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Developmental evidence for sensitivity to hierarchical structure in the noun phrase

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Abstract

In most of the world's languages, complex noun phrases are created by placing adjectives closest to the noun, and demonstratives farthest away, with numerals in the middle (e.g., "this one short paper"). Theoretical linguistics suggests that this tendency may result from a typical hierarchical structure, in which adjectives form an immediate constituent with nouns, numerals combine with that sub-constituent, and demonstratives combine with the resulting unit. Recent experimental studies also support this idea, showing learners prefer orders that follow this hierarchy (e.g., Martin et al. 2020). However, it is unknown whether this same preference is found in children, who have less experience than adults with these structures, and who might be less sensitive to the hierarchical structure of language. Here, we investigate ordering preferences in 5-6-year-old children. Results show that children, like adults, prefer hierarchy-following orders, strengthening the hypothesis that the prevalence of these orders reflects a universal cognitive bias.

Keywords: artificial language learning; learning bias; language universals; word order

Introduction

One of the central questions in the language sciences is to what extent common properties of language can be explained by features of the human cognitive system. Ordering tendencies—i.e., evidence from the world's languages that some ways of ordering words are more common than others—have long been a key testing ground. Here, we follow up on a number of recent studies that have explored the potential cognitive underpinnings of word order in complex noun phrases involving nouns, adjectives, numerals, and demonstratives (e.g., "these three white kittens"). There are 24 logically possible ways to order these four elements, many (if not all) found in some language (Dryer, 2018). However, most languages appear to follow a similar organizational principle: the most commonly attested orders involve placing adjectives closest to nouns, and demonstratives farthest away, with numerals falling in the middle (Dryer, 2018; Cinque 2005; Greenberg, 1963).

This cross-linguistic tendency has been hypothesized to reflect an abstract hierarchical template, as in Figure 1 (e.g., Abels & Neeleman, 2012), and a universal bias for linear orders that can be transparently derived from it (e.g., Culbertson & Adger, 2014; Culbertson et al., 2020). This hypothesis is supported by a series of experimental studies (Culbertson & Adger, 2014; Martin et al., 2019; Martin et al., 2020; Steinert-Threlkeld & Shapiro, 2023; Martin, Adger, Abels, Kanampiu, et al., 2024). In these studies, participants learn a lexicon of nouns and nominal modifiers, and are given evidence that individual modifiers appear in a non-native-like order (e.g., following the noun for English speakers), but no evidence for the relative order of multiple modifiers. When tested on what order they infer, participants in these studies mirror the cross-linguistic tendency to place adjectives closer to nouns, and demonstratives furthest away (e.g., "kittens white these" vs. "kittens these white"). Participants were found to prefer these orders even over orders that are more similar to the linear order of their own language (e.g., as shown in Culbertson & Adger, 2014), and even if their own language does not have a hierarchy-following order (Martin et al., 2024).

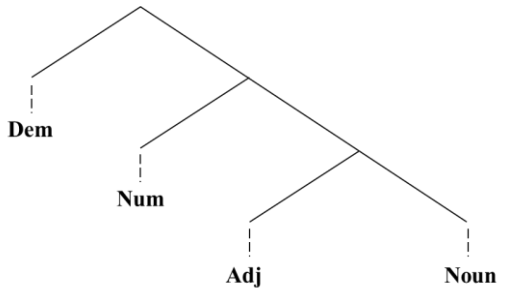


Figure 1: Illustration of the proposed underlying hierarchy of the noun phrase: nouns form a constituent with adjectives, this constituent combines with numerals, and this expanded constituent combines with demonstratives.

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Importantly, however, the current evidence comes only from adults. Children, who have less language experience and often show different cognitive biases from adults (Hudson Kam & Newport, 2005, 2009; Raviv & Arnon, 2018; Schwab et al., 2018; Tal & Arnon, 2022), might not show a preference for the hierarchy-following order. First, children have less exposure to the hierarchical structure of language compared to adults (Gertner & Fisher, 2012), something they may need to learn (Perfors et al., 2011). Second, children are argued to chunk linguistic material more than adults (Arnon, 2021; Arnon & Christiansen, 2017), and hence treat it less compositionally. For this reason, they might be less prone than adults to represent linguistic material in a hierarchical way. If, nevertheless, young children exhibit a preference for hierarchy-following order, it would strengthen the argument that the prevalence of such orders in the world's languages is derived from fundamental cognitive biases that do not necessarily rely on linguistic experience. Here, we use a relatively new paradigm, *iconic artificial language learning* (Steinert-Threlkeld & Shapiro, 2023) to investigate this hierarchy-following preference in children. In what follows we describe in more detail this method, which builds on previous artificial language learning experiments on noun phrase word order done with adults.

Previous behavioural experiments

In recent years, a number of experiments have been conducted to investigate whether learners have a preference for noun phrase word orders that conform to the hierarchy in Figure 1, i.e., have adjective closest to the noun, then numeral, then demonstrative. The first such evidence was provided by Culbertson and Adger (2014). In their experiment, English-speaking adults were trained on a novel language that is based on English lexicon, but in which modifiers appear after the noun (e.g., "handbag green"). Crucially, participants were trained on combinations of nouns with single modifiers. Following this training, they were asked to infer what a combination of a noun with two modifiers would look like in this novel language. Results revealed that participants preferred hierarchy-following orders (e.g., "handbag green this") over non-hierarchy-following ones (e.g., "handbag this green"), even though the latter more closely resembles the linear order of English (where 'this' precedes 'green' in complex noun phrases). Martin et al. (2019) replicated this study with Thai-speaking adults, whose native word order is the mirror of English (i.e., they have the equivalent of "handbag green this" as their default order). These participants were trained on nouns with single pre-nominal modifiers, again using a Thai lexicon. These participants inferred a pre-nominal hierarchy-following order (e.g., "this green handbag").

Martin et al. (2020) present a series of studies conceptually replicating these original experiments, but with a fully artificial language. English-speaking participants were trained on phrases in a novel language, used to describe images of objects placed on a table that was placed in front of a girl. The objects could be red or black, have numerosity two or three, and be located near to or far from the speaker. As before, phrases in the language were composed of a noun and a single post-nominal modifier. For example, an image of a red feather would be described as "puku taka" (akin to 'feather red'), and an image of a feather that is far from the girl would be described as "puku hono" (akin to 'feather that'). In testing, they were asked to describe images which required using both modifiers together. Again, participants preferred the hierarchy-following order ("puku taka hono"). Since English (and Thai) speakers have extensive experience with a hierarchy-following language, the experimental results summarised so far are compatible with the idea that participants prefer these orders because of their prior language experience. To address this, the experiment was recently replicated with speakers of Kîîtharaka – a language that places demonstratives closer to nouns than adjectives, and hence does not follow the hierarchy (Martin et al., 2024). Again, results revealed that participants preferred using the hierarchy-following order.

Another recent study attempted to abstract away from participants' linguistic experience a step further by employing a visual artificial language (Steinert-Threlkeld & Shapiro, 2023). This study used the same design and images as Martin et al. (2020) but utilized an icon-based lexicon instead of phonologically-realized words. For example, an image of a red feather was described with an icon of a feather followed by an icon of the colour red. As in previous studies, following training on combinations of nouns with single modifiers, English-speaking participants were asked to create phrases with two modifiers, in this case, using icons. The results revealed, again, a preference for hierarchy-following orders. These findings further support the argument that this preference is not dependent on participants' experience with their natural language (for corroborating evidence using a different non-linguistic method, see Culbertson et al., 2020). Importantly for our purposes, this paradigm also offers a less taxing (and a more playful) way to teach participants a novel language. Since the iconicity of this language eases the burden of lexicon learning, it makes the overall task more feasible for children. Building on these results, as well as other experiments training children on icon-based languages (Tal et al., 2023), we used this method in the present study to investigate children's word order preferences in the noun phrase.

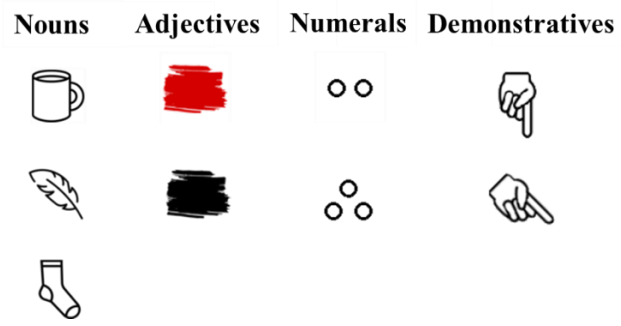


Figure 2: The iconic lexicon.

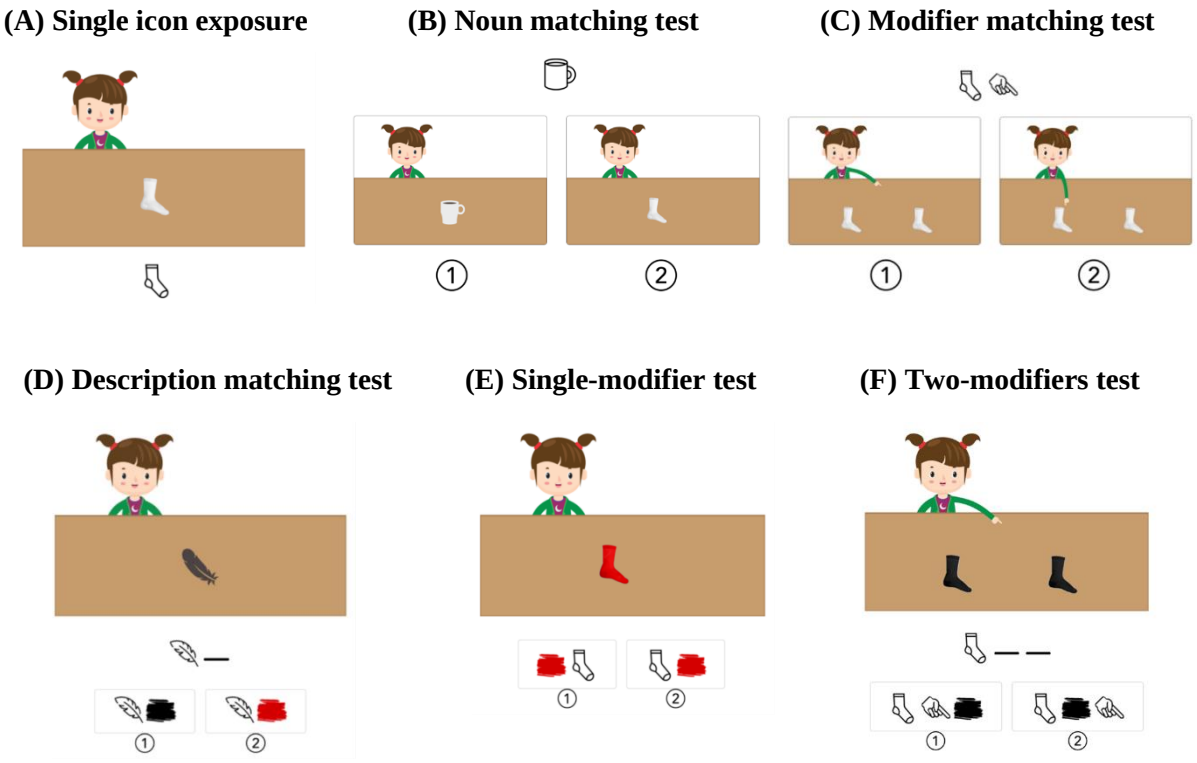


Figure 3: Experimental procedure. In this example, the condition is Adj-Dem.

The Experiment

Following previous experiments, in our design we again ask participants to extrapolate beyond their input (for a summary of uses of this kind of paradigm see Culbertson, 2023). In this case, participants are trained on sequences of icons, the first conveying the object (e.g.,), and the second conveying a single modifier: either an adjective (e.g.,), and a demonstrative (e.g.,), a numeral (e.g.,) and a demonstrative, or an adjective and a numeral. As in previous studies with English-speaking participants, the modifier icons in this language are post-nominal (e.g.,). Following training, participants are asked to guess the relative order of two modifier icons when both are required. If children, like adults, have a preference for hierarchy-following orders, then they should choose to order the two modifier icons accordingly (e.g.,). If, alternatively, children are more sensitive to linear order than adults, then they should prefer to arrange the modifiers in a way that resembles more the order in their native language (e.g.,).

Methods

Participants 107 English-speaking 5–6-year-old children participated in the experiment. They were randomly assigned to one of three conditions, each including two modifiers: adjectives and demonstratives (henceforth Adj-Dem), numerals and demonstratives (henceforth Num-Dem), and adjectives and numerals (henceforth Adj-Num). 17 participants were excluded for failing to reach at least 83% accuracy in the single-modifier test trials (see below). This resulted in 90 participants, 30 in each condition. Participants received a £5 gift voucher as a token of appreciation. Parental consent was obtained for all children.

Stimuli Following Steinert-Threlkeld and Shapiro (2023), we created an iconic lexicon to represent 3 noun meanings (mug, feather, sock) and 6 modifier meanings (2 demonstratives: this, that; 2 numeral meanings: two, three; 2 adjective meanings: red, black. see Figure 2). In descriptions containing more than one icon, the order was from left to right, and the icons appeared sequentially.

The visual images that the novel language described were taken (and slightly adapted) from Martin et al., (2020). The images depicted different objects on a table in front of a cartoon girl. In trials featuring an adjective, objects were coloured in either red or black (see Figure 3D). In all other trials they were white. In trials featuring a demonstrative the girl was shown pointing to an object that was either near her or far from her (see Figure 3C). In all the other trials the girl was simply standing behind the table.

Procedure The experiment was programmed in JavaScript using JsPsych (De Leeuw, 2015) and was conducted online. The experimenter and the child participant communicated via Zoom, where the experiment, displayed in the experimenter's web browser, was shared with the child through screen sharing. The design required the child to instruct the experimenter on which elements to click (further details are provided below). To train children on doing so, the session

began with a short "warmup" session, composed of two 2AFC trials. In each such trial, the child saw two numbered images on screen and had to instruct the experimenter which one to click on based on the experimenter's instruction. For example, the experimenter would ask "which one of them is a butterfly, number 1 or number 2?". The experimenter repeated the instructions until the child chose the correct picture and instructed the experimenter which image to choose in the correct way (i.e., one of the numbers, rather than, e.g., "this one" or "the butterfly"). Following this warmup, participants were told they were going to meet a girl who invented a new language, made up of little drawings. They then went through several training stages. First, in the single icon exposure (3 trials), they were introduced to the icons that corresponded to each noun. In each trial they saw an image of the girl with one of the objects, and beneath the image the corresponding icon that describes this image (see Figure 3A). This was followed by a noun matching test (6 trials), where in each trial participants saw an icon and two images, and had to choose the image that was described by the icon (see Figure 3B). Here and in all 2AFC tasks following, the images were numbered, so that the child could instruct the experimenter which image to click on. The child received feedback, which was the same in all the following test trials: a correct choice resulted in the chosen image marked in green, a cartoonish success sound and an image of accumulated gold. An incorrect choice resulted in the chosen image marked in red and a cartoonish sound of a failure. Following this stage, the experimenter instructed the child that they would see the girl describing more complex things. This was then demonstrated for each of the two modifiers that appeared in the given condition. For example, in the Adj-Dem condition, the child would see an image depicting a red feather, alongside the icons used to describe this image. The experimenter would emphasize their order ("first comes the icon that describes the feather, then the icon that describes red"). Then the other adjective would be presented in the same way. Following that, the child would see an image requiring the use of the demonstrative, alongside the corresponding two-icon description. The experimenter would again emphasize the order of the icons. The other demonstrative would then be presented in the same way. The order of presentation of the modifiers was randomized for each participant. Following this demonstration, there was a modifier matching test (6 trials). In each trial, children saw a sequence of two icons alongside two images and had to choose the image that was described by the icons. The foil image always corresponded to the same noun combined with the other modifier of the same category (see Figure 3C). This was followed by a description matching test (6 trials), which presented the opposite test: children were shown an image along with two descriptions and had to select the description that correctly matched the image. The foil description always had the same noun combined with the other modifier of the same category (see Figure 3D). The next stage was a single-modifier test (12 trials), designed to ensure that participants had learned the word order of the novel language. In this phase, participants again saw an image and two possible icons-descriptions for it, and had to choose the correct description. This time, however, the foil description had the same icons as the correct one, but in the reverse order (see Figure 3E). Participants who were not accurate in at least 10 test trials were excluded from the final analysis (this was determined using the binomial test as a threshold for success: correct answers in 10 out of 12 trials is significantly above chance). Following this test, participants were informed that they would now see more complex images, and were shown the kind of images they were about to see next (e.g., an image of a girl with two red feathers on the table). They were told that the girl would have to use three icons to describe these kinds of images, and that their task was to guess how she would do it. They then reached the critical stage – the two-modifiers test (12 trials). In each trial, children saw an image and two options for describing it, each composed of three icons. Both descriptions started with the noun, and differed only in the relative order of the two modifier icons (i.e., hierarchy-following order and non-hierarchy following order, see Figure 3F). In this stage, participants received no feedback (as, indeed, there were no correct answers in this test).

Results

Figure 4 shows the proportion of hierarchy-following order as a function of condition. We used a mixed-effect logistic regression model to predict use of hierarchy-following icon orders. The model included a fixed effect for condition (sum coded) and random by-participant intercepts. The intercept was positive and significant, suggesting that children prefer the hierarchy-following order (β=0.84, SE=0.3, p=.005). However, Figure 4 suggests a difference between the conditions. To investigate this difference, we ran the same model but with condition treatment-coded with Num-Dem as the baseline. This model revealed that participants' icon-order choices in the Num-Dem condition did not differ from chance (β=-0.68, SE=0.48, p=.16), and choice of the hierarchy-following order was significantly higher in the Adj-Num condition (β=2.15, SE=0.72, p=.003) and the Adj-Dem condition (β=2.4, SE=0.72, p<.001). Crucially, when using either Adj-Num or Adj-Dem as the baseline, the intercept was positive and significant (for Adj-Num: β=1.47, SE=0.52, p=.005; for Adj-Dem β=1.72, SE=0.52, p<.001), suggesting that preferences in these conditions were significantly above chance. Taken together, the preference for the hierarchy-following order was found in two out of the three conditions. We discuss the possible reason for this discrepancy in the next section.

Discussion

Many of the world's languages follow the same organizational principle in the noun phrase: adjectives tend to appear closer to nouns, then numerals, and demonstratives are furthest away. This structure has been argued to reflect a hierarchy in which nouns form an immediate constituent or sub-unit, the numeral combined with this sub-unit, and the

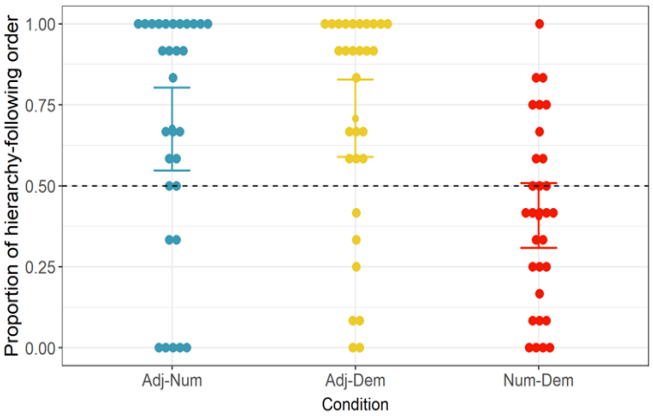


Figure 4: Proportion of choosing the hierarchy-following order by condition. The dashed line indicates the chance level; Each dot represents a participant; error bars represent 95% bootstrapped confidence intervals around the mean.

demonstrative combines with this larger unit, as in Figure 1. Growing evidence suggests that learners prefer hierarchy-following orders, even over ones that resemble the linear order of their native language (Culbertson & Adger, 2014; Martin et al., 2020), and even if their own language does not (Martin et al. 2024). This line of work provides empirical evidence linking the prevalence of hierarchy-following orders in the world languages to the cognitive biases of learners. However, the evidence for this bias has so far come exclusively from adults. The current study explored whether this preference is also attested in young children. To this end, we taught children combinations of single modifiers and nouns in a novel iconic artificial language, and asked them to infer how a sequence of icons consisting of a noun icon and two modifier icons would be ordered. Although they had no evidence for how to combine two modifier icons in their training, children showed a preference for hierarchy-following orders (e.g., "feather red the") over orders that are more similar to the linear order of their native language (e.g., "feather the red").

Surprisingly, however, this preference was not found for one of our conditions, Num-Dem. That is, when choosing between different ways to order demonstrative and numeral icons, children did not show a preference for either type of order (e.g., vs.). What could explain this asymmetry? In previous experiments, it has been systematically found that the preference for relative order of adjective and demonstrative is consistently strongest, and the preference for order of adjective and numeral weakest, with numeral and demonstrative falling somewhere in between. Martin et al. (2020) argued that this might reflect hierarchical distance: adjective and demonstrative are farthest apart in the hierarchy and thus perturbing them is the most strongly dispreferred. Therefore, it could be that we are seeing something similar to this here, but adults and children are a bit different in how they represent the structural difference between these modifiers: adults represent adjectives and numerals as structurally closest or representationally most similar, while children treat numerals and demonstratives as most similar.

However, we think another possibility might lie in how we instructed children about the different icons and their meanings. In the original study using iconic artificial language learning with adults, Steinert-Threlkeld and Shapiro (2023) explicitly define the pointing icons as corresponding to "this" and "that". Instead, here we used the words "close" and "far". While we did this in an attempt to simplify, these meanings are not identical to demonstrative meanings and could have encouraged children to treat the demonstrative as a type of adjective. Doing this may result in a weaker ordering preference in some participants. Importantly, such an interpretation would still be in line with the observed preferences in the Adj-Dem condition. Speakers also show an ordering preference *within* adjectives; colour adjectives tend to appear closer to the noun than many other adjective types, including spatial adjectives (for a review see Scontras, 2023). Hence, even if children interpreted the demonstratives as "close" and "far", they should still place colour adjectives closer to the noun, as observed in the Adj-Dem condition. Indeed, we have preliminary evidence to suggest that such an interpretation could lead to this pattern of results. We replicated our study with adults (i.e., describing pointing icons using "close" and "far"), and found that as for children, there was a hierarchy-following preference in the Adj-Num and Adj-Dem condition, but not in the Num-Dem condition. When we explicitly told participants that pointing icons referred to "this" and "that" we recovered a preference for a hierarchy-following order. We are currently conducting this revised version of the study with children to corroborate this explanation.

Setting aside this issue for now, the present results support the idea that the cross-linguistic tendency in nominal order might reflect a hierarchical-template and a bias for orders that transparently reflect this template. In particular, it strengthens the argument that learners' preference for these orders does not stem from their experience with their own language, but rather reflects a core cognitive bias (Culbertson et al., 2020; Martin et al., 2024). In future work, we plan to test this idea more stringently by investigating this preference in infants.

A remaining open question is what drives this core cognitive preference. Some have argued that the hierarchical template in Figure 1 is innately specified (Adger, 2003; Cinque, 2005). Others have argued that this preference stems from learned knowledge. Under one account, this knowledge is about the linguistic categories themselves: adjectives are more predicative of the nouns they modify than numerals, which are in turn more predictive than demonstratives, and thus the order reflects a strategy for dependency-locality (Futrell & Levy, 2017; Hahn et al., 2021). Under a different account, the relevant knowledge originates in the world itself: properties (typically conveyed by adjectives) are most closely related to or inherent to objects (conveyed by nouns), distance from the speaker is least closely related (Culbertson et al., 2020). Future work is needed in order to adjudicate between these hypotheses.

More generally, the present findings showcase the importance of investigating the developmental trajectory of cognitive biases that are postulated to shape language structures. In some cases, finding relevant biases in children might suggest that they actively play a role in shaping cross-linguistic trends (Hudson Kam & Newport, 2009b; Tal & Arnon, 2022). While the role of children in these processes is heavily debated (Cournane, 2019; Kempe et al., 2018; Labov, 2007; Raviv & Arnon, 2018), studying them is crucial also for other reasons. Research of this kind can provide a more nuanced understanding of the cognitive biases in question. In the present case, finding the preference for hierarchy-following orders in children strengthens the argument that this preference does not rely on extensive experience with languages, but more likely reflects a core cognitive preference.

Acknowledgments

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