al., 1997). However, the present stimuli consisted of simple geometric configurations with minimal facial detail and lacked individuating features typically associated with expert face processing. Moreover, global-local processing tendencies observed for objects generalise to schematic face-like stimuli (Gerlach & Starrfelt, 2018), suggesting that not all face-like patterns override broader attentional biases. Thus, it is unlikely that canonical face-processing mechanisms fully account for the observed effects.

Despite a shape bias of similar magnitude when categorizing unnamed objects, the subsequent impact on word learning varied as a function of language experience. First, we observed that regardless of the attentional bias, monolinguals were more successful at learning shape-biased names than English-Spanish bilinguals. To the extent that linguistic categories organised by shape are more salient in English compared to Spanish, this finding suggests that experience with Spanish may reduce sensitivity to linguistic shape cues, even among those with native English proficiency. In addition to overall differences in the acquisition of shape vs. colour-biased names, we observed that monolinguals and bilinguals differed with respect to the impact of their attentional biases on learning. We predicted that learning would be promoted by a match between attentional and linguistic biases – that is, that having a predisposition toward sorting by shape *[colour]* would facilitate the ability to learn shape- *[colour-]* biased labels. This was indeed the case for English-Spanish bilinguals, who had significantly higher accuracy when there was a match vs. mismatch in attentional and linguistic biases. This pattern was not observed, however, among English monolinguals, who showed a nonsignificant numerical tendency toward better performance when there was a mismatch than a match in attentional and linguistic biases.

The present findings raise important questions regarding the scope of generalization. The bilingual participants tested here were English-Spanish bilinguals, and English and Spanish differ in the extent to which early noun learning privileges shape-based generalization (Hahn & Cantrell, 2012; Imai & Gentner, 1997). However, the critical effect observed in the present study was not a shape-specific advantage, but rather a bias match advantage: bilinguals benefited when their attentional sorting bias aligned with the visual-phonological regularities embedded in the labels, regardless of whether that bias favoured shape or colour. This pattern suggests that the facilitative effect may reflect bilinguals' experience managing multiple mappings between form and meaning, rather than exposure to a particular type of lexical categorization system.

Importantly, supplemental analyses indicated that neither Spanish age of acquisition nor proficiency moderated the bias match effect, suggesting that the observed advantage was not contingent on early acquisition or high proficiency in Spanish per se. Nevertheless, caution is warranted in extending these findings to all bilingual populations. Although further research is needed to determine the generalizability of the effect to more diverse language pairings, the present findings suggest that bilingual experience may alter how attentional predispositions interact with the statistical structure of novel input.

Notably, the impact of attentional and linguistic bias congruity was not just limited to the shared phonemic roots, but extended to the whole word. Acquisition of the unique stems of labels was impacted by whether the shared root of the item label highlighted colour vs. shape similarities, even though the unique stems were unrelated to the items' visual forms. Consequently, the English monolingual advantage observed for learning shape-biased shared roots extended to the acquisition of unique stems that were independent of both colour and shape. Bilinguals learned both the shared roots and the unique stems of alien names significantly better when there was a match between naming condition and attentional bias (when learning both colour- and shape-biased names). In contrast, monolinguals more successfully learned the shared roots and unique stems of shape-biased, but not colour-biased aliens when there was a mismatch compared to a match. These findings suggest that bilinguals may be better able to learn the correspondence between visual and phonological forms when items that are more intuitively related to each other also share linguistic features. In monolinguals, however, not only does the compounded high visual and linguistic similarity not show any facilitatory effect on memory, but it also seems to contribute to more confusion between items. One possible explanation for the divergent effects for monolinguals and bilinguals may relate to differences in their ability to suppress interference from linguistically and visually similar competitors during cross-modal integration of auditory and visual inputs (Marian, Hayakawa, et al., 2021).

Phonological and orthographic similarity between novel words can help or hinder learning (Bartolotti & Marian, 2017). On the one hand, contrasting similar words can facilitate learning by sharpening each representation (Baxter et al., 2022), and the acquisition of one form can support acquisition of similar forms by providing a basis for positive transfer (Marian, Bartolotti, et al., 2021). During early stages of second language acquisition, however, words with similar phonological or orthographic forms can interfere with one another due to the fact that the novel representations are relatively underspecified and more easily confused with competitors (Kemp & McDonald, 2021; Laufer, 1988; Lian et al., 2004; Llach, 2015; Nation, 2000; Papagno & Vallar, 1992). Likewise, similarities between the physical appearances of novel words' referents can increase the confusability of yet underspecified representations (Ishii, 2013, 2015). A match between attentional and linguistic biases could therefore compound the amount of interference that is experienced by increasing the perceived visual similarity of competitors that also have similar labels. Critically, however, bilingual experience has been shown to enhance the capacity to control interference from competing lexical representations

(Bartolotti & Marian, 2012; Kaushanskaya & Marian, 2009; Marian et al., 2014). Combined with the fact that second language learners may have developed more efficient strategies (Baxter et al., 2022) for managing competition, bilinguals may have been able to benefit from the increased salience of heuristic associations between form and meaning without undue interference from the increased similarity of linguistically and visually overlapping items.

The present study presented novel labels in written form, which may influence the balance between orthographic and phonological competition. Auditory word learning engages phonological working memory and incremental temporal processing, potentially heightening sensitivity to phonological overlap and increasing competition among similar-sounding forms (Lian et al., 2004; Papagno & Vallar, 1992). In spoken-word recognition, phonological competitors are activated dynamically as the speech signal unfolds (Marslen-Wilson, 1987), which may amplify interference when items share initial segments. Thus, presenting labels aurally might strengthen competition effects associated with phonological overlap, potentially modulating the observed match and mismatch patterns. Direct comparisons of written and auditory learning contexts would help clarify how modality interacts with attentional-linguistic congruity.

Finally, examination of participants' errors revealed that while bilinguals' tendency to swap names across referents most reliably varied by whether or not there was a match in biases, monolinguals with an attentional shape bias were more likely to confuse labels than those with an attentional colour bias. Although speculative, it may be the case that the tendency to sort by shape vs. colour reflects a more general predisposition toward abstract, categorical processing vs. concrete, featural processing. Research with English monolinguals indicates that young children (between 4–7 years old) are predisposed to conceptualise novel information in terms of abstract kinds (e.g. that dogs catch a bug called "fep") rather than individuals (e.g. that a particular dog catches a bug called "fep," Cimpian & Erickson, 2012). Such a predisposition is conducive to shape-biased generalizations for many concrete nouns – while any given dog may be a variety of different colours or sizes, dogs as an abstract category can be described by a canonical shape. In this way, conceptualizing in terms of abstract kinds should increase the salience of shape information, and likewise, a predisposition toward focusing on shape may increase focus on superordinate categories rather than particular individuals. A predisposition toward focusing on colour, on the other hand, may be associated with greater attention to individuating features, thereby reducing the likelihood of confusing exemplars within a given category.

In sum, the present study provides preliminary evidence that adult word learning is predicted by individual differences in attentional biases toward colour vs. shape. While having a shape bias has been shown to promote the acquisition of category labels among English-speaking children, our findings suggest that an attentional shape bias may instead be associated with less precise linguistic representations among monolingual English-speaking adults learning partially overlapping labels of subordinate exemplars. We additionally find that while English-speaking monolinguals and bilinguals exhibit similar attentional biases when categorizing unnamed visual objects, the subsequent impact on word learning differs depending on prior language experience.

We conclude that language background influences the impact of attentional biases in word learning. More broadly, we show that knowing more than one language shapes learning and cognition (Marian, 2023). The results of the present study highlight the complex interactions between language, attention, and perception, and contribute to understanding word learning throughout the lifespan. Notably, these findings underscore the need to expand research on categorization and learning to include speakers of multiple languages in order to develop accurate theories of cognition reflecting heterogeneous groups and contexts.

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## Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

## References


Bartolotti, J., & Marian, V. (2012). Language learning and control in monolinguals and bilinguals. *Cognitive Science*, *36*(6), 1129–1147. https://doi.org/10.1111/j.1551-6709.2012.01243.x

Bartolotti, J., & Marian, V. (2017). Orthographic knowledge and lexical form influence vocabulary learning. *Applied Psycholinguistics*, *38*(2), 427–456. https://doi.org/10.1017/S0142716416000242

Baxter, P., Bekkering, H., Dijkstra, T., Droop, M., van den Hurk, M., & Leoné, F. (2022). Contrasting orthographically similar words facilitates adult second language vocabulary learning. *Learning and Instruction*, *80*, 101582. https://doi.org/10.1016/j.learninstruc.2022.101582

Cimpian, A., & Erickson, L. C. (2012). Remembering kinds: New evidence that categories are privileged in children's thinking. *Cognitive Psychology*, *64*(3), 161–185. https://doi.org/10.1016/j.cogpsych.2011.11.002

Colunga, E., & Smith, L. B. (2008). Knowledge embedded in process: The self-organization of skilled noun learning. *Developmental Science*, *11*(2), 195–203. https://doi.org/10.1111/j.1467-7687.2007.00665.x

Colunga, E., Smith, L. B., & Gasser, M. (2009). Correlation versus prediction in children's word learning: Cross-linguistic evidence and simulations. *Language and Cognition*, *1*(2), 197–217. https://doi.org/10.1515/LANGCOG.2009.010

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, *41*(4), 1149–1160. https://doi.org/10.3758/BRM.41.4.1149

Gathercole, V. C. M., & Min, H. (1997). Word meaning biases or language-specific effects? Evidence from English, Spanish and Korean. *First Language*, *17*(51), 31–56. https://doi.org/10.1177/014272379701705102

Gauthier, I., & Tarr, M. J. (2002). Unraveling mechanisms for expert object recognition: Bridging brain activity and behavior. *Journal of Experimental Psychology: Human Perception and Performance*, *28*(2), 431–446. https://doi.org/10.1037//0096-1523.28.2.431

Gerlach, C., & Starrfelt, R. (2018). Global precedence effects account for individual differences in both face and object recognition performance. *Psychonomic Bulletin & Review*, *25*(4), 1365–1372. https://doi.org/10.3758/s13423-018-1458-1

Golinkoff, R. M., Shuff-Bailey, M., Olguin, R., & Ruan, W. (1995). Young children extend novel words at the basic level: Evidence for the principle of categorical scope. *Developmental Psychology*, *31*(3), 494–507. https://doi.org/10.1037/0012-1649.31.3.494

Graham, S. A., Namy, L. L., Gentner, D., & Meagher, K. (2010). The role of comparison in preschoolers' novel object categorization. *Journal of Experimental Child Psychology*, *107*(3), 280–290. https://doi.org/10.1016/j.jecp.2010.04.017

Graham, S. A., Williams, L. D., & Huber, J. F. (1999). Preschoolers' and adults' reliance on object shape and object function for lexical extension. *Journal of Experimental Child Psychology*, *74*(2), 128–151. https://doi.org/10.1006/jecp.1999.2514

Grigorenko, E. L., & Sternberg, R. J. (1998). Dynamic testing. *Psychological Bulletin*, *124*(1), 75–111. https://doi.org/10.1037/0033-2909.124.1.75

Hahn, E. R., & Cantrell, L. (2012). The shape-bias in Spanish-speaking children and its relationship to vocabulary. *Journal of Child Language*, *39*(2), 443–455. https://doi.org/10.1017/S030500091100016X

Hammer, R., & Diesendruck, G. (2005). The role of dimensional distinctiveness in children's and adults' artifact categorization. *Psychological Science*, *16*(2), 137–144. https://doi.org/10.1111/j.0956-7976.2005.00794.x

Imai, M., & Gentner, D. (1997). A cross-linguistic study of early word meaning: Universal ontology and linguistic influence. *Cognition*, *62*(2), 169–200. https://doi.org/10.1016/S0010-0277(96)00784-6

Ishii, T. (2013). Reexamining semantic clustering: Insight from memory models. *Vocabulary Learning and Instruction*, *2*(1), 1–7. https://doi.org/10.7820/vli.v02.1.ishii

Ishii, T. (2015). Semantic connection or visual connection: Investigating the true source of confusion. *Language Teaching Research*, *19*(6), 712–722. https://doi.org/10.1177/1362168814559799

Kanwisher, N., McDermott, J., & Chun, M. M. (1997). The fusiform face area: A module in human extrastriate cortex specialized for face perception. *Journal of Neuroscience*, *17*(11), 4302–4311. https://doi.org/10.1523/JNEUROSCI.17-11-04302.1997

Kaushanskaya, M., & Marian, V. (2009). The bilingual advantage in novel word learning. *Psychonomic Bulletin & Review*, *16*(4), 705–710. https://doi.org/10.3758/PBR.16.4.705

Kemp, L. S., & McDonald, J. L. (2021). Second language vocabulary acquisition: The effects of semantic relatedness, form similarity, and translation direction. *Language Learning*, *71*(3), 716–756. https://doi.org/10.1111/lang.12449

Labrecque, L. I. (2020). Color research in marketing: Theoretical and technical considerations for conducting rigorous and impactful color research. *Psychology & Marketing*, *37*(7), 855–863. https://doi.org/10.1002/mar.21359

Landau, B., Smith, L. B., & Jones, S. (1988). The importance of shape in early lexical learning. *Cognitive Development*, *3*(3), 299–321. https://doi.org/10.1016/0885-2014(88)90014-7

Landau, B., Smith, L. B., & Jones, S. (1992). Syntactic context and the shape bias in children's and adults' lexical learning. *Journal of Memory and Language*, *31*(6), 807–825. https://doi.org/10.1016/0749-596X(92)90040-5

Laufer, B. (1988). The concept of 'synforms' (similar lexical forms) in vocabulary acquisition. *Language and Education*, *2*(2), 113–132. https://doi.org/10.1080/09500788809541228

Lemhöfer, K., & Broersma, M. (2012). Introducing LexTALE: A quick and valid lexical test for advanced learners of English. *Behavior Research Methods*, *44*(2), 325–343. https://doi.org/10.3758/s13428-011-0146-0

Lian, A., Karlsen, P. J., & Eriksen, T. B. (2004). Opposing effects of phonological similarity on item and order memory of words and nonwords in the serial recall task. *Memory*, *12*(3), 314–337. https://doi.org/10.1080/096582103440000426

Llach, M. d. P. A. (2015). Lexical errors in writing at the end of primary and secondary education: Description and pedagogical implications. *Porta Linguarum: Revista Internacional de Didáctica de las Lenguas Extranjeras*, *23*, 109–124.

Luna, M. L., & Sandhofer, C. M. (2021). Arbitrary but predictive cues support attention to overlooked features. *Journal of Memory and Language*, *120*, 104251. https://doi.org/10.1016/j.jml.2021.104251

Marian, V. (2023). *The power of language: How the codes we use to think, speak, and live transform our minds*. Penguin.

Marian, V., Bartolotti, J., Chabal, S., & Shook, A. (2012). CLEARPOND: Cross-linguistic easy-access resource for phonological and orthographic neighborhood densities. *PLoS One*, *7*(8), e43230. https://doi.org/10.1371/journal.pone.0043230

Marian, V., Bartolotti, J., van den Berg, A., & Hayakawa, S. (2021). Costs and benefits of native language similarity for non-native word learning. *Frontiers in Psychology*, *12*, 651506. https://doi.org/10.3389/fpsyg.2021.651506

Marian, V., Blumenfeld, H. K., & Kaushanskaya, M. (2007). The language experience and proficiency questionnaire (LEAP-Q): Assessing language profiles in bilinguals and multilinguals. *Journal of Speech, Language, and Hearing Research*, *50*(4), 940–967. https://doi.org/10.1044/1092-4388(2007/067)

Marian, V., Chabal, S., Bartolotti, J., Bradley, K., & Hernandez, A. E. (2014). Differential recruitment of executive control regions during phonological competition in monolinguals and bilinguals. *Brain and Language*, *139*, 108–117. https://doi.org/10.1016/j.bandl.2014.10.005

Marian, V., Hayakawa, S., & Schroeder, S. R. (2021). Cross-modal interaction between auditory and visual input impacts memory retrieval. *Frontiers in Neuroscience*, *15*, 661477. https://doi.org/10.3389/fnins.2021.661477

Markman, E. M. (1990). Constraints children place on word meanings. *Cognitive Science*, *14*(1), 57–77. https://doi.org/10.1207/s15516709cog1401_4

Marslen-Wilson, W. (1987). Functional parallelism in spoken word-recognition. *Cognition*, *25*(1-2), 71–102. https://doi.org/10.1016/0010-0277(87)90005-9

Nation, P. (2000). Learning vocabulary in lexical sets: Dangers and guidelines. *TESOL Journal*, *9*(2), 6–10. https://doi.org/10.1002/j.1949-3533.2000.tb00239.x

Niese, H., & Brackenbury, T. (2020). Teaching shape bias to increase the expressive vocabularies of late talkers. *Clinical Archives of Communication Disorders*, *5*(2), 55–65. https://doi.org/10.21849/cacd.2020.00234

Ning, S., Hayakawa, S., Bartolotti, J., & Marian, V. (2020). On language and thought: Bilingual experience influences semantic associations. *Journal of Neurolinguistics*, *56*, 100932. https://doi.org/10.1016/j.jneuroling.2020.100932

Papagno, C., & Vallar, G. (1992). Phonological short-term memory and the learning of novel words: The effect of phonological similarity and item length. *The Quarterly Journal of Experimental Psychology Section A*, *44*(1), 47–67. https://doi.org/10.1080/14640749208401283

Roediger, H. L., III, & Karpicke, J. D. (2006). The power of testing memory: Basic research and implications for educational practice. *Perspectives on Psychological Science*, *1*(3), 181–210. https://doi.org/10.1111/j.1745-6916.2006.00012.x

Samuelson, L. K. (2002). Statistical regularities in vocabulary guide language acquisition in connectionist models and 15–20-month-olds. *Developmental Psychology*, *38*(6), 1016–1037. https://doi.org/10.1037/0012-1649.38.6.1016

Samuelson, L. K., & Horst, J. S. (2008). Confronting complexity: Insights from the details of behavior over multiple timescales. *Developmental Science*, *11*(2), 209–215. https://doi.org/10.1111/j.1467-7687.2007.00667.x

Samuelson, L. K., & Smith, L. B. (1999). Early noun vocabularies: Do ontology, category structure and syntax correspond? *Cognition*, *73*(1), 1–33. https://doi.org/10.1016/S0010-0277(99)00034-7

Schonberg, C. C., Russell, E. E., & Luna, M. L. (2020). Effects of past language experience and present language context on the shape bias in Spanish–English bilingual children. *Developmental Science*, *23*(2), e12879. https://doi.org/10.1111/desc.12879

Smith, L. B. (1999). Children's noun learning: How general learning processes make specialized learning mechanisms. In B. MacWhinney (Ed.), *The emergence of language* (pp. 277–303). Lawrence Erlbaum Associates.

Smith, L. B., Jones, S. S., Landau, B., Gershkoff-Stowe, L., & Samuelson, L. (2002). Object name learning provides on-the-job training for attention. *Psychological Science*, *13*(1), 13–19. https://doi.org/10.1111/1467-9280.00403

Subrahmanyam, K., & Chen, H.-H. N. (2006). A crosslinguistic study of children's noun learning: The case of object and substance words. *First Language*, *26*(2), 141–160. https://doi.org/10.1177/0142723706060744

Vlach, H. A. (2016). How we categorize objects is related to how we remember them: The shape bias as a memory bias. *Journal of Experimental Child Psychology*, *152*, 12–30. https://doi.org/10.1016/j.jecp.2016.06.013

Wagner, R. K., Torgesen, J. K., Rashotte, C. A., & Pearson, N. A. (1999). *Comprehensive test of phonological processing: CTOPP*. PRO-ED.

Wechsler, D. (1999). *Wechsler abbreviated scale of intelligence (WASI)*. Harcourt Assessment.

Yoshida, H., & Smith, L. B. (2005). Linguistic cues enhance the learning of perceptual cues. *Psychological Science*, *16*(2), 90–95. https://doi.org/10.1111/j.0956-7976.2005.00787.x