The emergence of word order conventions: improvisation, interaction and transmission

Marieke Schouwstra Kenny Smith Simon Kirby

Abstract

When people improvise to convey information by using only gesture and no speech ('silent gesture'), they show language-independent word order preferences: SOV for extensional events (e.g., boy-ball-throw), but SVO for intensional events (e.g., boy-search-ball). Real languages tend not to condition word order on this kind of semantic distinction but instead use the same order irrespective of event type. Word order therefore exemplifies a contrast between naturalness in improvisation and conventionalised regularity in linguistic systems. We present an experimental paradigm in which initially-improvised silent gesture is both used for communication and culturally transmitted through artificial generations of lab participants. In experiments 1 and 2 we investigate the respective contributions of communicative interaction and cultural transmission on natural word order behaviour. We show that both interaction and iterated learning lead to a simplification of the word order regime, and the way in which this unfolds over time is surprisingly similar under the two mechanisms. The resulting dominant word order is mostly SVO, the order of the native language of our participants. In experiment 3, we manipulate the frequency of different semantic event types, and show that this can allow SOV order, rather than SVO order, to conventionalise. Taken together, our experiments demonstrate that where pressures for naturalness and regularity are in conflict, naturalness will give way to regularity as word order becomes conventionalised through repeated usage.

1 Introduction

All languages have conventionalised ways to describe who did what to whom, and many do this through Basic Word Order. Although all possible orderings of Subject, Object and Verb have been attested as dominant word orders in at least one language (Dryer, 2013), some word orders are more common than others. For example, SVO (e.g. English) and SOV (e.g. Japanese) are common, whereas VOS (e.g. Malagasy) is found in relatively few languages (Hawkins, 2014). Very little is known about the dominant forces in the evolution of conventionalised word order. A theme of much recent research is that cognitive biases operating at the level of the individual play an important role in shaping linguistic systems at the population level (Griffiths & Kalish, 2007; Kirby, Dowman, & Griffiths, 2007; Christiansen & Chater, 2008; Culbertson, Smolensky, & Legendre, 2012; Kirby, Tamariz, Cornish, & Smith, 2015). We propose that bias should not be taken to be a unitary and constant force; rather, we see different biases at play at different stages in the formation of linguistic rules.

We provide an account of the emergence of systematic word order that is the result of cognitive biases that are dominant when there are no conventions to build on, combined with the dynamics of language usage and language learning.

We investigate the origins of basic word order by focusing on three mechanisms that may play a role in cultural evolution: *improvisation*, *interaction* and *iterated learning*. Improvisation occurs when an individual has to convey information in the absence a conventional language. Improvisation is spontaneous, and the basis for communication in this kind of situation is shared biological makeup and shared world knowledge. Interaction is a process in which two or more individuals build up a shared history, a common ground. Iteration is what happens when an emerging system is passed on to a new learner, who learns by observing other learners.

Real life examples of improvisation, interaction and iterated learning can be observed, for example, in emerging languages in the manual modality. Home-sign systems are largely based on improvisation (Goldin-Meadow, 2005).¹ In places where multiple homesigners come together with no existing sign language in place, such as in the first cohort of Nicaraguan Sign Language, interactive principles come to play a dominant role (Kocab, Senghas, & Snedeker, 2016). Finally, the influence of iterated learning can be seen in subsequent cohorts of NSL (Senghas & Coppola, 2001; M. E. Flaherty, 2014).

The three mechanisms can also be studied in the laboratory. Silent gesture experiments, in which naïve participants convey information using only gesture and no speech, investigate the biases that play a role in improvisation situations (Goldin-Meadow, So, Özyürek, & Mylander, 2008; Schouwstra & de Swart, 2014; Gibson et al., 2013; Hall, Mayberry, & Ferreira, 2013; Schembri, Jones, & Burnham, 2005). We can combine silent gesture with mechanisms for interaction and iterated learning to investigate how the products of improvisation change over time, to investigate how individuals improvise solutions to communicative challenges, how pairs of individuals create conventions through interaction, and how these conventions are transmitted over time through iterated learning (Motamedi, Schouwstra, Smith, Culbertson, & Kirby, 2019). Below, we will describe each of these mechanisms (improvisation, interaction and iteration) in more detail, and discuss how we expect they act on the emergence of word order regimes in a series of silent gesture experiments.

1.1 Improvisation

When people are forced to communicate in a novel way without using an existing language, they will show consistent word order preferences that seem independent of the dominant order of their native language; this has been observed in a number of studies of silent gesture, in which people are asked to convey information using only gesture and no speech. Previous research has shown that for transitive events that involve movement through space (such as ‘boy drops glass’), people show a language independent preference for SOV word order, and SOV word order has been proposed as the natural word order (Goldin-Meadow et al., 2008). When other types of event are described, however, people show

¹Admittedly, homesign is used in interaction between the homesigner and their family members, but the construction of the system is driven by the deaf child, and comprehension of the subtleties of the system by family members is surprisingly poor (Carrigan & Coppola, 2017).

a different word order preference: they condition the word order of their utterances on the semantic properties of the events they describe. For example, when events are reversible (typically, when a transitive event has two animate participants, such as in ‘the boy kicks the firefighter’), the preference for SOV order becomes less dominant, in favour of SVO among other orders (Meir, Lifshitz, Ilkbasaran, & Padden, 2010; Hall et al., 2013; Meir et al., 2017; Kocab, Lam, & Snedeker, 2017; Hall, Ahn, Mayberry, & Ferreira, 2015; Gibson et al., 2013; Futrell et al., 2015).

Another contrast in event type that has an effect on word order relates to the referential properties of the verb. When events do not involve just movement through space, but can be categorised as *intensional* instead, this leads to a substantial, and cross-linguistic, change in word order preference in silent gesture (Schouwstra & de Swart, 2014).² Intensional events are those events in which the direct object is dependent on the action (e.g., a creation event like ‘man knits scarf’), possibly non-existent (e.g., ‘girl looks for unicorn’), or non-specific (e.g., ‘woman likes apple’) (Forbes, 2013). For the interpretation of intensional sentences, the intension (i.e. meaning) of the direct object is more important than the object in the world it refers to. This can be contrasted with extensional events (such as the motion events used in the studies mentioned above), in which the specific objects in the world *are* relevant. The change in word order preference can be explained as a cognitive preference to convey specific and less relational information before abstract and more relational information: in order to describe an event in which a girl throws a ball, the information about the thrower (the girl) and the object thrown (the ball) is more specific than the throwing, which is a relation between the girl and the ball. On the other hand, for an event in which a girl dreams of a ball, the object dreamt of is not necessarily specific, and, in fact dependent on the action. (Schouwstra & de Swart, 2014; Schouwstra, 2017)³. There is also experimental evidence that suggests that production biases are mirrored in *interpretation* of silent gesture. In an experiment with SOV and SVO ordered silent gesture strings with ambiguous action gestures, Schouwstra, de Swart, and Thompson (2019) found that participants use constituent order as a cue to distinguish between intensional and extensional events. Participants were more likely to interpret SVO ordered gesture strings (than SOV ordered strings) as intensional events, but the strength of the effect was much less pronounced than for production. Bayesian modelling of this data shows that these results are consistent with the production data from Schouwstra and de Swart (2014), under the assumption that interpretation differs from production in that it takes uncertainty about the target meaning into account.⁴

These findings complexify the idea of a natural word order that was mentioned above, and we suggest that the term naturalness should be applied to behaviour in which word order is variable, and depending on the semantic prop-

²See Christensen, Fusaroli, and Tylén (2016) for a related distinction between creation and manipulation events. Creation events are a sub-class of intensional events (Schouwstra, 2012).

³Schouwstra (2017) mainly focuses on word order preferences for complex events in which temporal information is included, but the study replicates the word order effects for intensional and extensional events.

⁴Contrasting results were found by Hall, Ahn, et al. (2015), who report that when participants interpret gesture strings of reversible and irreversible event in different orders, their preferences differ from those in production. See Schouwstra et al. (2019) for a detailed discussion of the different findings.

erties of the message. In this way, naturalness can be seen as a special case of iconicity, in which there is a similarity relation between the content and the constituent ordering.⁵

The studies mentioned so far focused on improvisation, and investigate its production and interpretation separately. One crucial difference between improvisation and fully established languages (even when these are rooted in an improvised setting), is that languages are used for communicative interaction, in which production and comprehension alternate in quick succession, and are often even relevant at the same time (Pickering & Garrod, 2013). This is what we will focus on next.

1.2 Interaction

Interaction, and its influence on natural or artificial communication systems, has been studied in a wide range of experimental studies. It has been shown that in conversation, hearers activate mental representations during comprehension, and these are then more likely to be used in production, through a process known as priming (Pickering & Garrod, 2004). *Structural priming* has been demonstrated in contexts where multiple syntactic constructions are possible, such as in the case of the Double Object and the Prepositional Object construction: ‘the girl gave the boy a book’ versus ‘the girl gave a book to the boy’; for instance, participants were more likely to produce a particular structure after just being primed with one (Branigan, Pickering, & Cleland, 2000). Structural priming has also been shown in natural dialogue, either in elicitation situations (Levitt & Kelter, 1982), or in corpora (Gries, 2005). Similar methods have been applied in artificial language tasks to explore the connection between priming and regularisation. and it was shown that priming was robustly present in interaction, which in turn showed a reduction in unpredictable variation over the course of interaction, following earlier work by Jäger and Rosenbach (2008) and Pickering and Garrod (2017). For example, (Fehér, Wonnacott, & Smith, 2016) trained pairs of participants on an artificial language with variable word order then had them interact; they found that participants were primed by their partners’ productions even in artificial languages, and that partly as a result of this reciprocal priming process, pairs of participants rapidly converged on a shared and regular word order, eschewing the word order variation present in their input. This happens even if the change violates other preferences, for instance, for effort reduction (Feher, Ritt, & Smith, 2019).

These experimental paradigms therefore show how interaction shapes the use of variation pre-existing communicative conventions (either in a natural or experimenter-designed artificial language). Work in the *experimental semiotics* tradition, in which experiment participants create and negotiate novel ways of conveying information (Galantucci & Garrod, 2011), explores how initially-improvised systems are reshaped during communicative interaction. Participants confronted with a novel graphical communication task, where they must use drawings to convey concepts, initially produce complex and iconic drawings; however, over the course of interaction in pairs or groups those drawings become less complex, less iconic, and communicatively more successful (Garrod, Fay,

⁵See e.g. de Ruiter, Theakston, Brandt, and Lieven (2018) for a related phenomenon; Christensen et al. (2016) describe the word order behaviour for manipulation and creation events as *structural iconicity*.

Lee, Oberlander, & MacLeod, 2007; Fay, Garrod, Roberts, & Swoboda, 2010); sets of such drawings develop systematicity, such that drawings come to be composed of combinations of increasingly arbitrary sub-parts (Theisen, Oberlander, & Kirby, 2010). In a similar vein, recent work has implemented silent gesture in an interactive setting, to investigate how multiple participants improvise and then negotiate a manual communication system together (Motamedi, Schouwstra, & Kirby, 2017; Christensen et al., 2016; Schouwstra, Smith, & Kirby, 2016; Motamedi, Schouwstra, Smith, Culbertson, & Kirby, 2018).⁶ For instance, Nölle, Staib, Fusaroli, and Tylén (2018) found that systematicity develops rapidly in interaction sets of improvised communicative gestures, particularly when communication was 'displaced' (communication about items that are not immediately present in the moment of communication). Particularly relevantly for the case of word order that we focus on here, Christensen et al. (2016) investigated which word orders are used for two kinds of events, manipulation events and creation events, a classification that is similar to that in Schouwstra and de Swart (2014); creation events are a subtype of intensional events (Schouwstra, 2012), and all manipulation events are extensional. In an experiment in which silent gesture is used for communication (but role switches between production and interpretation occur infrequently), they replicate Schouwstra and de Swart (2014) and show that SOV word order is preferred for manipulation events, and SVO for creation events. In a second experiment (which was run as an additional communication round for a subset of the participants of Experiment 1), in which participants switch roles between production and interpretation every trial, they found that word order usage is influenced by interactive alignment. In a third experiment, they show that the relative frequency of the event types (manipulation events vs. creation events) influences the word order frequencies used by the participants, but iconicity remains the strongest determinant for word order in all these experiments. This latter result suggests that, when biases for naturalness (arising through improvisation) and regularity (as favoured in interaction, as shown by e.g. Fehér et al. (2016)) are both at play, the effects of naturalness dominate and persist, suggesting that some other factor might be at play in driving a change from naturalness to conventionalised word order.

1.3 Iteration

Iteration, or transmission to novel learners, is implemented in iterated learning experiments, in which participants are trained on an initial artificial language, and the output they produce after learning is given as the input to a new 'generation' of learners, and so on for multiple generations. In a series of experiments that compared the contributions of interaction and iteration on artificially learned languages, it was found that whereas learning alone favours simplicity and can lead to degenerate languages (i.e. languages in which many distinct meanings are expressed ambiguously with a single form: Kirby, Cornish, and Smith (2008); Silvey, Kirby, and Smith (2015)), when transmission is combined some pressure against degeneracy (either from an arbitrary block on

⁶Note that overview papers of experimental semiotics (Galantucci & Garrod, 2011; Galantucci, Garrod, & Roberts, 2012) do not typically include silent gesture, because the work that had been done up until recently did not involve interaction (Galantucci & Garrod, 2011, footnote 3).

ambiguous forms, or actual communicative use), this forces a language to be both simple and sufficiently informative, promoting the emergence of compositional regularities (Kirby et al., 2008, 2015; Beckner, Pierrehumbert, & Hay, 2017). A number of related studies have added to our knowledge about how systematic structure in language emerges, investigating, for instance, the role of the meaning space (Carr, Smith, Cornish, & Kirby, 2017; Perfors & Navarro, 2014), or the influence of context and saliency (Silvey et al., 2015; Winters, Kirby, & Smith, 2015). Related experiments looking at the effect of iteration on unpredictable variation in artificial languages show that variation tends to either be eliminated (Real & Griffiths, 2009) or becomes conditioned on linguistic context (Smith & Wonnacott, 2010; Smith et al., 2017), in either case suggesting how regularity can emerge as a result of the iteration process.

Iterated artificial language learning studies typically initialise each chain of transmission with an experimenter-designed starting language, and see how transmission reshapes that language over generations. There are a small number of graphical communication studies in the experimental semiotics tradition that combine improvisation with iteration, forcing participants to improvise the initial behaviours spontaneously. These studies produce results broadly compatible with the equivalent studies of improvisation and interaction reviewed in the previous setting, showing that symbolic symbols develop from initially-iconic improvised representations through transmission (Caldwell & Smith, 2012), and that transmission to novel learners plays a crucial role in increasing the systematicity of graphical signs Theisen-White, Kirby, and Oberlander (2011). Finally, there is one study we are aware of that combines improvisation, communicative interaction, and transmission to new learners, bringing together all three processes reviewed above. Motamedi et al. (2019) focused on how participants use improvised silent gesture to communicate about sets of thematically related concepts (e.g. chef, frying pan; hairdresser, scissors), and how their gestures develop over time in interaction between pairs of participants and/or across generations of learners. The study directly compared a communication condition, in which participants communicate repeatedly about the same concepts using initially improvised gestures, to an iterated condition, in which the output of one communicating pair is transmitted to a new pair of participants, for multiple generations (following the setup in Kirby et al. (2015), but with an improvised gesture starting-point). Motamedi et al. (2019) showed that systematic functional markers (gestures that indicate the meaning class a concept belongs to, such as a ‘point-to-self’ gesture to denote a person for a concept like ‘chef’) are rare in improvised gesture, emerge to some extent in the communication condition, but become prevalent and systematic when communicative interaction was combined with iterated transmission to new generations of learners.

1.4 Summary and plan

When people are engaged in silent gesture, and improvise in the absence of a conventional language system, they use semantic cues to structure their utterances, and they will use utterance structure to obtain different semantic interpretations. This semantically conditioned word order regime can be seen as *natural* word order behaviour, and is rooted in cognitive biases (Schouwstra & de Swart, 2014; Schouwstra et al., 2019), and conventional ordering rooted in the extensional/intensional distinction has not been observed in any existing

languages.⁷ However, although improvisation occurs in established languages, these languages are crucially different from silent gesture: they are used for communicative interaction and persist through cultural transmission. In this paper, we investigate the influence of the mechanisms of cultural evolution on this natural behaviour. Our lab experiments are the first that systematically combine silent gesture with interaction and transmission to study word order. Having the level of control of a laboratory setting will allow us, in addition, to study the emergence of linguistic conventions in closeup.

In experiment 1 we investigate what happens to the semantic conditioning of word order on extensional and intensional meanings that occurs in improvisation, when initially-improvised gestures are used in communicative interaction and transmitted across generations through iteration. Given that a number of studies show that the combination of interaction and iteration leads to the development of systematic or regular systems of behaviour (e.g. Motamedi et al., 2019; Kirby et al., 2015; Smith & Wonnacott, 2010), we predict that this setup will lead to a simplification of the word order regime: conditioning of word order on event type will decrease over generations, because participants will regularise their word order use, converging on a single word order (although since some iterated learning experiments show that iteration can lead to conditioning of variation, e.g. Smith and Wonnacott (2010), a sharpening of the conditioning on event type is also a possible outcome here).

In Experiment 2, by contrast, we implement interaction alone, in an experiment in which two participants use initially-improvised gesture to interact with each other repeatedly for an extended period. Given the findings by e.g. Christensen et al. (2016) and Fehér et al. (2016) indicating that reciprocal priming in interaction can lead to regularisation, we expect to see some simplification in word order use here; however, given that Christensen et al. (2016) still find a strong and lingering influence of the initial improvised structures here, and previously observed differences between interaction-only experiments and those that implement iterated transmission to new learners (Motamedi et al., 2019; Kirby et al., 2015), we expect greater retention of semantically-conditioned variation in word order here relative to Experiment 1.

Finally, in Experiment 3 we investigate whether the resulting word orders over interaction and transmission are dependent on the proportions of the event types. Our prediction is, following Christensen et al. (2016), that skewing the proportions of intensional and extensional events will influence the usage of word order over the experiment.

Together, our experiments will inform us about the conditions under which word order usage develops from being *natural*, i.e. dependent on semantic properties of individual events, to increasingly *conventional*, i.e. following a simpler word order regime.

⁷Recent work shows that the distinction may play a role in sign languages though (Napoli, Spence, & de Quadros, 2017); see the general discussion for discussion of this.

Figure 1: Two example stimuli: ‘Burglar cuts cake’ and ‘Nun dreams of violin.’ The former shows an extensional event, and the latter an intensional one. Previous work suggests that improvised orders should be SOV and SVO respectively.

2 Experiment 1: silent gesture, interaction and transmission

To investigate what happens to natural word order when silent gesture is used for interaction and transmitted to new generations of learners, we implemented silent gesture in a gradual turnover design (Caldwell & Smith, 2012). Two communicators start in the first ‘generation’, by taking turns to be director and matcher, and using silent gesture to communicate. They are watched by a third participant, the observer, giving the observer the opportunity to learn the gesture system used by the other participants before participating in communication themselves. Each consecutive generation, the observer replaces one of the communicators (the one that has been in the experiment for the longest time), and a new observer enters the room; we repeat this process 6 times, producing 6 simulated generations per group.

We predicted that at the start of the experiment, word order would pattern like in previous silent gesture experiments (a preference for SOV for extensional events and SVO for intensional events), but the combination of interaction and iteration would drive word order usage, over generations, to gradually become less natural (i.e., less conditioned on semantic type) and more regular (i.e., implementing a simpler word order regime with a single word order dominating across items).

Figure 2: Overview of the experimental setup. Participants 1 and 2 interact using silent gesture, taking turns as director and matcher, with target stimuli presented on iPads. The observer, who has a clear view of participants 1 and 2, as well as the target stimuli (presented on a screen) will replace participant 1 in the next ‘generation’ to experimentally simulate a gradual turnover of population. The experimenter (exp) is also present.

2.1 Method

Materials

We created 64 line drawings of intensional and extensional events. They were organised in 8 groups of 8, such that each group of stimuli contained all 8 combinations of 2 actors, 2 patients, and 2 actions. Each group of 8 stimuli had one intensional and one extensional action. All actors were animate, and all patients were inanimate. Only inanimate patients were used to rule out any possible effects of reversibility (see review in section 1). Two example line drawings are provided in figure 1.

The stimuli were presented on iPads (one iPad per communicating participant), which ran interactive software that we developed (a combination of Python/web sockets for the server end, and HTML/JavaScript for the front end), in a full screen web browser. For the observer, a non-interactive screen (on a laptop) was set up, that for each trial gave the same information as the matcher. To avoid an effect of the order of the elements in the images, a mirror image of every stimulus was created, and in the experiment, originals or their mirror images were used at random (randomised each trial).

Director and matcher were video recorded using two Logitech webcams connected to Apple Macbook Air laptops running VideoBox, custom software we developed for recording video (Kirby, 2016).

Participants

Eight groups of participants (all right-handed, native speakers of English, with no previous knowledge of any sign language) took part in this study (58 par-

generation	communicator 1	communicator 2	observer
1	1	2	3
2	2	3	4
3	3	4	5
4	4	5	6
5	5	6	7
6	6	7	8

Table 1: Gradual turnover design of Experiment 1: the experiment starts with two communicators and an observer. Each consecutive generation, the communicator who has been in the experiment the longest is replaced by the observer of the previous generation, and a new observer is brought into the lab. Note that participant 8 does not have an active role in the experiment, but was included since the presence of an observer may have an effect on the behaviour of communicators.

ticipants in total; mean age 21.5).⁸ All participants were recruited at the University of Edinburgh: three groups were recruited from a first year Linguistics and English Language course; the remaining 5 were recruited from a University of Edinburgh website used for advertising casual employment. The participants were paid between £5-10, depending on how long they were in the experiment for.

All experiments reported here were approved by the PPLS Ethics Committee at the University of Edinburgh. All participants gave consent prior to beginning their session. This included permission to share videos or images from their sessions for research purposes as well as with the general public. Two participants did agree to have their videos used for analysis by the researchers, but not for publication to the general public. All videos, except the videos from those two participants, are available on https://osf.io/4jk32/?view_only=683ef1d2f3d947d2bbfa511f2ee4bbe9.

Procedure

The experiment started with two communicating participants (taking turns to be director and matcher) and an observing participant in the first generation. In every subsequent generation, one of the communicators left the room, the observer of the previous generation took the place of one of the communicators, and a new observer entered the room. The experiment covered 6 generations, and in each generation (32 trials), director and matcher switched roles every trial; see table 1 for an illustration of the setup.

All 7 participants making up a single group were briefed simultaneously on the general procedure of the experiment, the software interface, and details of feedback: participants were made familiar with the software by playing four trials of a communication game that used numbers (one through eight) instead of pictures. After the instruction phase, the first three participants remained in the lab, and the other participants waited in separate booths in an adjacent

⁸When only seven participants showed up for the experiment, a confederate acted as the observer in the last round (note that the final observer had no active role in the experiment, and only watched the two communicators).

lab. The order in which participants would take part was assigned at random. After each generation, the next observer was brought into the lab. The waiting participants did not know in advance when they would start the experiment.

Each generation, the two communicators were seated at opposite ends of a table. The observer sat on one side of the table, and the experimenter on the other side, so that both had an unobstructed view of the communicators. In each generation, the observer was instructed to pay close attention to what the two communicators were doing, in order to be a good communicator in the next generation. The observers did not know which of the two communicating participants they would be replacing in the next round.

In each trial of the experiment, one of the participants—the director—saw one image on the iPad and conveyed what was on the screen using only their hands/upper body and no speech. The matcher saw eight images on their iPad, and they tapped the image that they thought was intended by the director. The matcher array consisted of the target picture, plus the seven alternatives from the same group of images (see above), ensuring that the alternatives presented two Actors, two Patients, and two Actions in all possible combinations. The director was therefore required to convey all relevant elements in the target image to guarantee successful communication.

The matcher array was visible throughout the trial, and there were no restrictions on when the matcher could tap their answer. The communicating participants switched roles every trial, and received full feedback immediately after each trial. Feedback was given by means of coloured borders around the relevant images on the iPads: director and matcher both saw a green border around the target image when the matcher was correct. The director saw a red border plus an additional image of the selected answer when the matcher was incorrect. The matcher saw a red border around the selected answer, plus a green border around the target image if the answer was incorrect.

On each trial the observer saw the same information on their iPad as the matcher of that particular trial (i.e., observers saw the matcher array, plus full feedback after the matcher’s response).

Each generation consisted of 32 trials: 16 intensional and 16 extensional events (4 stimuli from each group of 8). Each communicating participant was the director for exactly 8 intensional and 8 extensional stimuli, and these were presented in random order. For each subsequent generation, 16 ‘same’ (stimuli that were used in the previous round) and 16 new stimuli were used. In other words, the set of meanings to be communicated about changed somewhat at each generation, but since there were 64 stimuli pictures in total, all of them had been seen at least once after the end of the third generation.

Participants were encouraged to communicate faster each generation. If the current generation was faster than the previous, they received a wrapped sweet as a reward. In pilot experiments, we observed that participants were likely to be shy or very slow, and the reward system was introduced to remedy this. All participants received a wrapped sweet after the first generation.

2.2 Analysis

Video recordings were coded for word order by MS. To arrive at a word order characterisation, each gesture was categorised as referring to the Subject, Ob-

ject or Verb.⁹ Many of the responses had multiple consecutive gestures that referred to one element (such as hat + nose for ‘witch’); these were counted as one gesture. We kept a record of the lexical elements that were used (e.g., hat + nose), as well as the resulting word orders. For full details on second coding and coding agreement, see Appendix II.

To check the accuracy of the coding, a portion of the data was coded by a second coder (who was not familiar with the objective of the study). The second coder coded a randomly selected chain (12.5% of the data). A full chain was chosen rather than separate trials from different chains, to make sure that the coder could familiarise herself with the interactive history (because the gestures in some chains became quite fast, and coding this without knowing the history of the system is hard). To assess reliability we calculated Cohen’s κ (unweighted) for 2 raters; κ was 0.93, indicating almost perfect agreement.

During the task, the matcher selected an answer whenever they were ready. Occasionally, the director would continue gesturing (or repeat some of their gestures), even when the matcher had stopped observing the director. Unobserved gestures were not included in the analysis. Similarly, sometimes the matcher asked (using only gestures) a clarification question, either by indicating that they did not understand it, or by repeating one of the elements for confirmation. Clarification questions and their (gestured) responses were not included in the final analysis.¹⁰

Of 1536 strings in total (recorded in 8 sessions of 6 rounds, of 32 trials each), 1100 were SVO, 205 were SOV, and 231 were other orders, coded as ‘NA’, and resulting in 15.0% omitted data points. The other orders included strings that omitted elements (such as in SV) or repeated elements non-consecutively (such as in SVOV).

2.3 Results

Speed and accuracy

To assess changes in efficiency and effectiveness of communication, we looked at the mean number of constituents per trial and the number of correct matcher responses. To determine the number of constituents per trial (including trials marked as NA), we looked at the coded strings and counted the number of elements in these. This means that per trial we counted each occurrence of Subject, Object, and Verb, but not the lexical elements they consisted of (e.g. ‘hat’ and ‘nose’ to describe Witch was counted as one element).

A linear mixed effects model was performed on the number of constituents per trial, taking generation as fixed effect (coded numerically, with the first generation as the model intercept).¹¹ All model results can be found in table

⁹We are aware that the terms Subject, Object and Verb are syntactic terms, and it would be more correct to use semantic terms. However, in line with much of the literature, we will continue to describe the gestures in terms of S, O and V, to increase readability.

¹⁰Because the participants engaged in face to face interaction, there were cases of repair. This is an interesting and rich topic, and it has been suggested that repair sequences contribute in the emergence of linguistic rules (Micklos, 2016; Byun, De Vos, Roberts, & Levinson, 2018), but because it falls outside the immediate scope of this paper, we did not include repair sequences in our analysis.

¹¹All analyses here and henceforth were implemented using R, and lme4 (Bates, Mächler, Bolker, & Walker, 2014). All models were run using bound optimisation by quadratic approximation (*bobyqa*). Coded data and full specification of the models can be found on

Figure 3: In both figures, black line and error bars represent mean and 95% confidence intervals; coloured lines represent chains. On the left, number of elements per trial, by round. The minimum value on the y-axis is 3, because that is the fewest possible elements to convey the necessary information in one trial. Over time, gestures became more efficient. On the right, proportion of correct answers per chain, by generation. Performance of matchers was at or near ceiling for most of the experiment, except the first generation.

2. The current model took by-item random intercepts (trying to fit by-item slopes for generation resulted in singular fit) and by-chain random intercepts and random slopes for generation. A main effect of generation was observed, indicating that the number of constituents went down over generations; see figure 3.

We performed a binomial mixed effects regression on correctness of the matcher response per trial, with generation as fixed effect, and by-item and by-chain random intercepts and random slopes for generation. The model revealed a high proportion of correct answers in the first generation, as reflected in the intercept, and no main effect of generation, showing that communication was successful from the first generation and did not increase significantly over generations; see figure 3.

Word order

We coded whether word order on each trial was natural or not, i.e. if SOV was used for an extensional event and SVO was used for an intensional event, and analysed naturalness in a logit mixed effects regression, entering generation as fixed effect, with by-item and by-chain random intercepts and random slopes for generation. Participants were more likely than not to produce natural orders in the first generation (as reflected in the model intercept), and a significant negative effect of generation was observed, indicating that over generations, participants became less likely to produce natural orders; see figure 4.

Looking at the proportion of SOV word order (using the same random effect structure as in the previous model, but removing the correlations between random intercepts and slopes to allow the model to converge), we found that

https://osf.io/4jk32/?view_only=683ef1d2f3d947d2bbfa511f2ee4bbe9

Figure 4: On the left, proportion of natural gesture strings (SOV for extensional and SVO for intensional) by generation. Note that a set of strings that are, e.g., all in SOV order would be .5 natural, because half of the stimuli are extensional events (for which SOV is the natural order). Early generations produced natural word orders, but this decreased over generations. On the right, proportion of strings in SOV order, by generation. SOV order was dispreferred by participants, and this effect increased over generations. In both figures, black line and error bars represent mean and 95% CIs; coloured lines represent chains.

participants were less likely to use SOV than SVO in the first round (as reflected in the model intercept), and the proportion of SOV descriptions decreased further over generations; see figure 4.

The naturalness and word order measures show, respectively, that word order becomes less natural over time, and that SOV word order becomes less prominent. To measure if word order usage in the experiment became more *regular* over time, we calculated entropy scores for each chain, in each generation. This was done by calculating Shannon’s entropy, i.e. using $-\sum p_i \log(p_i)$ for the proportions of SOV, SVO, and other word orders. Generally, usage of different word orders in equal proportions results in high entropy (e.g. 1 bit for when two word orders are used equally often), and using the same word order throughout results in an entropy of 0 bits.

A linear mixed effects model that took generation as fixed effect and by-chain uncorrelated random intercepts and slopes for generation (entering random slopes on generation resulted in singular fit) showed a negative main effect of generation on entropy, showing that entropy went down over the course of the experiment; see figure 5.

Lineage specificity

In order to assess if the change in word order happened uniformly, or rather in a way that was unique per chain, we looked at *lineage specificity* (Dunn, Greenhill, Levinson, & Gray, 2011). We compared the word order usage of participants in the same chain to that of participants in pseudo-chains, created by scrambling participants who were not in the same session. More specifically, for each participant in a given generation, we took counts of SOV strings, SVO strings, and orders categorised as ‘other’, and generated two tuples describing

Table 2: **Model summary for measures in Exp. 1** Speed (number of gestured elements per trial), correctness, word order, entropy, and priming)

Predictor	β	SE	p
Number of elements			
generation	-0.13	0.04	0.009***
Correctness			
intercept	2.08	0.36	<0.001***
generation	0.29	0.16	0.0705
Naturalness			
intercept	2.47	0.64	<0.001***
generation	-0.36	0.10	<0.001***
SOV order			
intercept	-2.02	0.47	<0.001***
generation	-0.31	0.15	0.038
Entropy			
generation	-0.12	0.03	0.003**
Priming by interlocutor (current-SOV)			
previous-SOV	1.02	0.39	0.008**
Self-priming (current-SOV)			
previous-SOV	1.15	0.69	0.095

Figure 5: Entropy values plotted by generation. Black lines and error bars show mean and 95% CI's; coloured lines represent chains. Entropy decreases significantly over generations.

their word order usage: one for extensional and one for intensional events. For each two participants who participated in a pair, we calculated the euclidean distances for their word order use, by calculating the Euclidean distance (in three dimensional space) between the tuples:

$$dist = \sqrt{\left(\frac{\#SOV_{p1}}{\#SOV_{p2}}\right)^2 + \left(\frac{\#SVO_{p1}}{\#SVO_{p2}}\right)^2 + \left(\frac{\#other_{p1}}{\#other_{p2}}\right)^2} \quad (1)$$

We calculated separate distance scores for extensional and intensional events, and then summed the two, to calculate the Euclidean distance for each *veridical* pair of participants. We then ran a Monte Carlo simulation (1000 trials) in which we compared the veridical distances to those of pseudo-pairs (formed by pairing, for each generation, the director from one chain with another director from another chain at the same generation). We found that the veridical distances (mean = 9.72) were significantly smaller than the pseudo-distances (mean = 17.31, sd=2.58, z=3.006, p<.001), revealing that word order behaviour was specific to chains.

Underlying mechanisms for regularisation: priming

As mentioned in the introduction, language users can be primed by the structures of the utterances of the communicative partner, but also by their own productions (Jacobs, Cho, & Watson, 2019). Priming by the interlocutor is sometimes called comprehension-priming, and priming from one’s own productions is production-priming. Because in our experiment participants switched roles of director and matcher every trial, both types of priming are potentially relevant.

In order to assess if structural (comprehension-)priming was a relevant mechanism behind word order regularisation, we compared word orders in a given trial t to that of the previous trial $t_{(-1)}$. We compared cases in which $t_{(-1)}$ had SOV word order to those in which it did not, and assessed the effect on trial t_0 , by analysing whether SOV order was produced on the current trial (scored as 1 if the trial had SOV order, 0 if it had SVO order, and NA if it had any other order) in a logit mixed effects regression, entering partner’s word order at the immediately-preceding trial as fixed effect (coded as +1 for SOV order, -1 for SVO order), and by-chain and by-item random intercepts and slopes for previous-order (random slopes and intercept were uncorrelated for items, as the full model failed to converge). There was a main effect of previous-SOV, indicating that participants were more likely to use SOV if SOV order had been used on the previous trial; see figure 6.

To assess the role of production priming (or self priming) in this experiment, we modeled the data in a way similar to the above, except that now we compared a given trial t to trial $t_{(-2)}$ (the previous production of the same participant). Coding and random effect structures were the same as above. We did not find a main effect of the participant’s own previous production, indicating that in choosing a word order, participants at best marginally influenced by their own previous production (see figure 6).

Figure 6: On the left: priming, measured by comparing the proportions of SOV (on y-axis) for two kinds of trials (on x-axis): when the word order in the previous trial (produced by the interlocutor) was SOV, participants were more likely to use SOV than when the previous trial was SVO. Error bars represent 95% confidence intervals. On the right: self-priming. Comparing the proportions of SOV between the current trial and the previous *production*. When their previous trial was SOV, participants were not significantly more likely to use SOV than when their previous trial was SVO.

2.4 Discussion

In this experiment we investigated how the usage of natural word order in silent gesture develops over generations when silent gesture is used for communication, and learned by novel learners. First of all, we found that over time, communication became more efficient and more successful. Focusing on word order, we found that natural word order (observed in the first generation) is not maintained, but increasingly replaced by a simpler word order regime, in which the same word order is used irrespective of the semantic properties of the event being communicated. Entropy measures confirmed that the word order regimes became increasingly regular over generations.

Further, we found that the trajectory from natural to more regular word order did not happen uniformly; the 8 different chains showed lineage specificity in their usage of word order. Thus, the chains changed their word order regime in different ways (comparing by generation, participants from different chains behaved differently). However, SVO word order was found to become the dominant word order in nearly all of the chains. Because SVO is the dominant order of the native language of all participants (English), this might simply be a native language influence. Given this observation, we might ask whether it is *possible* for participants to converge on a different word order, i.e., one that is not the native word order. Experiment 3 below will investigate this.

Finally, we focused on priming as a potential mechanism behind word order change, and found that priming plays a role in the experiment: for a given trial, there was a higher chance to observe SOV order when that order was used on the previous trial, than when it was not. For self-priming, this was not the case: participants were only marginally influenced by their own previously produced trial. These results are interesting, given that they constitute an affirmed case of participants being primed by their interlocutors in the context of an emerging linguistic system.

Our regularisation results contrast in interesting ways with those by Christensen et al. (2016), who looked at the influence of social interaction on natural word order (they refer to this as structural iconicity), and found that although participants showed a statistical tendency to align with their communicative partners, natural word order was strongly represented throughout the experiment. Our experiment, on the other hand, shows a main effect of generation, indicating that the combination of transmission and interaction in our experiment was sufficient to make word order change to become significantly more regular (i.e. less meaning-dependent). A remaining question is, however, whether both mechanisms were *necessary* to make this process possible. In other words, was the addition of generations of new learners crucial for word order to become more regular over time? Or could interaction alone have yielded the same effect, as seen in e.g. Fehér et al. (2016)?

Experiment 2 investigates silent gesture in a setup that is nearly identical to Experiment 1, but instead of introducing a new participant each generation, the entire experiment is carried out by two participants who interact over the course of 6 ‘generations’.¹² In other words, we will investigate what happens to natural word order when silent gesture is used for communicative interaction,

¹²We will maintain the term generation, even though the experimental setup does not introduce new participants. This terminology was chosen to make comparison between the two experiments easier.

Figure 7: Overview of the experimental setup of Experiment 2. The setup was identical to Experiment 1, but there was no observer (the two participants were not replaced, and completed all 6 generations of the experiment).

but not transmitted to new learners.

3 Experiment 2: silent gesture in communicative interaction

3.1 Methods

To test how word order changes when silent gesture is used for communication, we asked pairs of participants to use silent gesture to communicate about simple events, in a communication game in which they alternated the roles of director and matcher. The setup of this experiment was similar to Experiment 1, but the same two participants took part throughout the experiment. See figure 7.

Materials

The experiment used the same stimuli materials as Experiment 1. Like in Experiment 1, they were presented to the participants on iPads (one iPad per participant). Because there was no observer in this experiment, no extra observation screen was needed.

Participants

Twelve pairs of participants took part in this study (24 participants in total; mean age 21.2). The participants were recruited at the University of Edinburgh recruitment web page. All participants were right handed, native speakers of English, with no knowledge of any conventional sign language; they were paid £7.50 for their participation.

Procedure

The two participants were seated opposite each other and each participant had an iPad in front of them, on which the stimuli and the feedback were presented. The procedure was the same as that for Experiment 1, except that the same participants communicated for the full duration of the experiment, and no observing participant was present. Like Experiment 1, this experiment lasted for 6 generations of 32 trials each.

Data analysis

The video coding procedure was the same as that of Experiment 1. Like for Experiment 1, a portion of the data for this Experiment (two of the dyads, picked randomly, making up 16.7% of the data) was second-coded, resulting in a Cohen’s κ score of 0.92, indicating almost perfect agreement.

Of 2304 strings in total, 1552 were SVO, 398 were SOV, and 354 were other orders, coded as ‘NA’, and resulting in 15% omitted data points.

3.2 Results

Speed and accuracy

To test the influence of generation on the number of constituents used per gestured utterance, we ran a linear mixed effects model on the number of constituents per trial, taking generation as fixed effect. The model took by-chain and by-item random intercepts (fitting random slopes resulted in singular fits) and revealed a main effect for generation (see table 3 on page 23), indicating that the number of constituents went down over generations.

In addition, we ran a model that combined the data of Experiments 1–2, to assess if they behaved differently with respect to the number of constituents used over generations. For this and all Exp. 1–2 combined models that follow, we use the same coding rationale: centered coding for generation to make the comparison between experiments more intuitive, and deviation coding for all binary inputs.

The combined model took generation and experiment and their interaction as fixed effects, and by-chain random intercepts and slopes for generation, as well as uncorrelated random slopes and intercepts for items (the full model resulted in singular fit), and showed a main effect for generation (see table 4 on page 24), but no effect of experiment, and no interaction of experiment and generation, indicating that the number of constituents went down similarly in Experiment 1 and 2. See figure 8.

Correctness of the responses in Exp. 2 was analysed in a binomial mixed effects regression, modelling correctness and taking generation as fixed effect. The model took by-chain and by-item random intercepts and slopes for generation, and revealed a high proportion of correct responses in the first generation, as reflected in the model intercept, and a main effect of generation.

To test for the differences between Experiments 1 and 2, we ran a model that included data from both experiments, modelling correctness, and taking generation and experiment, and their interaction as fixed effects, applying the same random effect structure as above. The model revealed a high proportion of correct responses overall, and an increase over generations as reflected by a main

Figure 8: On the left, number of elements per trial, by generation. For ease of comparison, the results of Experiment 1 are displayed as well (dashed line). Coloured lines represent individual dyads. The minimum value on the y-axis is 3, because that is the fewest possible elements to convey the necessary information in one trial. Participants used fewer constituents over time in a similar way to Experiment 1. On the right, proportion of correct answers per chain, by generation. Dashed line presents results of Experiment 1, for comparison. Coloured lines represent individual dyads of Experiment 2. Participants were at or near ceiling throughout, except for the first generation, similarly to Experiment 1.

effect of generation. The effect of experiment was not significant, but the model showed a marginal interaction between generation and experiment, indicating that overall, Experiments 1 and 2 showed an increase in correct responses over time, with a marginally slower increase for experiment 1. See figure 8.

Word order

For naturalness of word order (SOV for extensional events, and SVO order for intensional events) we predicted that the proportion of natural word orders would decrease over generations, but less sharply than in Experiment 1. We ran a logit mixed effects regression entering generation as fixed effect, with by-item and by-chain random intercepts and random slopes for generation (intercepts and slopes were uncorrelated, as running the full random effect structure resulted in singular fits). Participants were more likely than not to produce natural orders in the first round, as reflected in the model intercept, and the proportion of natural orders went down over rounds, as reflected in a significant effect of round.

Again we ran a model on the combined data from Experiments 1 and 2, focusing on proportions of natural word order, using generation and experiment as fixed effects, with random by-chain and by-item slopes for generation. The model showed a main effect of generation, no effect of experiment, and no interaction between generation and experiment, indicating that natural word order decreased over generations in similar ways in Experiments 1 and 2; see figure 9.

To explore how the proportion of SOV word order developed over generations, we ran a logit mixed effects regression, entering generation as a fixed effect, and by-chain and by-item random intercepts and slopes for generation (slope and intercept on chain were uncorrelated, because the full model resulted

Figure 9: On the left: proportion of natural gesture strings (SOV for extensional and SVO for intensional) plotted by generation. Participants started by producing natural word order, but this decreased over generations. Their behaviour is near identical to that in Experiment 1, showing that transmission has little effect on the decline of naturalness. On the right: proportion of strings in SOV order, by generation. Participants prefer SVO over SOV, and this preference increases over time, in a way similar to that in Experiment 1.

in singular fit). The model reveals that the proportion of SOV starts off lower than that of SVO in the first generation, as reflected in the model intercept, and gradually diminishes further over time, reflected as a significant effect of generation. We assessed the differences between Experiment 1 and 2 by running a combined model, entering generation and experiment as fixed effects, and by-chain and by-item random intercepts and slopes for generation. The model revealed a main effect of generation, no effect of experiment, and no interaction between experiment and generation, indicating that the proportion of SOV went down over generations similarly in the two experiments. See figure 9.

Like for Experiment 1, we calculated entropy scores per generation for each dyad, to measure whether there was regularisation of word order use over generations (see details above). We ran a linear mixed effects model that took generation as fixed effect and uncorrelated by-chain random slopes and intercepts for generation (the full model resulted in singular fit). The model showed a main effect for generation, indicating a downward trend for entropy over generations; see figure 10: the use of word order became simpler and more regular over time.

We ran a model on the combined data of Experiments 1 and 2, entering experiment and generation as fixed effects, and uncorrelated by-chain random intercepts and slopes for generation (running the full model resulted in singular fit). The model shows a main effect for generation, no effect of experiment, and no interaction between experiment and generation, indicating that in both experiments, entropy decreased over generations in similar ways. See figure 10.

Lineage specificity

As in Experiment 1, we were interested in whether we would find lineage specificity in our data. In this dyadic experiment, however, one cannot strictly speak

Table 3: **Model summary for measures in Exp. 2** Speed (number of gestured elements per trial), correctness, word order, entropy, and priming)

Predictor	β	SE	p
Number of elements			
generation	-0.11	0.00	<0.001***
Correctness			
intercept	1.39	0.17	<0.001***
generation	0.67	0.10	<0.001***
Naturalness			
intercept	1.34	0.30	<0.001***
generation	-0.12	0.05	0.013*
SOV order			
intercept	-1.34	0.35	<0.001***
generation	-0.30	0.09	<0.001***
Entropy			
generation	-0.11	0.02	<0.001***
Priming by interlocutor (measuring current-SOV)			
previous-SOV	0.25	0.38	0.51
Self-priming (measuring current-SOV)			
previous-SOV	1.01	0.30	<0.001***

Figure 10: Entropy values plotted by generation. Entropy decreases significantly over generations.

Table 4: **Model summary for measures in Exp. 1 & 2.** Speed (number of gestured elements per trial), correctness, word order, entropy, and priming)

Predictor	β	SE	p
Number of elements			
generation	-0.12	0.02	<0.001***
experiment	0.04	0.13	0.740
gen * experiment	-0.02	0.04	0.523
Correctness			
generation	0.44	0.08	<0.001***
experiment	-0.15	0.23	0.520
gen * experiment	-0.28	0.15	0.063
Naturalness			
generation	-0.14	0.05	0.001**
experiment	0.00	0.23	0.967
gen * experiment	-0.09	0.06	0.14
SOV order			
generation	-0.21	0.08	0.008**
experiment	-0.42	0.50	0.398
gen * experiment	0.04	0.14	0.753
Entropy			
generation	-0.10	0.04	<0.001***
experiment	-0.06	0.08	0.467
gen * experiment	0.02	0.03	0.529
Priming by interlocutor (measuring current-SOV)			
previous-SOV	0.66	0.27	0.014*
experiment	-0.26	0.45	0.567
gen * experiment	0.56	0.403	0.160
Self-priming (measuring current-SOV)			
previous-SOV	1.13	0.35	0.001**
experiment	-0.23	0.52	0.656
gen * experiment	0.37	0.603	0.540

of lineages, because there was no generational turnover. Instead, we calculated ‘dyad specificity,’ to assess if the pairs of participants who communicated together were more similar to each other than pseudo-pairs (formed by randomly combining the data of participants who were not in the same session). We calculated euclidean distances between participants on the basis of their proportions of SOV strings, SVO strings, and other orders in the same way as we did for Experiment 1. We then ran a Monte Carlo simulation (1000 trials), in which we compared the actual distances to the distances of pseudo-pairs (participants were scrambled to form these pseudo-pairs), and found that the actual distances (mean = 14.50) were significantly smaller than the pseudo-pair distances (mean = 26.32, sd=3.61, $z=7.205$, $p<.001$), showing that there was indeed dyad specific behaviour in Experiment 2.

Structural priming

We ran a linear mixed effects model, looking at whether a given trial was SOV, and taking the previous trial (previous-SOV) as a fixed effect in a linear mixed effects regression, that took by-chain and by-item random intercepts and slopes for previous-SOV. The model revealed no significant increase in SOV when the previous trial was SOV, suggesting there was no structural priming for word order.

We then combined the data of Experiment 1 and 2 into one model, investigating SOV, and entering previous-SOV and experiment as fixed effects, and the same random slope structure as the previous model. This model revealed a main effect of previous-SOV, no effect of experiment, and no interaction between previous-SOV and experiment, indicating that overall, priming *did* play a role in the two experiments; see discussion of this below on page 27, and visualisations in figure 11.

To measure priming of participants’ own previous production on their current trial, we ran a linear mixed effects regression, taking own-previous-SOV as a predictor for current-SOV, and using the same random effect structure as the previous model. The model revealed a significant increase in current-SOV when the previous production was SOV, indicating that participants were influenced by their own previous production. Combining the data of experiments 1 and 2 into one model we investigated current-SOV, entering own-previous-SOV and experiment and their interaction as fixed effects, and the same random effect structure as the previous model. We found a main effect of own-previous-SOV, no effect of experiment, and no interaction between experiment and own-previous-SOV, indicating that in Experiments 1 and 2, participants were similarly influenced by their own previous production.

3.3 Discussion

In Experiment 2 we found that communication between partners in the dyads became more efficient and successful over time, in essentially the same way and at the same rate as seen in Experiment 1.

Focusing on word order, we found that participants typically started out showing naturalness (SOV for extensional events, and SVO for intensional events) in the first generation, but this tendency decreased over time, in favour of a simpler word order regime (usage of the same word order irrespective of the

Figure 11: On the left, comparing the proportions of SOV for two kinds of trials: when the word order in the previous trial (produced by interlocutor) was SOV, participants were more likely to use SOV than when the previous trial was SVO. On the right, evaluating the proportions of SOV in the current trial, depending on the previous *production*. When their previous production was SOV, participants were more likely to use SOV than when their previous production was SVO.

semantic properties of an event), as confirmed in our entropy calculations over generation. When directly comparing these results to those of Experiment 1, we see no difference. This reveals important information about the mechanisms involved in word order change. From Experiment 1, we might have concluded that interaction *and* transmission to new learners are mechanisms involved in word order simplification, but Experiment 2 tells us that transmission to new learners is not crucial in this process: when two participants are engaged in prolonged interaction, they will simplify their usage of word order in a similar way. This result is consistent with work on artificial language learning and regularisation through interaction (Fehér et al., 2016; Feher et al., 2019). However, focusing on other work with emerging conventions in silent gesture experiments, we conclude that word order conventions develop differently from, for instance, systematicity in the lexicon (Motamedi et al., 2019). For the latter, transmission to new participants was a crucial factor; for word order it appears not to be. We will discuss this contrast in further detail in the general discussion.

Further, we found that participants who communicated in a pair were more similar to each other (in their usage of SOV and SVO word orders) than pseudo-pairs (formed by scrambling the participants). This shows that the word order change was not simply the result of a universal preference to increase usage of SVO word order; participants who formed a dyad *did* influence each other’s usage of word orders and different dyads changed their word order usage in different ways, and at different speeds (similarly to what was observed for chains in Experiment 1).

Zooming in on trial by trial behaviour of the participants allowed us to

study the mechanisms behind word order change in interaction. Looking at structural priming in Experiment 2, we saw that participants, again, were influenced by the structure their own previous production (we observed a significant production priming effect), but we could not confirm a comprehension priming effect statistically. However, when Experiment 1 and 2 were analysed together, a main comprehension priming effect, and no interaction of experiment, was found. These results are mixed, and it is not clear why there is this asymmetry between Experiment 1 and Experiment 2. The next section, in which the effects of interaction and interaction plus iteration are compared under a skewed distribution of items (in Experiment 3), may give us a more complete picture of priming.

4 Experiment 3: silent gesture and event frequency

Experiments 1 and 2 show that several different biases may play a role in the word order behaviour observed. First of all, there is a preference to use natural word orders at the initial stage of the experiment, but along the way this naturalness disappears. Apart from a pressure to use the same word order as in previous trials (which was confirmed in priming effects), participants had a clear preference for SVO word order. This order is the dominant order of the native language of all participants (English); however, the finding is unlike previous work that only implements improvisation, in which the native language order is of limited influence (see particularly Schouwstra and de Swart (2014), which uses very similar stimuli). To assess the strength of the SVO preference, we conducted an additional experiment, in which the proportions of event types were skewed against SVO.

There are two possible causes of the preference for SVO in Experiments 1–2. The first is the fact that English was the native language of all participants; participants may simply tend to start using the dominant order of English (possibly because it is an order they know is shared between them). A second possible explanation comes from Marno et al. (2015) and Hall, Ferreira, and Mayberry (2014). Both papers show that when participants have learnt a consistent lexicon of gestures, they prefer SVO order. If either of these accounts is true, one would expect SVO to become dominant, irrespective of the nature of the stimuli. However, Christensen et al. (2016) showed a general preference for SOV, in a dyadic interaction silent gesture experiment with native speakers of Danish (an SVO language). Christensen et al. (2016) further showed that changing the proportions of the stimuli changes the proportions of the word orders after interaction. They conclude that differences in frequency of referents may impact the structures that arise in interaction (however, the way in which interaction was implemented in their experiment does not allow for tracking word orders over the course of the experiment).

We ran an experiment that investigated the issue of event frequency for the two mechanisms of cultural evolution that have been the focus of this paper: interaction and transmission. In our experiment we increased the relative proportion of extensional events, for which in improvisation, participants show a preference for SOV order. Because SVO was the preferred overall order in Ex-

periments 1 and 2, we were interested in whether a skewed item set in favour of extensional events would lead to higher proportions of SOV throughout in this experiment: if SOV order shows up more often at the start of the experiment, it might be more likely to become the conventional order if regularisation favours the most common initial order. To allow us to run the same analyses that we ran for Experiments 1 and 2, we used exactly the same setups (chains and dyads respectively), in two separate conditions.

4.1 Methods

The setup of this experiment was the same as for Experiments 1 and 2, except for the properties of the stimuli. Instead of equal proportions of intensional and extensional events, we used a majority of extensional (75%) and a minority of intensional events (25%): each generation consisted of 24 extensional and 8 intensional trials, and we made sure that each participant had the role of director for 12 and 4 of these respectively.

The experiment consisted of two conditions.¹³ The setup of the first condition (interaction&iteration) was the same as that of Experiment 1, running groups in a gradual turnover design, to implement interaction and transmission. Eight groups of participants took part in this study (60 participants in total; mean age 20.6).¹⁴ All participants were recruited at the University of Edinburgh (three groups were recruited from a first year Linguistics and English Language course; the remaining 5 were recruited from the University of Edinburgh career platform). The participants were paid between £5-10, depending on how long they were in the experiment for. The instructions and procedure of this first condition were identical to those of Experiment 1.

The setup of the second condition (interaction only) was identical to that of Experiment 2 (except for the proportions of intensional and extensional events, which was identical to the first condition). Twelve pairs of participants (24 participants in total; mean age 21.5) were recruited at the University of Edinburgh recruitment web page, and paid £7.50 for their time.

4.2 Data analysis and results

Data analysis was done following the same procedure as that of Experiments 1 and 2. Again, a portion of the data (one chain of Experiment 3a, and two dyads of Experiment 3b) was second-coded, resulting in a Cohen’s κ score of 0.97, indicating almost perfect agreement.

For the interaction&iteration condition, of 1536 trials in total (8 chains of 6 generations of 32 trials each) 760 were SOV, 595 were SVO, and the remaining 181 were other orders (resulting in 11.8% omitted data points). For the interaction-only condition, of 2304 trials in total (12 dyads of 6 generations of 32 trials each) 1061 were SVO, 955 were SOV, and 288 were other orders (resulting in 12.5% omitted data points).

¹³Note that due to logistic difficulties the participants were not assigned to one of the two conditions at random, but the two were run separately.

¹⁴When only seven participants showed up for the experiment, a confederate acted as the observer in the last round (note that the observer had no active role in the experiment, and only watched the two communicators).

Table 5: **Model summary for measures in Exp. 3.** Speed (number of gestured elements per trial), correctness, word order, entropy, and priming)

Predictor	β	SE	p
Number of elements			
generation	-0.08	0.02	<0.001***
mechanism	-0.08	0.06	0.192
gen * mechanism	0.02	0.03	0.551
Correctness			
generation	0.24	0.05	<0.001***
mechanism	-0.43	0.23	0.062
gen * mechanism	-0.30	0.08	<0.001***
SOV order			
generation	-0.31	0.11	0.005**
mechanism	0.71	1.12	0.519
gen * mechanism	-0.17	0.21	0.422
Entropy			
generation	-0.12	0.02	<0.001***
mechanism	-0.09	0.13	0.448
gen * mechanism	-0.02	0.03	0.634
Priming by interlocutor (measuring current-SOV)			
previous-SOV	0.18	0.26	0.487
mechanism	0.73	1.05	0.492
prev-SOV * mechanism	0.08	0.53	0.875
Self-priming (measuring current-SOV)			
previous-SOV	1.13	0.35	0.001**
mechanism	-0.23	0.52	0.656
prev-SOV * mechanism	0.37	0.60	0.540

For the statistical analysis, we will present two models for every measure: the first uses the data of Experiment 3 alone, but because we wanted to be able to directly compare all three experiment for the different measures, we also constructed models on the data of all experiments. To do this, we structured the analysis as a 2x2 design with mechanism (dyads vs. turnover) and skewing (equal vs. skewed) as the two factors. In all models (either linear mixed effects models or binomial mixed effects regressions), binary factors were deviation coded, and generation was centered.

Speed and accuracy

We ran a linear mixed effects model to assess how the number of constituents per utterance developed over time. The model took generation and mechanism (dyads or turnover) as fixed effects, and random slopes and intercepts for generation on item and chains (slopes and intercepts were uncorrelated for chain due to singular fit). The model revealed a main effect for generation, no effect for mechanism, and no interaction between generation and condition (see table 5), indicating that participants used fewer constituents per trial over the course of the experiment, similarly in both conditions.

In addition, we ran a model on data from all experiments, to asses the influ-

Figure 12: Number of constituents per trial, by generation. All experiments show a downward trend over generations: over time participants use fewer constituents to express each meaning. See table 6 for full details.

ence of changing the mechanism (dyads vs chains) and changing the proportions of the stimuli (equal vs skewed). We entered mechanism, skewing, generation, and the interactions of generation and mechanism, and generation and skewing (other interactions were not included because they were not of interest). We entered random intercepts and slopes for generation on item and chain. The model revealed a main effect for generation, and none of the other effects or interactions were significant (see table 6), indicating that in all experiments, participants decreased the number of constituents used over time similarly.

To assess the correctness of responses over time, we ran a binomial mixed effects regression, taking generation and experiment (and their interaction) as fixed effects, applying the same random effect structure as above. The model revealed a main effect of generation. In addition, the model revealed a marginal effect of condition, and a significant interaction between generation and experiment, indicating that correctness was higher overall, and increased more rapidly in the dyadic condition than in the turnover condition.

To compare Experiments 1–3, we combined all data in a logit mixed effects regression, taking generation, mechanism, and skewing as fixed effects, plus interactions between generation and skewing, and generation and mechanism, as well as uncorrelated by-chain random intercepts and slopes for generation, and by-item random intercepts and slopes (plus their interaction) for generation. The model revealed a main effect for generation, marginal effects for skewing and mechanism, and significant interactions between generation and skewing, and generation and mechanism (see table 6). Overall, the number of correct responses was high, but the increase over generations was different for the different experiments; see figure 13.

Word order

To assess how the proportion of SOV was affected by generation, we ran a binomial mixed effects regression with generation and condition as fixed effects,

Figure 13: Proportion of correct responses, by generation. The proportion of correct responses is high overall; the experiments show an upward trend over generations, but the proportion of correct responses goes up more in the dyadic experiments than in the turnover experiments.

and by-chain and by-item random intercepts and slopes for generation. The model revealed a decrease of SOV over generations, no effect for condition, and no interaction between condition and generation, indicating that the proportion of SOV went down over generations similarly for both conditions of Experiment 3. See figure 14.

Additionally, to compare how the proportion SOV develops over generations in the current experiment vs Experiments 1 and 2, we ran a binomial mixed effects regression on SOV, including generation, skewing, and mechanism and the interactions between generation and skewing, and generation and mechanism as fixed effects. We entered by-chain and by-item random intercepts and slopes (plus their interactions) for generation. The model revealed a main effect for generation, as well as a main effect of skewing, but no effect of mechanism, and no interactions between generation and skewing, or generation and mechanism, indicating that in all experiments, the proportion of SOV strings went down over generations (not influenced by skewing or mechanism), but, crucially, the overall proportion of SOV strings was higher in skewed conditions. See table 6 for full details, and figure 14. Observation of the individual lines in figure 14 points out that despite an overall downward trend for SOV strings across experiments, some individual chains and dyads converged on a word order regime that consisted of a large majority SOV.

For Experiments 1–2, we looked at the proportion of natural word orders (i.e. those that were SOV for extensional events, or SVO for intensional events). Because of the skewed distribution of the items in this experiment, the expected naturalness values for highly regularised word order regimes would be dependent on the majority word order (the values would be close 100% natural for SOV-dominant systems, and close to 25% for SVO-dominant systems). Moreover, it would not be straightforward to compare naturalness values accross experiments. For these reasons, we use entropy alone as a measure for the extent to

Table 6: **Model summary for the combined data of Exp. 1, 2 and 3**
(Efficiency, Accuracy, Word order, entropy, and priming)

	β	SE	p
Number of constituents			
generation	-0.098	0.014	<0.001 ***
mechanism	-0.02	0.07	0.782
skewing	-0.06	0.07	0.555
gen:mechanism	-0.00	0.02	0.918
gen:skewing	0.03	0.03	0.284
Correctness			
generation	0.34	0.044	<0.001 ***
mechanism	-0.32	0.17	0.062
skewing	-0.31	0.17	0.063
gen:mechanism	-0.30	0.08	<0.001 ***
gen:skewing	-0.20	0.08	0.011 *
SOV order			
generation	-0.28	0.062	<0.001 ***
mechanism	0.16	0.62	0.799
skewing	1.64	0.61	0.006 **
gen:experiment	-0.09	0.12	0.455
gen:skewing	0.06	0.12	0.594
Entropy			
generation	-0.10	0.01	<0.001 ***
mechanism	0.014	0.09	0.878
skewing	0.03	0.09	0.764
gen:mechanism	-0.02	0.02	0.441
gen:skewing	-0.02	0.02	0.335
Priming, measuring current-SOV			
previous-SOV	0.31	0.19	0.099
mechanism	0.24	0.59	0.680
skewing	1.44	0.58	0.014 *
previous-SOV:experiment	0.37	0.35	0.300
previous-SOV:skewing	-0.26	0.35	0.462
Self-priming, measuring current-SOV			
own-previous-SOV	1.37	0.22	<0.001 ***
mechanism	0.21	0.55	0.703
skewing	1.52	0.54	0.004 **
own-previous-SOV:experiment	0.49	0.40	0.223
own-previous-SOV:skewing	0.35	0.40	0.378

Figure 14: Proportion of SOV order over generations for all experiments. In experiment 3, SOV has a higher proportion throughout, but this proportion goes down over the generations, just like in Experiments 1 and 2. Some chains, however, arrive at a word order regime that consists of a high proportion of SOV strings, showing that it is possible for participants to converge on a single word order that is different from SVO.

which participants regularised over time.

As for Experiments 1 and 2, we calculated entropy scores per generation for each chain/dyad. We ran a linear mixed effects model that took generation as fixed effect and by-chain random intercepts and slopes for generation (uncorrelated, as the full model resulted in singular fit). The model revealed a main effect of generation, no effect of condition, and no interaction between generation and condition (see table 5), indicating that entropy went down over generations, similarly for both conditions.

To compare entropy accross Experiments 1–3, we modeled data from all experiments, entering generation, mechanism, skewing, and the interactions between generation and mechanism, and generation and skewing, as well as uncorrelated by-chain random intercepts and slopes for generation (the full model resulted in singular fit). The model revealed a main effect for generation, and none of the other effects or interactions were significant (see table 6), indicating that in all experiments, participants used increasingly simple word order regimes over time, and that this simplification process took the same pace, independently of skewing and mechanism; see figure 15.

Lineage specificity

As for the previous experiments, we calculated euclidean distances between participants on the basis of their proportions of SOV strings, SVO strings, and other orders, and ran a Monte Carlo simulation (1000 trials), in which we compared the actual distances to the distances of pseudo-pairs. We found that actual distance was significantly smaller than the pseudo-distances in both conditions. Experiment 3a (the turnover condition): veridical = 12.66; simulated mean = 40.27; $SD = 9.01$; $z = 8.19$, $p = 0$. Experiment 3b (the dyadic condi-

Figure 15: Entropy (in bits) plotted by generation. Entropy values go down over generations, similarly in all experiments, indicating that participants simplify their word order regimes over time in similar ways irrespective of mechanism

tion): veridical= 20.07; simulated mean= 48.16; $SD = 9.3$; $z = 14.93$, $p = 0.001$. This shows that, like in Experiments 1 and 2, there is lineage specificity in the chains and dyads of Experiment 3: communicative partners in the experiment were more similar to each other than simulated communicative partners from different chains or dyads.

Structural priming

To assess whether participants were influenced by the usage of word orders used in the previous trial by their communicative partner, we analysed (comprehension) priming, running a binomial mixed effects regression. We modelled SOV, taking the order of the previous trial (SOV or SVO) and condition (dyads and chains) plus their interaction as fixed effects, and uncorrelated by-chain random intercepts and slopes for previous-trial. The model revealed no significant increase in SOV when the previous trial was SOV, and no interaction between previous-trial and condition (see table 5 on page 29), indicating that there was no measurable structural priming effect in either condition of Experiment 3.

We then combined the data of Experiment 1, 2 and 3 into a binomial mixed effects regression, investigating SOV, and entering partner's use of SOV on the previous trial, mechanism (dyads vs turnover) and skewing as fixed effects, and random intercepts and slopes for partner SOV (and their correlation) on chains and items. This model revealed (see table 6) a significant increase in SOV when a skewed distribution of events was used, but, crucially, no significant increase in SOV order when the previous trial was SOV. There was no main effect for mechanism, and no interaction between previous-trial and either mechanism or skewing. This shows that when all the data is pooled together, there is no significant effect of priming by the interlocutor.

To assess if participants were influenced by *their own* previous production, we analysed self-priming by running a binomial mixed effects regression, modeling SOV, and taking own-previous-SOV, and condition plus their interaction

Figure 16: Priming in Experiments 1 and 2 vs Experiment 3a and 3b. In Experiment 1, the proportion SOV was higher for trials following an SOV trial than for trials following an SVO trial, but this effect was not replicated in Experiment 2 or 3. When all data is pooled, there is no statistically significant priming effect. The reason for the asymmetry between the experiments is not clear and we will discuss priming in more detail in the General discussion.

as fixed effects, and random intercepts and slopes (and their correlations) for chain and item. The model revealed a main effect for own-previous-SOV and no interaction between own-previous-SOV and condition (table 5), indicating that participants were more likely to produce SOV after having produced one in their previous production trial than when they produced SVO in their previous trial (they self-primed), and this tendency was similar in both conditions of Experiment 3.

We combined the data of all experiments, investigating SOV, and entering own-previous-SOV, mechanism and skewing as fixed effects. We entered random intercepts and slopes on own-previous-SOV for chains and items. The model revealed a main effect of own-previous-SOV and no interaction of mechanism or skewing (see table 6), indicating that participants self-primed in all experiments; self-priming was not affected by mechanism or skewing.

4.3 Discussion: event frequency and word order conventionalisation

Experiments 1–2 showed a strong preference for chains and dyads to conventionalise SVO order; in Experiment 3, we skewed the set of events to be described, including greater proportion of extensional events; because SOV word order is preferred for extensional events in improvisation, we expected to see a higher proportion of SOV descriptions in participants’ initial productions, leading to more frequent conventionalisation of SOV order. This was confirmed in the analysis. Although the way in which the proportion SOV *developed over generations* was only marginally different from Experiments 1 and 2, inspection of the

Figure 17: Self-priming in Experiments 1 and 2 vs Experiment 3a and 3b. In all experiments, SOV was more likely to occur when the participant produced SOV in their previous production than when they produced SVO previously.

individual chains in figure 14 confirms that when participants had a skewed set of stimuli, a considerable number of chains and pairs converged on a word order regime with high proportions of SOV word order. This shows that a pressure towards SVO is certainly not the only relevant pressure in these experiments, and that having a different distribution of semantic items can influence the conventionalised word order. For other measures, using a skewed distribution of items did not make a difference: when all data was pooled, entropy, priming and self-priming behaved similarly in Experiments 1, 2 and 3.

5 General Discussion

When people communicate in the absence of a shared system of linguistic rules, they will structure their utterances according to their semantic properties (Meir et al., 2010; Hall et al., 2013; Gibson et al., 2013; Schouwstra, 2017). Specifically, they prefer SOV word order for extensional, and SVO for intensional events, and this patterning emerges, probably, as a result of cognitive biases of the communicator, and represent natural ordering (Schouwstra & de Swart, 2014).

Conventional languages, on the other hand, do not condition word order on the type of event, at least for the extensional/intensional distinction, in the way silent gesture does. Instead they apply word order regimes that are more regular, and simpler. A crucial difference between improvised utterances and conventional languages is that the latter are the result of repeated communicative interaction, and transmission to new learners over many generations. We investigated the influence of these cultural evolutionary mechanisms by combining silent gesture with interaction and transmission in three laboratory experiments. This allowed us to assess the influence of these cultural mechanisms on word order change, and to look at the online mechanisms driving it in closeup.

5.1 The emergence of word order conventions: improvisation, interaction and transmission

We investigated what happens to the natural word order that comes up in improvisation, when silent gesture is used for communicative interaction, and transmitted to new learners. Experiment 1 implemented both interaction and transmission and showed that under these circumstances, word order becomes less natural over generations, leading to a general preference for SVO (but at the same time showing lineage specificity), and showing an effect of structural priming between participants. This finding contrasts with those found by Christensen et al. (2016), who conducted an experiment in which participants use silent gesture for communicative interaction (see the description of this paper in section 1.2), and shows a statistical influence of structural alignment. However, in their experiment, this effect is quite weak, and their observations ‘do not point towards generalization and stabilization of one constituent order for both event types’ (Christensen et al., 2016, p. 75). One might thus conclude that a combination of interaction and transmission to new learners boosts conventionalisation of word order simplification. Something along similar lines is suggested by (Christensen et al., 2016, p. 77): ‘the frequent change of task-partners within a ‘speech community’ can radically enhance the conventionalization effect.’ This conclusion would be consistent with previous observations, on the one hand, that iterated learning of variable languages leads to regularisation or conventionalised stable conditioning (Smith & Wonnacott, 2010), and on the other hand that a combination of interaction and transmission to new learners—but not these factors individually—lead to language systems that are both expressive and compressible (Kirby et al., 2015), and exhibit systematic structure (Motamedi et al., 2019).

To be sure there actually *was* an additional contribution of transmission on top of communicative interaction, we ran a second experiment, which, like Experiment 1, involved communicative interaction of silent gesture, but with transmission taken out. The results of this experiment were remarkably similar to those in Experiment 1: word order usage changed at a similar pace, from natural (varying with meaning type) to more consistent over time. As a system goes from being natural, and grounded in improvisation, it rapidly becomes more conventional and more regular through communicative interaction. The specific way in which naturalness disappears is a cultural process: the emerging conventions for word order are specific to the individuals creating them (as was shown by the lineage specificity results). However, they are transferrable at the same time: novel learners can take over the process of conventionalisation (if they get a chance to observe the emerging system) and it will continue to take place.

Our finding that the pace and level of word order regularisation was the same for Experiments 1 and 2 is surprising, given previous results that indicate that a combination of interaction and transmission to new learners affects an emerging system differently from interaction alone. The contrast with the result described by Motamedi et al. (2019) is notable: in that study, a combination of interaction and transmission led to an increase in the systematic usage of lexical markers for different types of nouns (e.g. a person marker), while interaction alone led to some usage of markers, but less systematically. This finding and our finding combined suggest that different aspects of an emerging language are

affected differently by cultural mechanisms like interaction and transmission. Specifically, word order regimes may be affected by interaction and less so by transmission, but the structure of the lexicon may need transmission to new learners in order to become fully systematic. Additionally, recent work shows that properties of the meaning space (Nölle et al., 2018), and communicators’ access to it (Raviv, Meyer, & Lev-Ari, 2019), or context of use (Winters, Kirby, & Smith, 2018) might be a complicating factor in how emerging linguistic rules behave, and this interaction between interactive mechanisms and meaning space is another point of interest for future work. The idea that language is not a uniform phenomenon, and has different aspects that develop and evolve in different ways, should be studied in further detail in targeted experiments investigating the emergence of lexical and structural linguistic rules.

5.2 The emergence of word order conventions in closeup: structural priming

The experiments in this paper measure priming in situations where there are no conventions yet, and our results might have consequences for the priming literature. In existing work on structural priming, experiments typically investigate two different types of structure that convey the same information (these structures coming from either an existing language or from an artificial language participants are trained on), under the assumption that there is a system in place that offers multiple structural options to convey certain information: ‘from the point of view of communicative interaction, sentence structure is somewhat independent of the propositional content of utterances—languages typically provide a number of structurally distinct means of conveying a given idea.’ (Fehér et al., 2016).¹⁵ This situation, in which semantic content can be conveyed in multiple structurally distinct ways, is seen as one that establishes the possibility of structural priming: the phenomenon of structural priming is defined primarily in terms of an established system of linguistic conventions, and although the role of priming in language change has been studied (see foundational work by (Kroch, 1989), work by Jäger and Rosenbach (2008) on conceptual priming and language change, and Fehér et al. (2016) on experimental work on priming and language change), the role of priming in the *emergence* of language rules has not been explored to a great extent. By exploring this approach, the current work fits in a line of work proposed already by Pickering and Ferreira (2008) as a fruitful approach to extend the knowledge gained by studying the priming phenomenon.

Another difference between this and previous work is the modality: our experiment focuses on the manual modality, whereas existing work in structural priming typically works with written or spoken stimuli (Branigan, Pickering, Stewart, & McLean, 2000; Hartsuiker, Bernolet, Schoonbaert, Speybroeck, & Vanderelst, 2008). Structural priming has been shown in the manual modality (Hall, Ferreira, & Mayberry, 2015), but this is in an existing sign language, whereas our work shows structural priming in a situation of emerging linguistic rules.

¹⁵It should be noted though, that the general phenomenon of priming is not restricted to language; there is a broad literature on social priming, for example (Molden, 2014; Bargh, 2006).

The priming results in this paper were not entirely straightforward, so it is worth discussing them in more detail. First of all, there was no overall effect (based on the data of all three experiments) of comprehension-to-production priming, and this effect only came out in Experiment 1. Self-priming, on the other hand, seems to be a more robust result.

On a very general level, the finding that participants are likely to show patterns of behaviour heavily inspired by their own previous behaviours (rather than copying the behaviour of others) is not unique; similar results were shown in a graphical communication task (Tamariz, Ellison, Barr, & Fay, 2014) and in a written communication task (Rogers & Fay, 2016). Comparing this imbalance (between self-priming and priming from comprehension) to existing work in the structural priming literature, however, is hard. Structural priming studies exist in many flavours, some of which involve the participant producing the prime structure (by reading it out or by doing a sentence completion task), and some of which only involve comprehending the prime structure (by reading or hearing it), but a meta-analysis showed (Mahowald, James, Futrell, & Gibson, 2016) that this aspect of the design does not seem to influence the strength of the priming effect.

It should be noted that for the experiments in this paper, unlike for classical confederate priming methods used in many experimental demonstrations of structural priming studies, there was no script, and participants were free to use any structures they wanted (i.e. there were no rules that restricted them to using only SOV and SVO word order). In addition, variability in word order typically went down over time, and when there is no variability, an effect of priming cannot be measured. In that respect, the circumstances for measuring priming were not ideal, and a more controlled version of the experiment (e.g. with a confederate who uses silent gesture following a script) could give us a clearer view of how priming works in silent gesture.

Finally, is it fair to talk about the experiments in this paper to show an effect of communicative interaction, if the data seems to provide stronger support for self-priming than for priming by the interlocutor? The measures for lineage specificity showed that communicative partners robustly behaved more similar than pseudo-partners created by scrambling data from communicative partners. In other words, on a more general level, participants *were* influenced by the word order behaviour of their interlocutor. We think more detailed work needs to be done to make a full assessment of priming in this context, and make a comparison between the two kinds of priming; the current work can be seen as a first exploration of priming in the setting of language emergence in the visual-manual modality, showing that priming can be a mechanism behind word order regularisation.

5.3 Predictions for and analogues in existing languages

It is clear from the results sketched here that indeed, usage of word order changes over time, and some pairs or chains of participants really converged on one word order, but this did not happen for all participants. In fact, we see that some level of naturalness still remains even at the end of the experiment. This observation suggests a pattern to be observed in newly emerged languages like Nicaraguan Sign Language and other sign languages: that we may find traces of natural word order (i.e., SVO order for intensional events, and SOV order

for extensional events) in them, even in languages that do have conventions for word order.

Research into word order in signed languages is not without problems, e.g. in determining a so-called unmarked word order (Leeson & Saeed, 2012), and the potential influence of theoretical considerations on the coding type (Johnston, Vermeerbergen, Schembri, & Leeson, 2007), but fortunately, there has been a recent surge in collecting data on syntactic structure and word order information in signed languages (Schembri, Fenlon, Rentelis, Reynolds, & Cormier, 2013; Napoli & Sutton-Spence, 2014), the analysis of which has helped researchers reconsider theoretical decisions from the past (Schembri, Cormier, & Fenlon, 2018). With a growing body of evidence, it has become possible to further investigate the precise circumstances of word order variation. Recently, word order patterns for intensional and extensional events have been investigated in two languages. Napoli et al. (2017) studied LIBRAS (Brazilian Sign Language), and found that even though LIBRAS has been classified as an SVO dominant language, extensional events are likely to be described in SOV order (while for intensional events, SVO remains dominant).

A study of the same phenomenon in Nicaraguan Sign Language shows a slightly different, but essentially consistent picture (M. Flaherty, Schouwstra, & Goldin-Meadow, 2018). Nicaraguan Sign Language can be categorised as a strongly Verb-final language, with SOV being a dominant order, alongside other V-final orders (M. E. Flaherty, 2014). NSL signers showed this verb-final preference quite consistently for both extensional and intensional events (i.e., very few SVO strings were observed). However, many strings contained repetitions of O and V, and when sub-strings were analysed, there turned out to be a significant difference between intensional and extensional events: V was more likely to be directly followed by an O for intensional events than for extensional events. Interestingly, this pattern was similar for first, second and third cohort NSL signers. In other words, NSL word order conventions seem not to have changed much, in this respect, over the course of generations, suggesting that transmission to new generations contributes relatively little to the evolution of this aspect of language.

Observations from these two languages show that traces of natural word order behaviour can continue to exist in a fully conventionalised language; the case of NSL illustrates that there may be other word order conventions (in this case, strong V-finalness) that the natural pattern may interact with. Apart from the two languages mentioned here, we do not know whether or how languages (signed or spoken) encode extensional and intensional events differently, and this is another area for future research.

6 Conclusion

The experiments in this paper offer a testing ground for investigating the emergence of linguistic conventions in the laboratory. Using the case of basic word order as a case study, we observed that participants behave according to a bias for naturalness initially, and alternate their word order by event type. Communicative interaction is a mechanism that drives this natural behaviour towards simpler word order regimes, and our experimental method enabled trial by trial analysis of word order usage, singling out structural priming as a potential driv-

ing mechanism behind word order simplification. Surprisingly, when transmission to new learners is implemented in addition to communicative interaction, the rate at which word orders become less natural remains exactly the same, a result that was replicated in the two conditions of Experiment 3. Our experiments thus show that different biases can play different roles, depending on the mechanisms that are dominant in a given situation: natural word order is preferred in improvisation, but a transition towards simpler word order regimes happens under the influence of communicative interaction.

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Appendix I

The line drawings that were used as stimuli in all experiments were tested for clarity on a crowdsourcing platform, on which 640 participants were each asked to give a single sentence description of one picture. We chose this setup, asking each participant to only describe one picture, to assess how well the pictures were understood under the least favourable circumstances, i.e. without the context of other, similar, pictures to help them along. We realised that in the actual experiment, the circumstances were like that only for the very first trial.

Those pictures that were clearly misinterpreted by more than 3 out of 10 participants in our picture description task were adapted and re-tested. For ten adapted pictures ten extra judgements were collected, obtaining at least 7 out of 10 correct responses for each.¹⁶

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¹⁶Some of the actions were not described entirely accurately by all participants. For instance, some participants described the target action ‘swing above head’ as ‘hold up’, or ‘want’ as ‘think of’. We included these slight misinterpretations as correct, as long as extensional events were interpreted as extensional, and intensional events as intensional.

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