Incremental Grammatical Encoding in Event Descriptions

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Abstract

Speech is produced incrementally. The Incremental Parallel Formulator (De Smedt, 1996) is a computational model of grammatical encoding that takes this notion of incrementality into account. It predicts that the order and time-scale with which conceptual fragments activate lexical segments affect the syntactic shape of an utterance. We derived predictions from this model and tested these in two online experiments. In these experiments, participants described computer animations in which two objects moved in upward or downward directions. We manipulated the availability of pieces of the conceptual input by withholding either the information about the movement direction, or about the identity of one of the objects for various amounts of time. The experiments showed that both the type and the temporal availability of conceptual information strongly affect the syntactic shape of an utterance.

Introduction

According to Levelt (1989) three processing modules for fluent speech production can be distinguished: the Conceptualizer, the Formulator, and the Articulator. These modules work in an incremental fashion on different parts of an utterance simultaneously. The view that speakers produce spoken language incrementally has now become common ground in the psycholinguistic community (e.g., Levelt, 1989). On the modeling side, this has resulted in the formulation of several computational models of grammatical encoding, one of which is the Incremental Parallel Formulator (IPF; De Smedt, 1996). A central prediction of this model is that the order and time-scale with which conceptual fragments become available to the speaker exert an influence on the syntactic format of an utterance. We tested this prediction in two experiments in which we asked participants to describe simple computer animations.

The Incremental Parallel Formulator has its roots in Segment Grammar (e.g., Kempen, in preparation). The building blocks of Segment Grammar are segments: small structures of lexical origin that have a root node and a foot node with an arc in between. The arc specifies the syntactic function of a segment, the root and the foot node represent syntactic categories. The construction of syntactic structures takes place in the so-called Unification Space (see also Kempen & Vosse, 1989), where the roots of segments can unify with root nodes (by bifurcation) or with foot nodes (by concatenation) of other segments.

An important general principle in incremental language production has been formulated by Hoenkamp (1983, p. 18) as follows: "What can be uttered, must be uttered immediately". If we extend this principle to the process of grammatical encoding, we can formulate the following processing assumption for unification: "What can be unified, must be unified immediately".

Consider the application of this processing assumption to the following example. Imagine a speaker who is asked to describe a scene in which a circle moves in upward direction. The conceptual input will activate the following lexical segments in the Unification Space:

(1)	NP_1	----	head	----	n	*(circle)*
(2)	NP_1	----	det	----	art	*(the)*
(3)	S	----	HEAD	----	verb	*(move)*
(4)	ADVP	----	head	----	adv	*(up)*
(5)	S	----	SUBJ	----	NP	
(6)	S	----	MOD	----	ADVP	

By unification of the segments (i.e., by bifurcation of segments (1) & (2), and of segments (3), (5) & (6), and by concatenation of segments (5) & (1,2), and of segments (6) & (4)), the speaker can utter the simple sentence: *"The circle moves up"* (denoted as S_1 hereafter). Now suppose that the speaker sees an animation displaying a circle and a triangle both moving upward simultaneously. In this case, the speaker can either say *"The circle moves up and the triangle moves up"* (a Sentence Coordination or SC), or the speaker can say *"The circle and the triangle move up"* (a Noun Phrase Coordination or NPC). To describe the scene by means of an NPC, the conceptualizer will activate the following additional segments:

(7)	NP_2	----	head	----	n	*(triangle)*
(8)	NP_2	----	det	----	art	*(the)*
(9)	S/NP	----	OP	----	conj	*(and)*

Segment (9) is a special kind of segment that requires some further comment. As Kempen (in preparation) proposes, a few segments have the special status of Operator. These special segments accommodate for conjunctions (*and* and *but*) and negations (*not* and *nor*). As the double category of the root (S/NP) of segment (9) indicates, we introduce a special syntactic segment here that can be regarded as a 'generic syntactic conjunctor'. That is, it can unify two sentences or two noun phrases. In the former case, the operator is nothing more than just an ordinary conjunction between two full sentences. In the latter, it combines two noun phrases. The result of grammatical encoding will then be an NPC. We further assume that this special segment should not be allowed to unify with only one other segment at the time. That is, for a coordination to take place, segment (9) requires two roots of the same category to be available at the same time (i.e., two S-nodes or two NP-nodes).[1]

So far, we have only considered a situation in which all segments are available at the same time. What would happen if we systematically delay the availability of some parts of the conceptual input? This was tested in our first experiment.

Experiment 1

Participants were asked to describe simple computer animations as fast and as accurately as possible. The animations displayed two geometrical objects making movements in either upward or downward directions. The objects either moved in the same direction (conjunct movements) or in opposite directions (disjunct movements). Both objects appeared on the screen simultaneously. Immediately following their appearance, one of the objects (e.g., a circle) started to move, whereas the other one (e.g., a triangle) started to move with some delay. As a result of this Movement Onset Asynchrony (henceforth MOA), the conceptual information associated with the movement direction of the object moving second was withheld from the grammatical encoder by MOA milliseconds relative to that of the object moving first. In terms of IPF, the Conceptualizer will activate lexical segments (1) - (6) to verbalize the event in which a circle moves upward. In the mean time, segments (7) and (8) are also activated. The movement of the triangle cannot yet be conceptualized because it is still stationary at this point. If we now apply the principle "what can be unified, must be unified immediately", then unification of segments (1) (6) yields a full sentence: *"The circle moves up"*. At the same time, segments (7) and (8) are also unified, resulting in a noun phrase: *"the triangle"*. After MOA milliseconds, the triangle has also started to move upward. The conceptualizer can now activate the conjunctor and (re)activate segments (3) (6), thereby unifying two full sentences, yielding an SC: *"The circle moves up and the triangle moves up"*. Had there been no delay between onset of the movements (i.e., MOA = 0 ms), a situation as described in our earlier example would have resulted. The grammatical encoder might have had segment (9) available before unification of the first sentence had been completed and the speaker would have uttered an NPC. As a consequence, we expect a decrease in the proportion of NPCs with increasing MOA.

Until now, we have argued as if the processes of conceptualization and unification are deterministic. That is, we assumed that not only the speed with which the event is conceptually encoded is constant, but also the speed with which lexical and syntactic segments are activated. Thus, going from an MOA of 0 milliseconds up to a certain MOA of *n* milliseconds, speakers would produce only NPCs, and at MOAs longer than *n* milliseconds only SCs. However, this is not a realistic assumption. Because both the time needed to conceptualize objects and their movements, and the time needed for segments to be unified will probably vary around some mean value, one would not expect a sudden transition from NPCs to SCs at a certain MOA. Rather, one would expect a gradual decrease in the proportion of NPCs for describing conjunct movements with increasing MOA. This prediction presupposes that speakers do not wait until the movement direction of the second object becomes available too, but start uttering as soon as possible. In other words, we expect that the grammatical encoder does not have to wait until all conceptual information about the to-be-described event is processed before a (partial) result is passed on to phonological encoding and articulation. If this is indeed the case, then utterance onset latencies should not be affected by MOA.

Thus far, we have only discussed the effect of the temporal availability of conceptual fragments on utterance format (either SC or NPC) and neglected utterance onset latencies (i.e., the time between onset of the animation and onset of the utterance). However, utterance onset latencies will allow us to look at the temporal development of incremental grammatical encoding also at a more fine-grained level. Let us assume that the grammatical encoder starts constructing the first noun phrase (by bifurcation of segments (1) & (2)) as soon as the corresponding object becomes available. The time needed for unification of this noun phrase (NP_1) will vary around some mean value. If, on a given trial, NP_1 is completed early, then the likelihood that the information about the movement direction of the object moving second is

[1] In addition, there is a second constraint. The conceptualizer has to indicate that the two objects triggering their respective segments move in the same direction. Otherwise, the two NPs might, erroneously, also be unified during the grammatical encoding of a description of an event in which two objects move in different directions. This, of course, would result in an inappropriate structure (an NPC), because only an SC is an adequate description for such an event.

already available should be rather low. As a consequence, NP_1 will probably be unified with the other available segments in the Unification Space, thus yielding the first simple sentence (S_1) in an SC. If, by contrast, NP_1 is completed relatively late, then the likelihood that information about the movement direction of the object moving second should be higher. As a result, the probability that an NPC is constructed will be higher. Thus, taken together, within a given MOA, the proportions of NPCs should be higher for a subset of responses that have relatively long utterance onset latencies compared to a subset of responses with relatively short utterance onset latencies. This would also show that the eventual utterance format (SC or NPC) is determined by both MOA and utterance onset. In order to quantify this prediction we will divide all descriptions (irrespective of type of utterance) of conjunct movements for a given participant and MOA into two equally large sets: one set containing all responses with utterance onset latencies that were shorter than the median latency for a given participant and MOA (fast responses), and one set with responses with latencies slower than the median (slow responses). We will refer to this division of responses according to their latencies as the factor Speed. Thus, we would expect that the resulting factor Speed yields higher proportions of NPCs in the set of slow responses than in the set of fast responses. Furthermore, this difference should become larger with increasing MOA.

In sum, we hypothesize that with increasing MOA, the chance that a speaker describes a conjunct movement by means of an NPC will gradually decrease. Furthermore, the proportion of NPCs will be lower for fast than for slow responses.

Method

Participants Twenty undergraduate students at the University of Nijmegen participated in the experiment.

Design Participants were asked to describe 120 short animations in which two geometrical objects, positioned to the left and the right of the center of a computer screen, made phi-movements in either upward or downward directions. On every trial, participants saw a combination of two objects selected from a set containing a circle, a triangle, a square, and a cross. All possible combinations of two objects occurred equally often, excluding pairs of identical objects. There were 48 critical trials in which the objects made conjunct movements (24 upward and 24 downward). In addition, there were 48 distractor trials in which the objects made disjunct movements (24 trials with the left object moving upward and the right downward and 24 trials with reversed directions). Movement Type (conjunct or disjunct) was crossed with MOA. There were four different MOAs: 0 ms, 300 ms, 500 ms, and 700 ms, which were equally distributed over left and right objects. In addition to these 96 trials, 24 filler trials (12 upward and 12 downward) were added in which the objects started to move in the same direction without delay (i.e., the MOA was 0 ms). These trials were added to induce participants to use NPCs in their descriptions where applicable.

Procedure Participants were instructed to describe the animations on the screen as fast and accurately as possible. This instruction provided two examples possible animations. For conjunct movements, the example was: *If you see a cross moving up and a triangle moving up, you say: "the cross and the triangle move up"*. For disjunct movements, the example was: *If you see a circle moving up and a square moving down, you say: "the circle moves up and the square moves down"*. The instruction did not explicitly state to use only NPCs for describing conjunct movements and only SCs for disjunct movements. Participants were also instructed to complete their utterance as naturally as possible, without making corrections or re-starting their utterances. Participants were free to choose the object they wanted to mention first (either the left or the right object).

Results and Discussion

As valid NPC utterances we scored all responses like *"The circle and the triangle (both) move up"*. As valid SC utterances we scored all responses like *"The circle moves up (and) the triangle (also) moves up (too)"*. Moreover, SC utterances containing ellipses (e.g., *"The circle moves up and the triangle too"* or *"The circle moves up and the triangle down"*) were also treated as valid responses. Apart from the type of utterance, we also scored hesitations, self-corrections and errors. All responses containing any of these dysfluencies (8.5% in total) were excluded from further analyses.

To determine the effect of the factor Speed, we computed the median of the utterance onset latencies for descriptions of conjunct movements for each MOA and subject separately. Next, the proportions of NPCs below (fast responses) and above (slow responses) the median were computed.

Table 1: Proportions of NPCs on Critical Trials by MOA and Speed in Experiment 1.

	MOA in ms			
Speed	0	300	500	700
Fast	.950 (.134)	.597 (.401)	.354 (.322)	.236 (.271)
Slow	.975 (.082)	.633 (.408)	.498 (.385)	.412 (.384)

Note. Standard deviations in brackets.

The proportions of NPCs on the critical trials (see Table 1) were subjected to a 4 (MOA) × 2 (Speed) analysis of variance. The main effect of MOA was significant for the linear contrast, $F(1,19) = 122.16$; $p < 0.01$, and for the quadratic contrast, $F(1,19) = 6.08$; $p < 0.05$.[2] In addition, the main effect of Speed and the interaction effect between

[2] We tested the linear, quadratic, and cubic polynomial contrasts. Therefore, the degree of freedom of the numerator is always equal to 1, even if a factor has more than two levels. In the remainder, we will only report the F-ratios associated with the linear contrasts. Unless explicitly stated, the tests on the quadratic and cubic contrasts were not significant.

MOA and Speed were significant, $F(1,19) = 18.571$; $p < 0.01$ and $F(1,19) = 4.61$; $p < 0.05$, respectively. An analysis of variance on utterance onset latencies of NPCs on conjunct movements (see Table 2) yielded no significant effect of MOA, $F(1,19) < 1$, showing that participants did not systematically postpone their utterances with increasing MOA.

Table 2: Average Utterance Onset Latencies (UOL) for NPCs on Critical Trials by MOA in Experiment 1.

	MOA in ms			
	0	300	500	700
UOL in ms	862 (148)	886 (153)	901 (143)	862 (143)

Note. Standard deviations in brackets.

The results of the experiment are in line with the predictions outlined above. They stated that there should be a systematic decrease in proportions of NPCs with increasing MOA, and that the proportion of NPCs would be smaller in the set of fast responses than in the set of slow responses. The results strongly suggest that the temporal relation between the point in time at which conceptual fragments are activated and utterance onset affects utterance format. The results further show that across MOAs, 70% of all utterance onset latencies were longer than the longest MOA of 700 ms. This implies that the average utterance onset latencies in the set of slow responses are presumably longer than their respective MOA. Nevertheless, we see a decrease in proportions of NPCs also for the slow set of responses at MOA = 300 ms and MOA = 500 ms. This implies that even when utterances were initiated after onset of the second movement, the grammatical encoder has on a relatively substantial proportion of trials committed itself to an SC. This commitment, moreover, appears not to be revised anymore within the time frame between onset of the second movement and initiation of the utterance. Thus, a possible revision of the syntactic format of the utterance under construction seems highly unlikely, perhaps even impossible, even when additional conceptual information becomes available before speech onset.

This conclusion is also in line with the observation that the proportion of NPCs for the utterances in the set of fast responses was lower than in the set of slow responses. One possible account of this effect is as follows: The grammatical encoder passes information to phonological encoding and articulation as soon as a commitment has been made for an SC or an NPC. As a result, the proportion of NPCs should be lower for fast than for slow responses. Under this view, the grammatical encoder forwards information to later processing stages as soon as a commitment to an SC or an NPC has been made. From that point onward, the encoded structure can only be expanded further to the right, but it cannot be revised anymore.

It should be noted, however, that the results do not exclude an alternative option. According to this option, the decision to construct an SC or an NPC might be taken while phonological encoding and/or articulation of the first noun phrase is carried out. Nevertheless, the large proportion of SCs in responses where utterance onset follows the onset of the second movement strongly suggests that once a commitment for an SC is taken, the probability that this commitment is revised to an NPC appears to be low (or even zero).

In sum, it appears that the temporal availability of conceptual fragments and, consequently, of the corresponding segments for grammatical encoding, plays a crucial role for the eventual syntactic format of an utterance. More specifically, the later the information with respect to the movement direction of the object moving second comes into play relative to speech onset, the lower the probability that speakers produce an NPC.

This conclusion was further tested in Experiment 2. In this experiment, the identity of only one object, but the movement directions of both objects, were available from the very beginning of the animation. There are two possible hypothesis in this situation. First, the grammatical encoder might use the movement information about both objects to take an 'early decision' on whether to encode an SC or an NPC in absence of information about the identity of the object moving second. In this case, one would expect the proportions of NPCs in this experiment not to be affected by the onset asynchrony manipulation. Second, if the coordinating segment (9) can only yield an NPC if both to-be-coordinated segments are available (as assumed by IPF), we should obtain the same pattern of proportions of NPCs as in Experiment 1.

Experiment 2

Method

Participants Sixteen undergraduate students from the same pool as in Experiment 1 took part in this experiment.

Design The experiment was identical to Experiment 1 except for two changes. First, instead of having an MOA, we introduced an Object Onset Asynchrony (OOA). At the start of the animation one object and a cloud of random dots started to move immediately. After OOA ms, the moving cloud of dots was replaced by the target object. Second, in order to obtain a more fine-grained picture of the development of the proportions of NPCs across asynchronies, we replaced the 700 ms delay by a 400 ms delay. Thus, the factor OOA had four levels: 0 ms, 300 ms, 400 ms, and 500 ms.

Results and Discussion

All utterances were scored in the same fashion as in Experiment 1. All responses containing dysfluencies (12% in total) were excluded from further analyses. The proportions of NPCs on the critical trials (see Table 3) were subjected to a 4 (OOA) × 2 (Speed) analysis of variance, which yielded a significant main effect for OOA, $F(1,15) = 8.93$, $p < 0.01$. The main effect of Speed and the interaction effect between OOA and Speed were not significant, $F(1,15) = 2.95$, $p > 0.10$ and $F(1,15) < 1$, respectively. Average utterance onset latencies on NPCs for descriptions of conjunct movements (see Table 4) showed no significant effect of OOA on utterance onset latencies, $F(1,15) = 1.49$, $p > 0.10$. It appears that participants did not postpone their utterances with increasing OOA. Had this been the case, this could have implied that they waited for the information about the identity of the object moving second to be able to produce an NPC.

Table 3: Proportions of NPCs on Critical Trials by OOA and Speed in Experiment 2.

	OOA in ms			
Speed	0	300	400	500
Fast	.948 (.146)	.833 (.184)	.777 (.332)	.814 (.221)
Slow	.967 (.094)	.938 (.103)	.881 (.159)	.801 (.288)

Note. Standard deviations in brackets.

Thus far, we have proposed that speakers do not revise syntactic commitments made once articulation is initiated. This conclusion is based on the substantial proportions of SCs in Experiment 1, even in trials where the movement of the object moving second starts before speech onset. By introducing an OOA in this experiment instead of an MOA (as in Experiment 1), participants are, in principle, provided with sufficient information at the start of the animation to encode an NPC. One could argue, therefore, that participants might have used a strategy such as prolonging the first part of an utterance to be able to produce an NPC with increasing delay. Obviously, such a prolongation would not be reflected in utterance onset latencies, but in the duration of the first part of the utterance.

To investigate this possibility, we measured the duration of the first NP (NP_1) and the conjunctor up to the beginning of the second NP (NP_2) for NPCs describing conjunct events (see Table 4). An analysis of variance yielded no significant effects for the linear and cubic contrasts, $F(1,15) < 1$ and $F(1,15) = 2.92$, $p > 0.10$, respectively. The quadratic contrast was only marginally significant, $F(1,15) = 3.85$, $p < 0.10$. In sum, although there was a slight tendency to prolong the first part of the utterance, this prolongation did by far not compensate for the longer OOA (see Table 4).

Table 4: Average Utterance Onset Latencies (UOL) and Duration of the First Part of the Utterance (DUR) for NPCs on Critical Trials by OOA in Experiment 2.

	OOA in ms			
	0	300	400	500
UOL in ms	928 (166)	896 (155)	934 (132)	876 (120)
DUR in ms	673 (111)	671 (106)	701 (142)	667 (125)

Note. Standard deviations in brackets.

The results provide only partial support for our predictions with respect to the effect of OOA. Although the proportions of NPCs for OOAs > 0 ms were considerably higher than in Experiment 1, there still was a significant decrease in the proportions of NPCs with increasing OOA. This was the case even though the information with respect to movement direction of both objects was available from the beginning of the animation. However, this decrease appeared to be considerably smaller than in the first experiment. An analysis of variance comparing Experiment 1 and 2 with respect to the proportions of NPCs for the MOAs/OOAs of 0 ms, 300 ms, and 500 ms supported this observation. This analysis yielded significant main effects of the factors Experiment, $F(1,34) = 10.31$, $p < 0.01$, MOA/OOA, $F(1,34) = 56.21$, $p < 0.01$, and Speed, $F(1,34) = 6.76$, $p < 0.05$. The interaction between Experiment and MOA/OOA was also significant, $F(1,34) = 17.86$, $p < 0.01$. No other interactions reached significance.

These results imply that the availability of information with respect to the movement direction of the objects is not the only information that determines the eventual syntactic format of the descriptions. Rather, the tendency to describe conjunct movements by means of an NPC seems to benefit from early availability of the identity of the object moving second. Had there been no such benefit, Experiment 2 should have yielded the same proportions of NPCs for all OOAs.

General Discussion

In sum, we have seen the following. First, the eventual syntactic structure of a description of a conjunct movement crucially depends on the point in time at which information about both movements becomes available, as indicated by the strong effect of MOA on the proportions of NPCs in Experiment 1. Second, the effect of Speed in Experiment 1 further qualifies this conclusion. It is not simply the absolute timing of the availability of conceptual information about the movement direction of the object moving second (MOA), that determines the commitment for an SC or an NPC, but rather the temporal relation between MOA and utterance onset. Third, as soon as the grammatical encoder has made a commitment to an SC, the chance that this commitment is revised during the articulation of the first part of the description appears to be low. Fourth, although there are indications that speakers prolonged the articulation of the first part of their descriptions with increasing OOA (Experiment 2), this prolongation was by far insufficient to compensate for the increase in OOA. Fifth, the immediate availability of information with respect to both movements does not appear to be the only force driving the encoding of an NPC, because we found a significant effect of OOA on the proportions of NPCs in Experiment 2. This result can be interpreted in two ways.

First, one could assume that availability of the identity of the object moving second is an independent force favoring the construction of NPCs. For example, one could assume that with the availability of two NPs, the grammatical encoder has a tendency to unify them in an NPC even if it is unknown whether the movements to be described are conjunct or disjunct. Note that this is in fact the state of affairs in Experiment 1, where at the start of an animation participants saw two objects, but only one movement.

Second, one could assume that information with respect to the identity of the object moving second is an additional force favoring the construction of NPCs which comes into play only when it is known that one is dealing with a conjunct movement. In other words, the grammatical encoding process leading to an NPC is started by information about the presence of a conjunct movement, but can be facilitated by the early availability of the identity of the object moving second.[3]

To conclude, although there is considerable consensus on the assumption that the grammatical structure of utterances is generated in a piecemeal fashion, there is almost no experimental research on the precise (temporal) properties of incremental grammatical encoding. This is due to the fact that such investigations would require the simultaneous measurement of the flow of thought forming the to-be-formulated conceptual input to grammatical encoding and the development of the corresponding syntactic structures over time. Obviously, this creates a very difficult, if not unsolvable empirical problem. Therefore, we instead developed an experimental paradigm that enables us to manipulate the temporal availability of pieces of conceptual information and thus to exert experimental control on the conceptual input. With this new paradigm, we were able to show that withholding information about either the movement direction of one of two objects (Experiment 1) or its identity (Experiment 2) for a short period of time, produces systematic effects on grammatical encoding. Furthermore, at some point in planning an utterance, which presumably lies before speech onset, there seems a point of no return in grammatical encoding. More specifically, the probability that a commitment for a specific syntactic structure (e.g., an SC) is revised appears to be low, even in situations in which the conceptual information that could trigger such a revision becomes available before utterance onset.

We believe that the experimental paradigm applied in this study has potential for the future: One no longer needs to rely solely on off-line data such as speech errors. Rather, this approach enables researchers to investigate the claim that language is produced incrementally under full experimental control in online tasks.

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[3] At present, we are planning experiments that allow to differentiate between these two interpretations.