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A Noisy-Channel Account of Crosslinguistic Word-Order Variation

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Abstract

The distribution of word orders across languages is highly nonuniform, with subject-verb-object (SVO) and subject-object-verb (SOV) orders being prevalent. Recent work suggests that the SOV order may be the default in human language. Why, then, is SVO order so common? We hypothesize that SOV/SVO variation can be explained by language users' sensitivity to the possibility of noise corrupting the linguistic signal. In particular, the noisy-channel hypothesis predicts a shift from the default SOV order to SVO order for semantically reversible events, for which potential ambiguity arises in SOV order because two plausible agents appear on the same side of the verb. We found support for this prediction in three languages (English, Japanese, and Korean) by using a gesture-production task, which reflects word-order preferences largely independent of native language. Other patterns of crosslinguistic variation (e.g., the prevalence of case marking in SOV languages and its relative absence in SVO languages) also straightforwardly follow from the noisy-channel hypothesis.

Keywords

language, linguistics, psycholinguistics, cognition(s)

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It has long been known that the possible orders of the basic units of a clause—the subject (S), verb (V), and object (O)—are highly nonuniformly distributed across languages. However, two generalizations are possible:

- In 1,017 of 1,056 (96.3%) studied languages with a dominant word order, subjects precede objects (Dryer, 2005; cf. Greenberg, 1963), and it has been argued that most of the exceptions to this generalization are spurious (Dryer, 2002).
- Two word orders—SVO (e.g., English: *the boy* [S] *kicks* [V] *the ball* [O]) and SOV (e.g., Japanese: *shonen-ga* ["boy"] *boru-o* ["ball"] *kero* ["kicks"])—are much more prevalent (41.2% and 47.1%, respectively) than the third subject-before-object word order, VSO (8.0%; Dryer, 2005).

A plausible explanation for the first generalization is that people tend to construct their utterances from the perspective of agents rather than patients (e.g., MacWhinney, 1977). However, until now, no explanation has been provided for the crosslinguistic prevalence of the SOV and SVO word orders specifically. Indeed, the inability of functionalist approaches to explain this distributional pattern (Haspelmath, 1999; Hawkins, 2004; Hockett, 1960; Pinker & Bloom, 1990) has contributed to the argument that grammars are independent of communicative and performance factors and are determined by an innate universal grammar (Baker, 2001; Chomsky, 1986).

Here, we present a communication-based explanation for the prevalence of the SOV and SVO orders and for the crosslinguistic OV/VO variation, building on recent communicative accounts of similarly unexplained linguistic features, such as ambiguity (Piantadosi, Tily, & Gibson, 2012). The starting point for this account is the observation that the SOV word order appears to be the default

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word order in human language (Gell-Mann & Ruhlen, 2011; Givón, 1979; Newmeyer, 2000a, 2000b). We can break down this preference for the SOV order into (a) a preference for subjects to precede objects (explained earlier) and (b) a preference for the verb to appear clause finally.

With respect to the latter preference, two sources of evidence suggest that there is an initial bias to place the verb after its arguments when developing a communication system. First, two sign languages that were created independently from home-sign systems have verb-final orders (either SOV or OSV): Nicaraguan Sign Language (Senghas, Coppola, Newport, & Supalla, 1997) and Al-Sayyid Bedouin Sign Language (Sandler, Meir, Padden, & Aronoff, 2005). Second, Goldin-Meadow, So, Ozyurek, and Mylander (2008) have recently observed that a verb-final order (specifically, SOV) is preferred in a task in which participants gesture event meanings—which essentially requires developing a new communication code. Note that a preference for SOV gesture production was found not only for speakers of SOV languages, such as Turkish, but also for speakers of SVO languages, such as English, Chinese, Spanish (Goldin-Meadow et al., 2008), and Italian (Langus & Nespor, 2010). These results suggest that this task reflects word-order preferences somewhat independent of the person's native language.[1]

If the SOV word order is the default word order in human language, why is SVO order so prevalent? In other words, why do all, or most, languages not use SOV order? We propose that the SVO order arises crosslinguistically from the SOV order as a result of communicative-memory pressures that can sometimes outweigh the default SOV bias. In particular, building on Shannon's (1948) communication theory, we assume that language comprehension and production operate via a *noisy channel* (Aylett & Turk, 2004; Gibson & Bergen, 2012; Jaeger, 2010; Levy, 2008; Levy, Bicknell, Slattery, & Rayner, 2009; Smith, 1969). A speaker wishes to convey a meaning m and chooses an utterance u to do so. This utterance is conveyed across a channel that may corrupt u in some way, resulting in a received utterance $\tilde{u}$. The noise may result from errors on the side of the producer, external noise, or errors on the side of the listener. The listener must use $\tilde{u}$ to determine the intended meaning m. The best strategy for a speaker is thus to choose an utterance u that will maximize the listener's ability to recover the meaning given the noise process.

One way to evaluate this noisy-channel hypothesis is to compare sentences for which the order of the elements does and does not affect the ease of recovering the intended meaning. Consider, for example, the nonreversible sentence *the girl kicks the ball*. The word order has little effect on how easily the meaning can be recovered, because the subject (agent) and object (patient) are clear from the semantics—a ball cannot kick a girl. In communicating such a situation, people should adhere to the default order, SOV. However, in the case of semantically reversible sentences (e.g., *the girl kicks the boy*), noise may lead to confusion about which noun phrase is the subject and which is the object in the SOV word order. Gibson and Bergen (2012) provided evidence that English speakers assume a noise process in which deletions are most likely, and insertions and transpositions are less likely. If either noun in the SOV sentence *the girl the boy kicks* is lost because of noise (resulting in *the girl kicks* or *the boy kicks*), the thematic role of the remaining noun phrase is ambiguous: The solitary noun could be either agent or patient. Critically, if SVO word order is used instead (*the girl kicks the boy*), a deletion will not change how the remaining noun phrase is interpreted: *The girl kicks* will allow the listener to recover the meaning of the girl kicking someone or something, and *kicks the boy* will allow the listener to recover the meaning of the boy being kicked. In other words, the positions of the noun phrases with respect to the verb can provide a cue about whether a given noun is the subject or the object.

Note that although the noisy-channel hypothesis is motivated by a communicative theory, it need not be restricted to situations in which people communicate with other people: It applies even if there is only one individual, who is encoding an event meaning for him- or herself. According to the noisy-channel hypothesis, the individual will choose a representation that maximizes meaning recoverability (Brady, Konkle, & Alvarez, 2009). Indeed, Goldin-Meadow et al. (2008) observed the preference for SOV order for events with animate agents and inanimate patients even when the task was explicitly noncommunicative.

In summary, a difference in people's preferred word order for encoding or communicating meanings of reversible versus nonreversible events would suggest that word orders are shaped by noisy-channel pressures. In the experiments reported here, we demonstrated exactly this pattern of performance: Across three languages, an SVO language (English) and two SOV languages (Japanese and Korean), gestured word order was dependent on the semantic reversibility of the event whose meaning was being represented.

General Method

In three experiments, participants verbally described and then gestured events that involved one, two, or three people. In Experiments 1 (English, Japanese, Korean) and 2 (Japanese, Korean), we considered three (not mutually exclusive) factors that might affect the order of a participant's gestures: (a) an initial bias in favor of SOV order (Goldin-Meadow et al., 2008), (b) an initial bias in favor of the word order of the participant's native language, and (c) communicative or memory pressures in the form of a noisy-channel model. In an SVO language, such as English, the second and third factors both predict a shift to SVO order (from the baseline SOV order) for reversible events, but for different reasons. In an SOV language, such as Japanese and Korean, only the third factor predicts a shift to SVO order for reversible events. In Experiment 3 (English), we investigated an alternative to the noisy-channel hypothesis based on minimizing syntactic dependency distances.

Thirty-eight native English speakers (Experiment 1: $n = 25$; Experiment 3: $n = 13$), 23 native Japanese speakers (Experiment 1: $n = 11$; Experiment 2: $n = 12$), and 24 native Korean speakers (Experiment 1: $n = 12$; Experiment 2: $n = 12$) participated for payment. Participants were excluded for knowing sign language ($n = 1$) or failing to follow instructions ($n = 3$). The final sample included 34 English speakers (12 males and 11 females in Experiment 1; 9 males and 2 females in Experiment 3), 23 Japanese speakers (2 males and 9 females in Experiment 1; 4 males and 8 females in Experiment 2), and 24 Korean speakers (8 males and 4 females in Experiment 1; 9 males and 3 females in Experiment 2).

Participants watched brief silent animations of intransitive and transitive events. First, participants verbally described each vignette. Then, they watched the vignettes again, in the same order, and gestured the meanings of the events (Figs. 1 and 2). Participants were informed that their gestures would be filmed, and they were asked to use hand gestures only. Participants readily completed the gesture task with minimal instruction. All responses were video-recorded and coded off-line by two independent coders.

Verbal and gesture responses to each vignette were coded for the relative position of the agent, action, and patient. Trials in which participants did not mention the patient, or mentioned the patient or the action in more than one position, were omitted from the analyses (Experiment 1: 9.7% of trials for English speakers, 5.1% of trials for Japanese speakers, 5.2% of trials for Korean speakers; Experiment 2: 6.3% of trials for Japanese speakers, 7.8% of trials for Korean speakers; Experiment 3: 3.4% of trials for English speakers). Intercoder agreement about the order of the agent, action, and patient was 95% across the experiments. If the coders disagreed, the primary experimenter's judgment was used (Kimberly Brink for English speakers in Experiments 1 and 3; Eunice Lim for Japanese and Korean speakers in Experiments 1 and 2).

Experiment 1: English (SVO) Participants

Method

In this experiment, we manipulated whether the patients of transitive events were human or inanimate entities, so that the sentences were either semantically reversible or nonreversible (Fig. 1). If gesture production is sensitive to

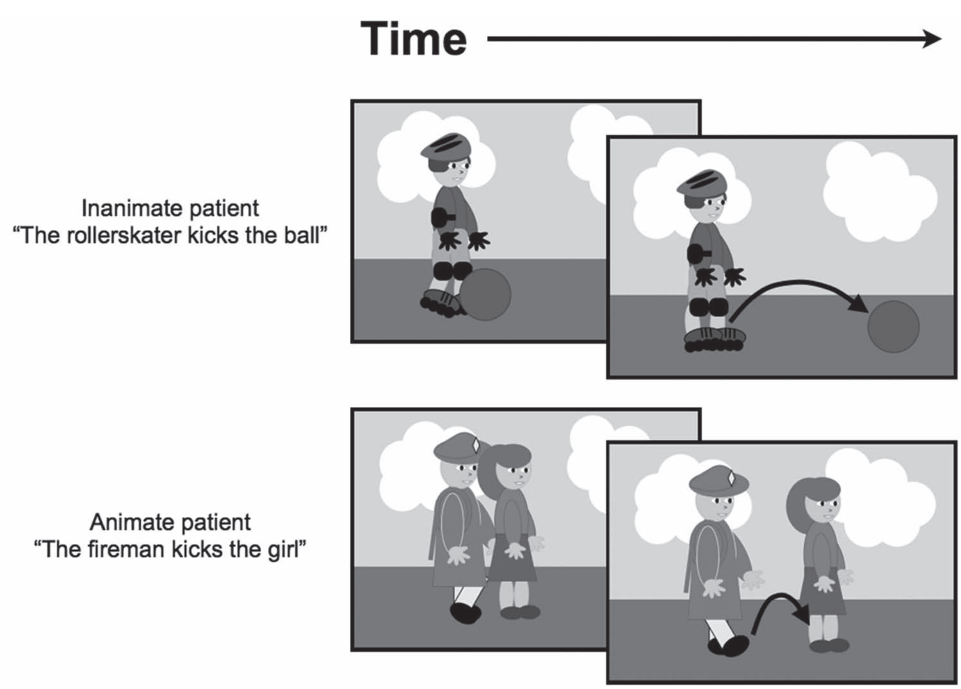

Fig. 1. Illustration of sample trials from Experiment 1. The top panel illustrates an event with an inanimate patient (nonreversible event), and the bottom panel illustrates an event with an animate patient (reversible event).

Fig. 2. Illustration of a sample trial from Experiment 2. In this event, an event with an animate patient is embedded within another event.

the reversibility of the event being described, then more SVO word orders should be produced for events in which both participants are human, and thus equally likely to be the agent or patient, than for events in which there is only one human participant. Participants saw eight transitive events with inanimate patients (e.g., “girl kicks ball”), eight transitive events with human patients (e.g., “girl kicks fireman”), and eight intransitive events (distractors). The same eight actions were used for the human and inanimate patients (pushing, poking, kissing, throwing, kicking, rubbing, elbowing, and lifting).

Results

Results are summarized in Figure 3. In their verbal responses, participants uniformly used English word order (SVO). As in Goldin-Meadow et al. (2008), they generally gestured the patient before the action when the patient was inanimate (68% of trials). However, they generally gestured the action before the patient when the patient was human (71% of trials), as predicted by the noisy-channel hypothesis. The difference in verb-final gestures (68% vs. 29%) was statistically significant in a one-tailed mixed-effects logistic regression that included participant slopes and intercepts, $\beta = 2.57$, $z = 5.25$, $p < .001$ (Gelman & Hill, 2007). (This test was used for all results reported,[2] except when the percentage for many participants was near 0, or 1. In such cases, logistic regression is inappropriate, and the models do not converge; for these contrasts, we present Wilcoxon paired comparisons.) Although human patients were gestured before the action on a minority of trials, the percentage of trials in which this order occurred was still significantly higher than in the verbal condition (29% vs. 0%; $p < .001$).

Experiments 1 and 2: Japanese and Korean (SOV) Participants

Design of Experiment 1

The results of Experiment 1 in English can be explained by the combination of the SOV default and the native-language word order, without invoking the noisy-channel hypothesis. In particular, participants may shift from the default to the word order in their native language as a response to increased ambiguity in reversible events. We therefore used the same method and materials that we had used with English speakers to test participants who spoke two SOV languages: Japanese and Korean. To the extent that the shift from SOV to SVO order in English speakers in the case of reversible events was due to communicative or memory pressures, as predicted by the noisy-channel hypothesis, Japanese and Korean speakers should also shift to SVO order for reversible events, although their native language has the SOV order.

Design of Experiment 2

For Experiment 2, we used more complex materials: the events from Experiment 1 embedded in a “thought” or “utterance” bubble (e.g., Fig. 2 conveys that the old woman says that the fireman kicks the girl; see Langus & Nespor, 2010, for a similar design but without the reversibility manipulation in the embedded clause). These more complex constructions provide an even stronger test of the native-language word-order hypothesis and the noisy-channel hypothesis. If participants simply use their native-language word order when materials are ambiguous or otherwise complex, then Japanese and Korean speakers should gesture both levels of embedded

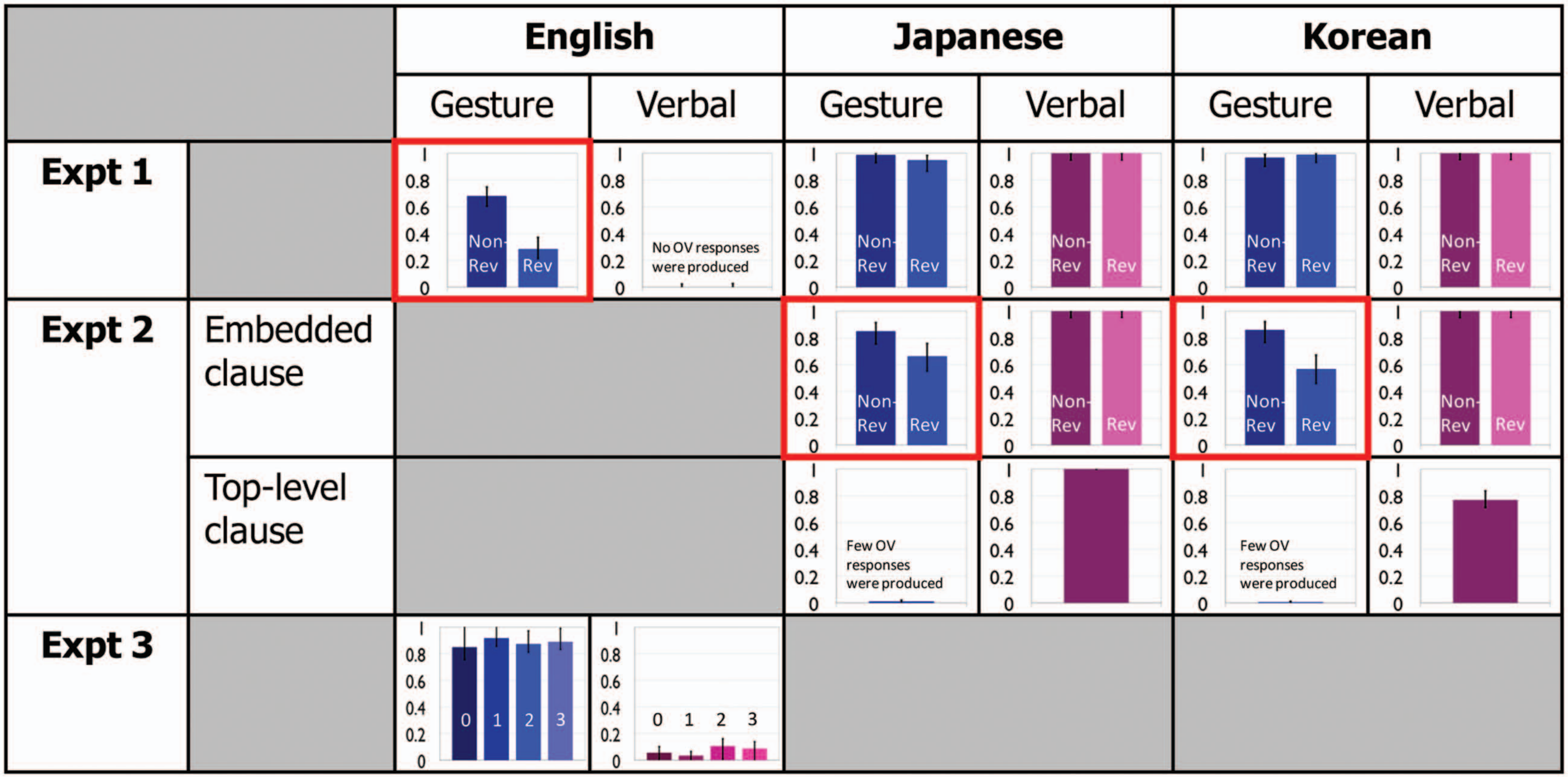

Fig. 3. Summary of results for English, Japanese, and Korean speakers in Experiments 1 through 3. For all experiments, the graphs show the proportion of patient-before-action (object-before-verb, or OV) productions; results for gestured responses are in blue, on the left, and results for verbal responses are in pink, on the right. For Experiments 1 and 2, responses are shown separately for nonreversible ("Non-Rev") and reversible ("Rev") events; for Experiment 2, the top row shows results for embedded events, and the bottom row shows results for top-level events. The graphs for Experiment 3 show the proportion of OV responses as a function of the number of features on the patient (0, 1, 2, or 3). The gesture patterns for reversible and nonreversible events that provide critical evidence in support of the noisy-channel hypothesis are highlighted by the red outlines. Error bars represent 95% confidence intervals.

events with the SOV order: S_1 [$S_2O_2V_2$] V_1 (e.g., "woman [fireman girl kicks] says"). However, in the case of reversible events, in which all three event participants are human, this word order creates maximum potential confusion according to the noisy-channel hypothesis. So, if participants aim to create event representations that are most robust to noise, Japanese and Korean speakers may gesture such events using the SVO order: S_1 V_1 [$S_2V_2O_2$] ("woman says [fireman kicks girl]").

Results

Results for both experiments are summarized in Figure 3. In Experiment 1, both Japanese and Korean participants always verbalized the patient before the action (100%); they behaved similarly in their gestures (Fig. 3): They gestured the patient before the action regardless of the animacy of the patient (Japanese: 99% for inanimate patients, 95% for human patients, Wilcoxon p = .25; Korean: 97% for inanimate patients, 99% for human patients, Wilcoxon p = 1.0). These results are consistent with a role for the native-language word order.

Critically, in Experiment 2, both Japanese and Korean participants gestured the top-level verb in second position (Fig. 3), between the top-level subject and the embedded subject, in 99% of the trials. In contrast, Japanese speakers never used this order in verbal descriptions, and Koreans used it in only 23% of the trials (top-level verb in second position in gestures vs. verbal descriptions: Wilcoxon $p < .005$ for each language).[3]

In the embedded clause, as predicted by the noisy-channel hypothesis, human patients were gestured before the action in only 66% (Japanese) and 57% (Korean) of trials, whereas inanimate patients were gestured before the action in 85% (Japanese) and 86% (Korean) of trials (Fig. 3)—Japanese: $\beta = 1.56$, $z = 1.74$, $p < .05$; Korean: $\beta = 3.01$, $z = 2.88$, $p < .005$. That is, Japanese and Korean participants gestured SVO order for events with human patients 34% and 43% of the time, respectively. Each of these percentages was reliably different from the corresponding percentage in the verbal condition, in which human patients were produced before the action on all trials in both languages. In summary, then, these results are predicted by the noisy-channel hypothesis, but not by the combination of the SOV default and native-language order.

Experiment 3: Minimizing Syntactic Dependency Distances?

Although the results of Experiments 1 and 2 are consistent with a noisy-channel approach to representational robustness, they are also potentially consistent with an alternative explanation: minimizing syntactic dependency distances. In particular, the memory demands of a sentence may be sensitive to the distance (the number of words) between a syntactic head (e.g., a verb) and its dependents (e.g., its subject and object), such that structures and languages with shorter head-to-dependent distances are easier to process, in both production and comprehension (e.g., Gibson, 1998; Hawkins, 2004; Temperley, 2007; Tily, 2010). The dependency-distance hypothesis—that shorter-distance dependencies are easier to process than longer-distance ones—provides an explanation for another crosslinguistic generalization: If verbs precede (rather than follow) their objects in a language—as in SVO languages—then prepositions generally precede their argument noun phrases, and complementizers (embedded clause markers) precede their embedded clauses (Greenberg, 1963). It is possible that dependency distances might also underlie a shift from SOV to SVO word order given that the SVO order allows shorter dependency distances across many constructions.

Method

To test whether dependency distances have an effect on gesturing, we varied the complexity of the descriptions of the patients of ditransitive verbs by including zero, one, two, or three salient features. Animations showed a boy and a girl interacting with one of a set of objects (a circle, a star, and a heart). The objects had up to three of the following features: distinctive surface (spotted or striped), container (in a box or pail), and headwear (wearing a top hat or a witch's hat). Twelve of the 36 vignettes involved a "giving" event (e.g., the girl gave the boy a circle). Another 12 vignettes involved a "putting" event (e.g., the girl put a star on a table). The remaining vignettes involved intransitive events that were similar to the ones in Experiments 1 and 2. Participants were asked to gesture each event, including all the features of the object that the boy and girl interacted with. If participants are sensitive to the linear distance between the agent and the verb, then a higher rate of SVO gesture order would be expected for longer patient descriptions, because this order minimizes the dependency distance between the agent and the verb. The noisy-channel hypothesis predicts no such shift to SVO order, because the patient is not a possible agent of the verb, and because adding modifiers to the patient does not affect the recoverability of the meaning (i.e., who is doing what to whom).

Results

Results are summarized in Figure 3. Participants gestured the patient before the action for 88% of ditransitive events, compared with 8% of spoken descriptions (Wilcoxon $p < .005$). Furthermore, the number of features indicated by gestures describing the patients (which was, on average, approximately the same as the number of features in the target objects: 0, 0.89, 1.89, and 2.68 for items with zero, one, two, and three features, respectively) did not predict the order of the gestures in a logistic mixed-effects regression that included participant slopes and intercepts, both when the number of features was treated as a continuous predictor, $\beta = 0.26$, $z = 1.11$, $p = .27$, and when it was treated as a categorical predictor, $\chi^2(12, N = 0) = 3.59$, $p = .98$. Even when the productions became very long and unwieldy, participants continued to gesture the patient before the action, a result consistent with the noisy-channel hypothesis, but inconsistent with the dependency-distance hypothesis.

Discussion

We have proposed and evaluated a novel account for the prevalence of SOV and SVO orders, and the OV/VO crosslinguistic variation, within the framework of Shannon's (1949) theory of communication. According to this account, speakers have a default SOV word-order preference, but their choice of word order is affected by the desire to maximize meaning recoverability in the face of possible noise.

We replicated a strong SOV preference in gesture production of English-speaking participants when the subject (agent) was human and the object (patient) was an inanimate object (Goldin-Meadow et al., 2008). We extended these results by demonstrating a similarly strong SOV preference even when the inanimate patient has up to three features to be gestured (Experiment 3, English participants). Consistent with the claims of Goldin-Meadow and her colleagues, these results suggest that SOV is the preferred word order in human communication.

Critically, our results also showed that when both the agent and the patient are human, the preference for the SOV order disappears, and participants become more likely to use the SVO word order. Although speakers of SOV languages (Japanese, Korean) nearly always gestured SOV order (consistent with the native-language bias) when describing simple events (Experiment 1), their gestures for more complex events were inconsistent with the native-language bias (Experiment 2). First, participants reliably produced the top-level verb in second position, thus separating the top-level subject (in initial position) and the embedded subject (in third position). In SOV order, the top-level verb would appear in the final position, following the embedded clause (see Langus & Nespor, 2010, for similar results with embedded events in Turkish, another SOV language). Second, participants had some tendency to shift to SVO order for the embedded clause when it was reversible, as predicted by the noisy-channel hypothesis, but not by the native-language bias. We propose that the shift to SVO order for semantically reversible events occurs in order to maximize meaning recoverability, as predicted by a model of language that includes a noisy-channel communicative component (see also Hall, Ferreira, & Mayberry, 2010, for similar results from English and Meir, Lifshitz, Ilkbasaran, & Padden, 2010, for similar results from Hebrew, another SVO language).

In addition to explaining gesture-production data, the noisy-channel hypothesis can explain four crosslinguistic typological patterns: First, case marking is often used in SOV languages. Case marking is one way to mark syntactic and semantic roles and can therefore mitigate the confusability of the subject and object in SOV order. The noisy-channel hypothesis predicts that if a linguistic community invents case marking, the default SOV order will be retained. If, however, the community does not invent case marking (or agreement, or some other way of conveying semantic roles), the noisy-channel hypothesis predicts that the community will shift to SVO order in order to communicate optimally. This hypothesis thus predicts that SOV languages should tend to be case marked, whereas SVO languages should tend not to be case marked. Indeed, descriptions of 502 languages from around the world indicate that the large majority of SOV languages (181 of 253, or 72%) are case marked, whereas few SVO languages are (26 of 190, or 14%, in Dryer, 2002; for similar claims, see Croft, 2002; Greenberg, 1963; and Vennemann, 1973).

To use the data from our gesture experiments in order to evaluate the hypothesis that SOV word order should be case marked, we looked for a plausible gestural cue that might serve a purpose similar to case marking. One such plausible cue is *location in space*: Many gesturers sometimes used one hand to gesture one event participant and the other hand to gesture the second participant in a transitive event, or they used different locations in space for different event participants, such that one spatial cue indicated the agent, and the other indicated the patient of the action. We evaluated whether or not spatial cues were used to disambiguate semantic roles in SVO and SOV gesture productions. In this post hoc analysis (see Table 1), we indeed observed a relationship between order and spatial "case marking." For the critical reversible events in Experiment 1 with English speakers, of the 36 spatially marked productions, 23 (64%) had SOV order (36% had SVO order); only 15 of the 109 non–spatially marked productions had SOV order (14%; 86% had SVO order). Similar results obtained for the reversible events in Experiment 2. For Japanese speakers, 40 of the 51 spatially marked productions (78%) had SOV order, but only 17 of the 35 non–spatially marked productions had SOV order (49%). For Korean speakers, 18 of the 28 spatially

Table 1. The Use of Spatial Case Markers in Experiments 1 and 2

Use of case markers and type of event	Experiment 1: English		Experiment 2: Japanese		Experiment 2: Korean	
	VO order	OV order	VO order	OV order	VO order	OV order
Spatial case markers absent						
Nonreversible event	38	26	6	26	5	31
Reversible event	94	15	18	17	28	32
Spatial case markers present						
Nonreversible event	18	93	7	48	7	43
Reversible event	13	23	11	40	10	18

Note: The numbers in the table refer to numbers of trials. V = verb; O = object. Note that for the reversible events, participants were more likely to gesture VO word order when they did not provide spatial case markers than when they did.

marked productions had SOV order (64%), but 32 of the 60 non-spatially marked productions had SOV order (53%).

Second, the noisy-channel hypothesis can explain why case marking is sometimes animacy dependent. If case marking resolves the communicative ambiguity that arises for reversible events, then it should be asymmetric: Animate direct objects should be more likely to be case marked than inanimate direct objects. Indeed, approximately 300 languages exhibit differential object marking (Aissen, 2003), in which only animate direct objects are case marked.

Third, the hypothesis can explain why word order is sometimes animacy dependent. In particular, many languages with relatively free word order (both SOV and SVO word orders are allowed) demonstrate word-order "freezing": In reversible constructions, if case marking does not disambiguate semantic roles, SVO word order is preferred (e.g., Russian—Bouma, 2011, and Jakobson, 1936; Kata Kolok, a sign language in northern Bali, Indonesia—Marsaja, 2008, and Meir, Sandler, Padden, & Aronoff, 2010).

Fourth, the noisy-channel hypothesis explains why non-SVO languages often have more word-order flexibility than SVO languages (M. Dryer, personal communication, April 25, 2012). According to this hypothesis, a non-SVO language (e.g., SOV or VSO) must contain mechanisms other than word order to unambiguously convey meanings of reversible sentences. Consequently, these languages do not need to use word order to disambiguate, and therefore can allow variability in order. Thus, fixed word order should be found primarily in SVO languages, and non-SVO languages should generally have less rigid word order.

To conclude, postulating sophisticated innate machinery (e.g., universal grammar; Chomsky, 1986) may not be necessary to explain word-order variation across languages. Many aspects of crosslinguistic word-order variation can be accounted for by communicative or memory pressures, which also explain other properties of human languages, including the composition of sound inventories (Hockett, 1955; Lindblom & Maddieson, 1988) and lexicons (Piantadosi, Tily, & Gibson, 2011; Zipf, 1949).

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The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Notes

1. The preference for clause-final verb placement can plausibly be explained by the crosslinguistic bias to present old information before new information (Jackendoff, 1972; Paul, 1880): The arguments of a verb are typically old information (already present in the context) and should therefore precede the new information, the verbal predicate. In a study consistent

with this explanation, Schouwstra, van Leeuwen, Marien, Smit, and de Swart (2011) demonstrated that people tend to gesture extensional verbs like "kick" and "push" clause finally, but intensional verbs like "create" (whose objects are new information) clause medially. Extensional verbs plausibly drive the word order within a language because they appear to be easier for children to acquire (e.g., the average age of acquisition of the verbs examined by Schouwstra et al., 2011, was 3.99 for the extensional verbs and 5.46 for the intensional verbs, according to Kuperman, Stadhagen-Gonzales, & Brysbaert, in press).

2. All theoretically relevant results that were significant using this test were also significant, $p < .05$, in a one-tailed paired Wilcoxon test computed on individual participants' percentages for each condition.

3. In the 23% of trials in which Korean participants put the top-level verb in second position, the productions were actually two sentences, as evidenced by the presence of the verbal suffix "-da"—a formal politeness pragmatic mood marker for top-level clauses—following each clause (e.g., "[Boy says]-da. [Girl heart pokes]-da.").

References

Aissen, J. (2003). Differential object marking: Iconicity vs. economy. *Natural Language & Linguistic Theory*, *21*, 435–483.

Aylett, M., & Turk, A. (2004). The smooth signal redundancy hypothesis: A functional explanation for relationships between redundancy, prosodic prominence, and duration in spontaneous speech. *Language and Speech*, *47*, 31–56.

Baker, M. (2001). *The atoms of language*. New York, NY: Basic Books.

Bouma, G. (2011). Production and comprehension in context: The case of word order freezing. In A. Benz & J. Mattausch (Eds.), *Bidirectional optimality theory* (pp. 169–190). Amsterdam, The Netherlands: John Benjamins.

Brady, T. F., Konkle, T., & Alvarez, G. A. (2009). Compression in visual working memory: Using statistical regularities to form more efficient memory representations. *Journal of Experimental Psychology: General*, *138*, 487–502.

Chomsky, N. (1986). *Knowledge of language: Its nature, origin, and use*. New York, NY: Praeger.

Croft, W. (2002). *Typology and universals*. Cambridge, England: Cambridge University Press.

Dryer, M. S. (2002). Case distinctions, rich verb agreement, and word order type (comments on Hawkins' paper). *Theoretical Linguistics*, *28*, 151–158.

Dryer, M. S. (2005). The order of subject, object and verb. In M. Haspelmath, M. S. Dryer, D. Gil, & B. Comrie (Eds.), *The world atlas of language structures* (pp. 330–333). Oxford, England: Oxford University Press.

Gell-Mann, M., & Ruhlen, M. (2011). The origin and evolution of word order. *Proceedings of the National Academy of Sciences, USA*, *108*, 17290–17295.

Gelman, A., & Hill, J. (2007). *Data analysis using regression and multilevel/hierarchical models*. New York, NY: Cambridge University Press.

Gibson, E. (1998). Linguistic complexity: Locality of syntactic dependencies. *Cognition*, *68*, 1–76.

Gibson, E., & Bergen, L. (2012, March). *The rational integration of noise and prior semantic expectation: Evidence for a noisy-channel model of sentence interpretation*. Poster presented at the 25th annual CUNY Sentence Processing Conference, New York, NY.

Givón, T. (1979). *On understanding grammar*. New York, NY: Academic Press.

Goldin-Meadow, S., So, W., Ozyurek, A., & Mylander, C. (2008). The natural order of events: How speakers of different languages represent events nonverbally. *Proceedings of the National Academy of Sciences, USA*, *105*, 9163–9168.

Greenberg, J. (1963). Some universals of grammar with particular reference to the order of meaningful elements. In J. Greenberg (Ed.), *Universals of language* (pp. 73–113). Cambridge, MA: MIT Press.

Hall, M., Ferreira, V. S., & Mayberry, R. I. (2010, November). *Argument order in pantomime: Consistency fails when it is needed most*. Paper presented at the annual meeting of the Psychonomic Society, St. Louis, MO.

Haspelmath, M. (1999). Why is grammaticalization irreversible? *Linguistics*, *37*, 1043–1068.

Hawkins, J. (2004). *Efficiency and complexity in grammars*. Oxford, England: Oxford University Press.

Hockett, C. (1955). *A manual of phonology*. Baltimore, MD: Waverly Press.

Hockett, C. (1960). The origin of speech. *Scientific American*, *203*(3), 88–96.

Jackendoff, R. (1972). *Semantic interpretation in generative grammar*. Cambridge, MA: MIT Press.

Jaeger, F. (2010). Redundancy and reduction: Speakers manage syntactic information density. *Cognitive Psychology*, *61*, 23–62.

Jakobson, R. (1936). Contribution to the general theory of case: General meanings of the Russian cases. In *Selected writings* (Vol. 2, pp. 23–71). The Hague, The Netherlands: Mouton.

Kuperman, V., Stadhagen-Gonzales, H., & Brysbaert, M. (in press). Age-of-acquisition ratings for 30 thousand English words. *Behavior Research Methods*.

Langus, A., & Nespor, M. (2010). Cognitive systems struggling for word order. *Cognitive Psychology*, *60*, 291–318.

Levy, R. (2008). A noisy-channel model of rational human sentence comprehension under uncertain input. In *Proceedings of the Conference on Empirical Methods in Natural Language Processing* (pp. 234–243). Stroudsburg, PA: Association for Computational Linguistics.

Levy, R., Bicknell, K., Slattery, T., & Rayner, K. (2009). Eye movement evidence that readers maintain and act on uncertainty about past linguistic input. *Proceedings of the National Academy of Sciences, USA*, *106*, 21086–21090.

Lindblom, B., & Maddieson, I. (1988). *Phonetic universals in consonant systems*. In C. Li & L. Hyman (Eds.), *Language, speech and mind* (pp. 62–78). London, England: Routledge.

MacWhinney, B. (1977). Starting points. *Language*, *53*, 152–168.

Marsaja, I. G. (2008). *Desa Kolok: A deaf village and its sign language in Bali, Indonesia*. Nijmegen, The Netherlands: Ishara Press.

Meir, I., Lifshitz, A., Ilkbasaran, D., & Padden, C. (2010, April). *The interaction of animacy and word order in human languages: A study of strategies in a novel communication* *task*. Paper presented at the 8th International Conference on the Evolution of Language, Utrecht, The Netherlands.

Meir, I., Sandler, W., Padden, C., & Aronoff, M. (2010). Emerging sign languages. In M. Marschark & P. Spencer (Eds.), *Oxford handbook of deaf studies, language, and education* (Vol. 2, pp. 267–280). New York, NY: Oxford University Press.

Newmeyer, F. J. (2000a). *Language form and language function*. Cambridge, MA: MIT Press.

Newmeyer, F. J. (2000b). On the reconstruction of 'proto-world' word order. In C. Knight, M. Studdert-Kennedy, & J. R. Hurford (Eds.), *The evolutionary emergence of language: Social function and the origins of linguistic form* (pp. 372–388). Cambridge, England: Cambridge University Press.

Paul, H. (1880). *Prinzipien der sprachgeschichte* [Principles of the history of language]. Tübingen, Germany: Max Niemeyer.

Piantadosi, S., Tily, H., & Gibson, E. (2011). Word lengths are optimized for efficient communication. *Proceedings of the National Academy of Sciences, USA*, *108*, 3526–3529.

Piantadosi, S., Tily, H., & Gibson, E. (2012). The communicative function of ambiguity in language. *Cognition*, *122*, 280–291.

Pinker, S., & Bloom, P. (1990). Natural language and natural selection [Target article and commentaries]. *Behavioral and Brain Sciences*, *13*, 707–784.

Sandler, W., Meir, I., Padden, C., & Aronoff, M. (2005). The emergence of grammar: Systematic structure in a new language. *Proceedings of the National Academy of Sciences, USA*, *102*, 2661–2665.

Schouwstra, M., van Leeuwen, A., Marien, N., Smit, M., & de Swart, H. (2011). Semantic structure in improvised communication. In L. Carlson, C. Hoelscher, & T. F. Shipley (Eds.), *Proceedings of the 33rd annual meeting of the Cognitive Science Society (CogSci11)* (pp. 1497–1502). Austin, TX: Cognitive Science Society.

Senghas, A., Coppola, M., Newport, E., & Supalla, T. (1997). Argument structure in Nicaraguan Sign Language: The emergence of grammatical devices. In E. Hughes, M. Hughes, & A. Greenhill (Eds.), *Proceedings of the 21st annual Boston University Conference on Language Development* (Vol. 2, pp. 550–561). Somerville, MA: Cascadilla Press.

Shannon, C. (1948). A mathematical theory of communication. *Bell System Technical Journal*, *27*, 623–656.

Smith, P. (1969). Coding strategies in language. *Information and Control*, *14*, 72–97.

Temperley, D. (2007). Minimization of dependency length in written English. *Cognition*, *105*, 300–333.

Tily, H. (2010). *The role of processing complexity in word order variation and change*. Stanford, CA: Stanford University.

Vennemann, T. (1973). Explanation in syntax. In J. Kimball (Ed.), *Syntax and semantics* (Vol. 2, pp. 1–50). New York, NY: Academic Press.

Zipf, G. K. (1949). *Human behavior and the principle of least effort*. New York, NY: Addison-Wesley.