Silent gesture and noun phrase universals

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Abstract

In this paper we investigate a hypothesized cognitive bias for isomorphic mappings between conceptual structure and linear order in the noun phrase. This bias has been proposed as a possible explanation for a striking asymmetry in the typology of the noun phrase–linear orders which place the adjective closest to the noun, then the numeral, then the demonstrative, are over-represented in the world's languages. Previous experimental work has provided evidence that an isomorphism bias affects English-speaking learners' inferences about the relative order of modifiers in an artificial language. Here, we use the silent gesture paradigm to explore whether the isomorphism bias influences spontaneous gestures innovated by participants in a modality with which they have relatively little prior experience. We find that gesture string order largely conforms to the same striking pattern found in noun phrase typology, supporting the role of the isomorphism bias in shaping the emergence of language (and language-like) systems.

Keywords: silent gesture; noun phrase; word order; linguistic universals; cognitive biases

Introduction

Linguists studying word order have long noticed striking differences in frequency among possible word order patterns. Explaining *why* certain patterns are more common than others is a source of ongoing debate. On the one hand, these typological differences may reflect evolved properties of human cognition. On the other hand, they may be the result of a complex interplay between various non-cognitive factors: genetic and areal relationships between languages, social or cultural pressures, and accidents of history (Evans & Levinson, 2009; Dunn, Greenhill, Levinson, & Gray, 2011; Piantadosi & Gibson, 2014; Ladd, Roberts, & Dediu, 2015).

In this paper we will investigate a well-known pattern in language typology relating to the structure of the noun phrase, using a experimental methodology that has not yet been applied in this domain, in which participants must improvise gestures to communicate pictures or scenes. What we find is a clear preference for gesture orders which conform to a structural template that is found in the majority of languages. These orders do not in general follow the typical linear order of noun phrases in their native language, English. Most prominently, they often produce adjective gestures *following* the noun. We argue that the results of our experiment reflect the underlying conceptual structure of the noun phrase, suggesting a cognitive explanation for the typological pattern.

Universal 20 and the isomorphism bias

Greenberg (1963) formulated a number of typological 'universals', based on the relative frequency of syntactic patterns in 30 different languages. Universal 20 concerns the Noun Phrase, in particular the order of the noun and its modifiers. It states that *when any or all of the items (demonstrative, numeral, and descriptive adjective) precede the noun, they are always found in that order. If they follow, the order is either the same or the exact opposite* (Greenberg, 1963).

In other words, the three most common NP orders according to Greenberg are `Dem-Num-Adj-N` ('these five large houses'), `N-Dem-Num-Adj` ('houses these five large'), and `N-Adj-Num-Dem` ('houses large five these'). More recent analyses, based on a larger set of languages have found that of the three orders, `N-Dem-Num-Adj` does occur, but is far less frequent than the other two (Cinque, 2005; Dryer, 2009).

To explain the difference in frequency between Greenberg's two post-nominal orders (`N-Adj-Num-Dem` and `N-Dem-Num-Adj`), Culbertson and Adger (2014) appeal to the notion of *isomorphism*, present in some form in a number of theoretical accounts of this universal (Cinque, 2005; Rijkhoff, 2004). In general, isomorphism refers to a transparent relationship between meaning and structure. To see how this applies to the noun phrase, consider the distinct semantic contributions of the different modifier types (Culbertson & Adger, 2014). Adjectives modify properties that are inherent to the noun, numerals group together these smaller units, and demonstratives connect these grouped units to the external discourse.

In a complex noun phrase, the adjective is thus conceptually closest to the noun, followed by the numeral, and finally the demonstrative. These relations determine constituency, and can be seen, for example, in *semantic scope*. A numeral (like 'five) takes scope over the noun+adjective unit (like 'large houses'); the meaning of the numeral applies to the noun as well as to the adjective. Similarly, a demonstrative takes scope over a noun+adjective+numeral unit (such as in 'these five large houses') to connect it to the discourse.[1] These conceptual relations are illustrated in Figure 1.

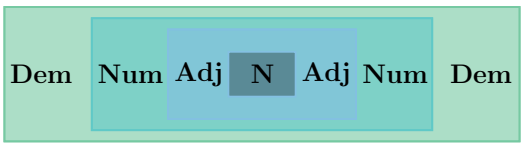

Figure 1: The conceptual structure of the noun and its modifiers: the adjective modifies the meaning of the noun most closely; the numeral takes scope over this unit; the demonstrative is conceptual most distant, taking widest scope.

[1]There is in fact converging evidence from formal semantics, syntax, and functional linguistics to support this analysis (Partee, 1987; Adger, 2003; Rijkhoff, 2004).

Note that the conceptual structure does not fully determine linear order, rather there are several possible ways to map structure to order, all of which preserve the underlying relations between elements. For instance, `Dem-Adj-N-Num`, `Dem-N-Adj-Num`, and `Adj-N-Num-Dem` can all be 'read off' the structure in Figure 1 directly, without perturbing the constituency relations. On the other hand, `Adj-Dem-N-Num` cannot be read off the structure directly, the only way to get this order is to move `Adj` outside of its unit with `N`. There are in fact eight ways of forming a structure-preserving string, these are the *isomorphic* orders. They make up one third of the 24 possible ways of ordering `Dem`, `Num`, `Adj` and `N`.

Returning to the two post-nominal orders mentioned above, `N-Adj-Num-Dem` and `N-Dem-Num-Adj`, we can now see that isomorphism is a possible explanation for the frequency asymmetry between them: the more frequent `N-Adj-Num-Dem` is isomorphic, while the infrequent `N-Dem-Num-Adj` is not. More generally, isomorphic orders tend to be more frequent than non-isomorphic ones, as shown in Figure 2.

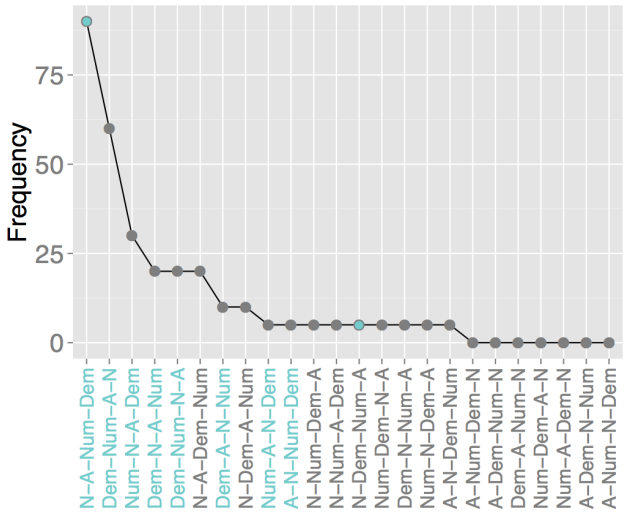

Figure 2: Frequency of NP structures: isomorphic orders are all among the most common in this sample (Cysouw, 2010).

To investigate whether a bias for isomorphism plays a role in language learning, Culbertson and Adger (2014) conducted a series of experiments in which participants were trained on an artificial language with simple noun phrases consisting of a noun plus a single modifier (either an adjective, a numeral or a demonstrative). Participants were then tested on complex noun phrases with more than one modifier (i.e., an adjective *and* a demonstrative), which they had not seen before. For instance, participants who learned `N-Adj` and `N-Dem` strings in the training phase were then prompted to construct a phrase containing all three elements. They could either choose `N-Adj-Dem`, which is isomorphic, or `N-Dem-Adj`, which shares the modifier order of English (`Dem-Adj`) but is non-isomorphic. Participants chose isomorphic structures in the majority of cases, suggesting that relative order of modifiers was inferred based on an underlying assumption of isomorphism rather than surface similarity to English.

Silent gesture: evidence from improvisation in the lab

The findings of Culbertson and Adger (2014) are limited in the extent to which they provide evidence for an isomorphism bias reflecting a general property of human cognition, since participants may have learned (through learning their native language) at a more abstract level that surface order is isomorphic to conceptual structure. Recent work using the 'silent gesture' paradigm offers a potential method for tapping into biases in word order while bypassing the effects of prior linguistic knowledge. In silent gesture experiments, participants with no knowledge of sign language are asked to convey information using only their hands and no speech. Existing work using this method has mainly focused on basic word order (sequences expressing information about who did what to whom). This research has found that when participants use silent gesture to describe simple transitive events, they do *not* rely on the dominant order of their native language (Goldin-Meadow, So, Özyürek, & Mylander, 2008), but instead take the semantic properties of the event into account (Gibson et al., 2013; Hall, Mayberry, & Ferreira, 2013; Schouwstra & de Swart, 2014; Schouwstra, 2016).

Experiment 1

To investigate the isomorphism bias in a modality distinct from participants' previous language experience, we conducted an experiment in which adult participants used silent gesture to describe pictures of objects modified in various ways. We hypothesise that the ordering of these gestures will conform to isomorphism, even when they do not reflect the linear order of English Noun Phrases.

Materials, participants, and procedure

We created a stimulus set consisting of images of groups of *4* or *5* (`Num`) shapes, which were either *squares* or *triangles* (`N`), either *striped* or *spotted* (`Adj`), and appeared in a *proximal* or a *distal* (`Dem`) location. Locations were represented by two iPads on which the images could appear–one closer to the participant, the other further away. Figure 3 provides example images, and Figure 4 shows the position of the iPads relative to the participant. The set of 8 different images, presented on two different iPads, together formed 16 total items.

Participants (N=20, native speakers of English, no experience with sign languages) were seated across the table from the experimenter, with the two iPads in front of them, as in Figure 4. They were filmed using a Logitech webcam connected to a MacBook Air. Before starting the silent gesture part of the experiment, participants were shown the full set of stimuli as printed pictures. Subsequently, they were asked to describe each stimulus item using only their hands, so that someone watching the recording would be able to work out

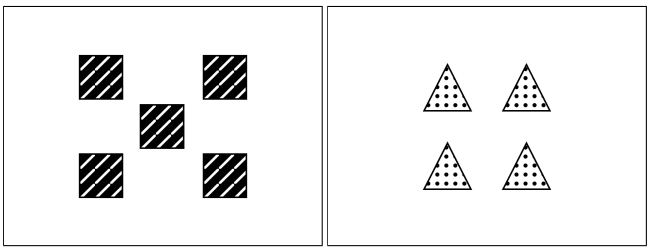

Figure 3: Example stimuli: 'five striped squares' and 'four spotted triangles'.

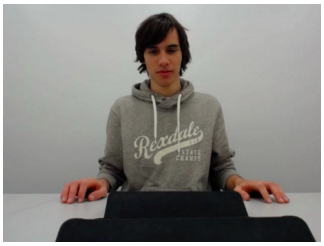

Figure 4: Experiment set-up. Note that the two iPads were placed on the table, in front of the participant: one close to the participant, and one further away.

which of the images appeared on which screen. The stimuli were presented twice in random order for each participant, with a brief break after the first run of the stimuli (32 trials in total).

Results

The videos were coded by identifying which of the gestures indicated information associated with `N`, `Adj`, `Num`, or `Dem`.[2] Occasionally, participants specified the spatial layout of the figures. This information was invariably provided in addition to other gestures referring to the number or the object, and was ignored for our coding purposes. In addition, some gestures included combinations of two elements (e.g., `N` with `Adj`). No relative ordering information can be determined for combined elements, therefore these were excluded from relevant analyses. We focused on two measures in analyzing this data: how were modifiers ordered relative to the noun (were they pre- or post-nominal), and how were modifiers ordered relative to each other (were they isomorphic given the position of the noun, or not). To code for isomorphism we looked at each modifier pair that appeared on the same side of the noun. For instance, a string `N-Num-Adj-Dem` would be coded as non-isomorphic for `Num-Adj`, but isomorphic for `Dem-Num` and `Dem-Adj`. Modifier pairs that were on different sides of the noun were excluded from this part of the analysis as these do not provide information about isomorphism. Finally, *overall* isomorphism for each full gesture string was coded according to whether any isomorphism violations were present. For this overall measure (contrary to what we did for the modifier *pairs*) we did include strings that had modifiers on different sides of the noun. Strings that excluded any of the modifiers (such as `N-Adj-Num`) were excluded.

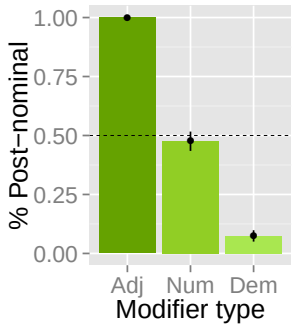

Figure 5: Results of Experiment 1: Proportion of modifiers placed post-nominally, by modifier type.

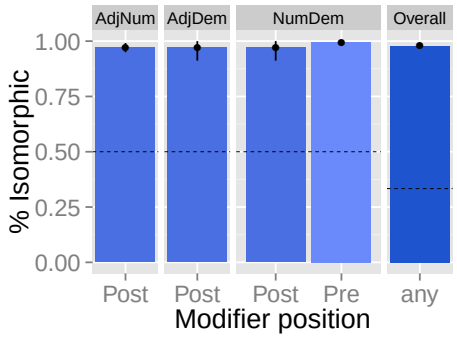

Figure 6: Results of Experiment 1: Proportion of modifier pairs conforming to isomorphic order, by modifier pair, in pre- and post-nominal position, plus overall scope isomorphism (last column). The dotted line represents chance level. Note that for overall isomorphism, chance level is at 0.33 (8 isomorphic orders/24 possible orders).

The typical order of English noun phrases is `Dem-Num-Adj-N`. Analysis of overall rates of pre- vs. post-nominal placement for each type of modifier reveal that participants' gestures deviate from pre-nominal order most obviously when it comes to the placement of `Adj`. Indeed, as shown in Figure 5, there was a strong preference for post-nominal placement. By contrast for `Dem`, participants preferred a pre-nominal position. `Num` fell in between. This was confirmed by one sample t-tests comparing average placement by participant to chance for each modifier type (t = -0.2717, df = 18, p = 0.79 for `Num`, and t = -6.9561, df = 15, p $<$.001 for `Dem`; because `Adj` was used post-nominally without exceptions, a t-test cannot be performed on that

[2]Note that we do not wish to make claims about the nature of the gestural elements produced by participants, and use the linguistic terms `N`, `Adj`, `Num`, and `Dem` for convenience.

data).[3].

Turning to isomorphism, as Figure 6 shows, participants had a strong tendency to provide gesture strings which conformed to isomorphic ordering for all modifier pairs. Importantly, this was the case both for pre-nominal and post-nominal pairs. A one sample t-test confirms that proportions of isomorphic word orders are significantly different from chance (t = 65.1549, df = 15, p <.001).

Discussion

Participants' overwhelming preference for isomorphic order in silent gesture strings provides support for a link between cognitive biases and this typological tendency. A further surprising finding is that participants very consistently produced post-nominal adjectives. This pattern is not dominant in the native language of the participants (English), although it is in fact more common typologically (Dryer, 2009).

However, two properties of our stimulus items suggest the possibility that our results may not generalize to other Noun Phrase types. First, the most common gesture order used by participants was `Dem-Num-N-Adj`. This corresponds to the physical layout of the information in each item: the iPad was the outermost, largest element, the numeral information was in some sense the next largest part of the scene, then the object shape itself, and finally, the adjective information (stripes or spots) which was always inside the object (Figure 3). If participants were starting from the outermost information and proceeding in, then, our stimuli could have set participants up to place the adjective after the noun.

Further, as mentioned above, some responses contained gestures which combined information for two of the elements present. For example, participants sometimes conveyed information about the numeral and the adjective simultaneously, for example by repeatedly drawing spots or stripes (`Adj`) four or five (`Num`) times. Such combinations were much more likely to involve the adjective, making it impossible to determine either isomorphism (for `Adj` combined with other modifiers), or position relative to the noun (for `Adj` combined with `N`) in a number of cases.

We therefore conducted an additional experiment using stimuli in which the adjective is not depicted *inside* the object, and which discourage the use of combined gestures.

Experiment 2

To address the concerns pointed out above, and to further investigate the prevalence of post-nominal adjectives, we conducted a second silent gesture experiment, using different stimuli, as described below.

Materials, participants, and procedure

Our stimuli consisted of line drawings of groups of *4* or *5* (`Num`) objects, which were either *toothbrushes* or *pencils*[4] (`N`), either *big* or *small* (`Adj`), and appeared on a *proximal* or a *distal* (`Dem`) location. The adjectives 'big' and 'small' were chosen on the basis of their visual properties: when depicted, the adjective information is not visually inside the object. Moreover, we expected that these adjectives would lead to fewer combined gestures, particularly with the noun (since both likely require difference handshapes).[5]

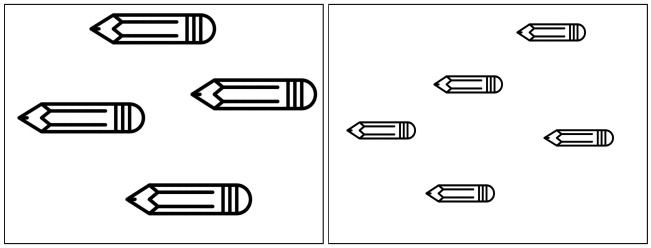

Figure 7: Example stimuli: 'five large pencils' and 'four small pencils'.

The procedure of the experiment was identical to that of experiment 1, except for the number of trials: participants (N=20, native speakers of English, no experience with sign languages) described each of the stimuli once (16 trials in total).

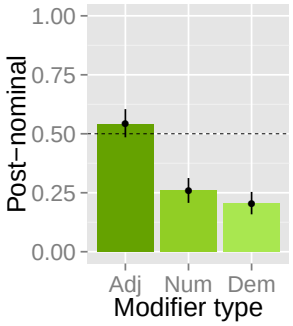

Figure 8: Results of Experiment 2: Proportion of modifiers placed post-nominally, by modifier type.

Results

As in Experiment 1, we coded the videos by identifying which portion of the gesture string indicated `N`, `Adj`, `Num`, or `Dem`. From this we determined whether the modifiers were placed pre- or post-nominally, and obtained isomorphism scores for modifier-pairs as well as full strings. The results show that although the proportions follow the pattern found in experiment 1 (note, however, that the proportion of post-nominal adjectives is no longer significantly greater than 0.5; t = 0.5138, df = 18, p = 0.61). Additionally, there was again

[3]Different t-tests have different degrees of freedom. This is due to the fact that not all data could be included for each test: some participants produced only incomplete gesture strings.

[4]Taken from: http://www.flaticon.com/packs/essential-set-2.

[5]Adjectives can be incorporated in the noun in sign languages (Sutton-Spence & Woll, 1999), and it is interesting that participants in Experiment 1 sometimes did this as well, but for the purposes of our experiment we wanted to discourage it.

an overall preference to produce isomorphic structures: a one-sample T-test confirms that the proportion of isomorphic strings differs from chance (t = 5.7149, df = 16, p <0.001).[6] However, this tendency was less deterministic than in Experiment 1.

Zooming in on the scores for different modifier pairs, participants are less likely to produce isomorphic order for `Adj-Num` combinations, in contrast to Experiment 1. When these two modifiers were placed post-nominally, they were no longer isomorphic (see Figure 9; t = 0.9077, df = 10, p = 0.39).

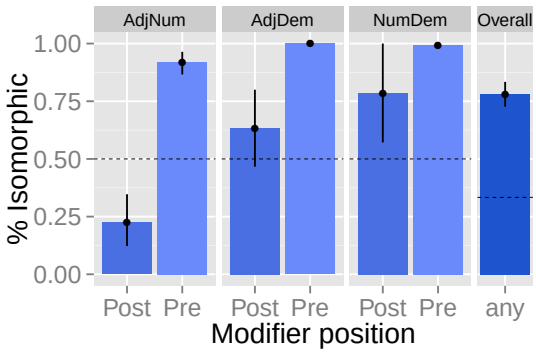

Figure 9: Results of Experiment 2: Proportion isomorphic orders, by modifier pair, plus overall scope isomorphism (last column). The dotted line represents chance level. Note that for overall isomorphism, chance level is at 0.33 (8 isomorphic orders/24 possible orders).

General discussion

Isomorphism is a hypothesized cognitive principle proposed to explain the way Noun Phrases tend to be ordered in languages of the world. Languages which obey isomorphism are much more frequent than those which don't. However, given the many other factors likely to influence typological distributions, evidence which explicitly links isomorphism to a cognitive bias is needed. Previous experimental studies confirmed that isomorphism appears to play a role in the kinds of inferences people make when learning an artificial language with word order that differs from their native language (Culbertson & Adger, 2014). However, the linguistic systems individual speakers of a given language know have already solved the problem of going from a multidimensional conceptual structure (see Figure 1 above) to a linear representation. In this paper, we investigated what happens when people start 'from scratch' and improvise utterances in the absence of a conventional system, by conveying information presented as images using only their hands and no speech.

This silent gesture paradigm has been shown to be a fruitful way of investigating what happens when people are forced to communicate without being able to use existing word order conventions. However, previous work using this paradigm focuses mainly on the order of major sentence constituents. The structure of the noun phrase has never before been studied using silent gesture.

Our experiments showed that the gestures improvised by participants to describe pictures with `N`, `Adj`, `Num`, and `Dem` information, are ordered in a way that is isomorphic to the underlying conceptual structure–adjective property closer to the noun than numerosity, and distal/proximal location furthest away. This result, combined with the fact that participants did not simply use English NP order for their gestures, supports the claim that a bias for isomorphism affects linear order independently of prior linguistic experience. This general bias therefore plays a plausible role in explaining the frequency distribution of NP orders across languages.

The clearest difference between the gesture orders participants provided and their native language experience is in the placement of the adjective. Experiment 1 showed an extremely strong preference to place the Adjective post-nominally (unlike in English), and in Experiment 2, though the placement was more variable, there was still no overall preference for pre-nominal adjectives. As mentioned above, post-nominal adjectives are in fact more common cross-linguistically, and this may represent a second active bias. Interestingly, `Adj` and `Num` gestures in Experiment 2 showed no isomorphism bias,[7] whereas they did in Experiment 1. One possible explanation for this may lie in the nature of the adjectives used in our two experiments. Adjectives describing a texture were used in Experiment 1, while adjectives for size were used in Experiment 2. Size adjectives are gradable (Kennedy, 2007), a property which affects the role of contextual information in their interpretation: for gradable adjectives, context is needed to determine what counts, e.g., as 'large' or 'small'. This closer connection to the context may make the adjectives in the second experiment less conceptually tied to the noun. Perhaps relatedly, size adjectives are general argued to scope higher, relative to other adjectives (Kemmerer, 2000), including 'striped' and 'spotted' (as reflected in their order: e.g., 'small striped triangle' sounds more natural than 'striped small triangle'). An non-isomorphic order of a numeral and a wider-scoping adjectives may thus be a weaker violation of isomorphism compared to a lower-scoping adjective. Additional investigating with a wider range of adjectives is needed to justify these claims. Note however, that they are related to a similar finding in Culbertson and Adger (2014), in which non-isomorphic orders were more likely to be chosen for structurally less distant modifier pairs (i.e., `Adj` with `Num`, compared to `Adj` with `Dem`).

[6] Because in this experiment, some participants produced English orders, we ran a separate T-test on the orders that did not follow English structure, and found that subset of the data to be significantly more isomorphic than chance (t = 3.3347, df = 10, p <0.01).

[7] Participants were as likely to produce structures like `N-Num-Adj` and `Num-Adj-N` as the isomorphic variants `N-Adj-Num` and `Num-Adj-N`.

Conclusion

The experiments reported here show that when people improvise gestures corresponding to simple pictures of objects with different properties, numerosities, and locations, they order their gestures in a way that corresponds to the underlying conceptual structure of these elements. This same structure is respected by the majority of languages in the way they order elements in the Noun Phrase (nouns, adjectives, numerals, and demonstratives), suggesting that a cognitive bias for isomorphism between meaning and linear order might shape linguistic systems in this domain.

Experiments that use improvised silent gesture, like the ones presented here, provides a window into the evolution of linguistic systems. The method gives us an experimental analog to real world situations in which language rules spontaneously emerge; for example, homesign (Goldin-Meadow & Brentari, in press), emerging sign languages (Meir et al., 2017) and early stages in spontaneous second (spoken) language acquisition by adults (Schouwstra, 2016). Accordingly, we believe that a fruitful line for future research will be an investigation of the structure of the noun phrase in these systems, providing an invaluable naturalistic complement to laboratory experiments.

Acknowledgments

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