RUNNING HEAD: Constituent Order Priming from Reading to Listening

Constituent order priming from reading to listening: A visual-world study

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INTRODUCTION

Studies of sentence generation have repeatedly shown a tendency of language producers to maintain aspects of syntactic structure over consecutive trials, if possible: when participants are restricted in their choice of possible syntactic alternatives in one trial (the *prime*) and are then confronted with a wider range of possible syntactic alternatives in the following trial (the *target*), there is an above-chance likelihood that they will re-produce the structure they have generated in the prime trial, despite the fact that they are free to produce an alternative structure in the target trial (e.g. Bock, 1986; Bock & Loebell, 1990; Pickering & Branigan, 1998; Corley & Scheepers, 2002; among many others). This phenomenon, which is commonly being referred to as *syntactic priming*, has been taken to reflect a mechanism whereby syntactic representations generated in the prime trial retain some residual activation over time which facilitates their (re-) activation in the following target trial.

The assumption of a similar short-term adaptation mechanism in comprehension is not only plausible (just like production, sentence comprehension requires the activation of syntactic representations, as highlighted in many chapters of this volume), but also widely agreed upon amongst psycholinguists (at least implicitly, as evidenced, for example, by comments on comprehension studies that do *not* control for syntactic priming): the comprehension of a given sentence structure in one trial may facilitate the comprehension of the same structure in a subsequent trial, and more specifically, syntactic ambiguity resolution within a given sentence may be influenced by the way in which the same (or a similar) ambiguity was disambiguated in the previously encountered sentence. Thus, the way in which sentences are being parsed might be preserved over consecutive trials, which is why it is common practise to have syntactically unrelated 'fillers' between the trials of interest when the experimental focus is on general syntactic ambiguity resolution strategies in comprehension.

However, in spite of a growing body of evidence for syntactic priming in production, experimental findings supporting a similar mechanism in comprehension are still rather sparse and, where available, not very conclusive: they either allow for alternative explanations (lexical or metrical parallelism rather than structural parallelism) or they fail to demonstrate reliable priming effects altogether, partly because of rather crude stimulus presentation techniques (e.g. Frazier et al., 1984; Branigan, 1995; Weskott, 2002). In these studies, structural priming has mostly been measured (more or less successfully) in terms of faster reading times for targets that match the structure of the preceding primes compared to targets that do not match the structure of the primes.

The present study aims at investigating the issue of syntactic priming in comprehension by looking at the resolution of constituent order ambiguity in German. It is a well-established fact that, although German allows for variable sequencing of subject and object NPs at the sentence surface, native German speakers reliably prefer a subject-before-object ordering (e.g., Hemforth & Konieczny (Eds.), 2000; see also Fiebach et al., this volume). Furthermore, the German case marking system, which is crucial for designating syntactic function in that language, is partially ambiguous such that, for example, sentence-initial feminine singular NPs like 'Die Krankenschwester …' (The nurse [fem, sing] …) can be interpreted as either subject (typically the agent) or object (typically the patient). Since the subject-first ordering is generally preferred, this sentence-initial case ambiguity is usually resolved in favour of a nominative (i.e. subject) interpretation of the critical NP (e.g. Hemforth, 1993).

The question we are going to address is whether this preference is subject to priming from a previous trial in which participants have to process either an unambiguous subject-first or object-first sentence. Provided that syntactic priming in comprehension exists, the subject-first preference should be strengthened after having encountered an unambiguous subject-first sentence in the previous trial; conversely, it should be weakened, or even overruled, after having encountered an object-first sentence in the previous trial. (Our experiment will include a baseline condition whereby such modulations of syntactic preference become more explicit). Moreover, we will look at priming effects across different modes of processing: while participants are presented with unambiguous written sentences (for reading) in the prime trials, they will listen to temporarily ambiguous auditory sentences in the target trials. This ensures that potential priming effects must rely upon the preservation of abstract sentence representations rather than low-level perceptual strategies.

In order to measure the critical constituent order preferences in the auditory targets, we will make use of the *visual-world* eye-tracking paradigm (e.g. Cooper, 1974; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995; Altmann & Kamide, 1999; Kamide, Scheepers, & Altmann, 2003; Kamide, Altmann, & Haywood, in press; Scheepers, Kamide, & Altmann, 2003; see also the chapters by Boland; Brown-Schmidt et al.; Huettig & Altmann; and Mitchell, this volume). The auditory materials will be concurrently presented with related visual scenes in which an *ambiguous* character (serving both as agent and patient) is pictured together with an unambiguous *agent* character (acting upon the ambiguous character) and an unambiguous *patient* character (being acted upon by the ambiguous character). (The pictures will actually show two transitive events at the same time.) The case-ambiguous first NP of the auditory sentences will always refer to the ambiguous character.

Previous visual-world research has shown that eye-movements around a visual scene are closely time-locked with the related auditory input, and more importantly, that participants are able to *anticipate* forthcoming linguistic reference to objects in the scene: visual attention is often drawn to critical objects in the scene before these objects are actually mentioned in the auditory input (Altmann & Kamide, 1999; Kamide et al., 2003; Kamide et al., in press; Scheepers et al., 2003). For example, Kamide et al. (2003) and Scheepers et al. (2003) found that native German participants rapidly combine unambiguous case-marking information at the first NP (if available) and semantic restrictions provided by the verb in order to predict a second forthcoming NP-argument. In these experiments, participants were presented with visual scenes showing, e.g., a hare, a cabbage, a fox, and a tree (distractor), while at the same time listening to unambiguous subject-first sentences like 'Der Hase frisst gleich den Kohl' (The hare [nom] eats shortly the cabbage [acc]) or unambiguous object-first sentences like 'Den Hasen frisst gleich der Fuchs' (The hare [acc] eats shortly the fox [nom]) – note that the critical actions were not displayed in the pictures (unlike in the present study). The main finding was that shortly after the verb was available in the auditory input (and clearly before the second NP was encountered), participants already launched reliably more and longer looks to the appropriate NP2-referents in the picture (i.e., the cabbage in the subject-first condition and the fox in the object-first condition) than to their inappropriate counterparts, suggesting that the most likely forthcoming referent was anticipated on the basis of the linguistic and visual information available. Crucially, in order to be able to display this pattern of anticipatory eye-movements, participants must have taken into account which one of the two available argument slots of the verb (subject or object) has already been filled with the first NP and its referent.

Given these findings, we assume that in the present experiment, the interpretation of the ambiguous first-NP referent (as either subject or object) should reveal itself in anticipatory looks to the visually unambiguous characters in the scene. That is, if participants prefer the subject-interpretation of the ambiguous first-NP referent, they should pay more attention to the unambiguous *patient* character (the most likely forthcoming object); however, if they prefer the object-interpretation of the ambiguous first-NP referent, they should pay more attention to the unambiguous *agent* character (the most likely forthcoming subject). The reasoning behind this assumption is that once listeners have committed to a particular role assignment for the ambiguous first-NP referent (which is assumed to proceed very quickly), they should start focusing their attention on a character that is likely to fill the *remaining* argument slot, as was the case in the earlier studies.[1]

A final important point is that all of our auditory target sentences will be disambiguated further downstream, after the case-ambiguous initial NP has been processed. This enables us to investigate potential garden-path effects during listening: overall, we expect that structures disambiguated towards an object-initial reading will be harder to process than structures disambiguated towards a subject-initial reading (see Hemforth, 1993; Hemforth & Konieczcny (Eds.), 2000), and that this effect should become stronger or weaker dependent on whether a subject-initial or an object-initial structure has been read in the previous prime trial, respectively. In order to measure garden-path effects during auditory sentence processing, we will look at pupil size changes over time (see details below).

EXPERIMENT

Method

Participants

Forty-eight undergraduates from the Saarland University community were paid for participation. All of them were native German speakers with normal or corrected to normal vision. Thirty-three (69%) had a right-eye dominance, as determined via a simple parallax test prior to the experiment.

Target Materials

Twenty-four experimental pictures (and another 24 fillers for a different experiment) were created using digital images from commercially available clip art collections. Each visual stimulus showed three human characters: a female character in the centre, a male character to the left and another male character to the right of the central character (cf. Figure 1).[2]

The visual scenes always depicted two events at the same time, one in which the female character acted as an agent (e.g. the nurse blow-drying the priest in Figure 1a and pushing the sportsman in Figure 1b) and one in which she acted as a patient (e.g. the nurse being pushed by the sportsman in Figure 1a and being blow-dried by the priest in Figure 1b). The direction of action was counterbalanced between and within material files, i.e., in half of the trials, it was left-to-right (Figure 1a), and in the other half of trials it was right-to-left (Figure 1b). This was done to ensure that potential viewing preferences for particular characters in the scene (agents vs. patients) were not explainable in terms of a simple left-to-right scanning strategy. Furthermore, the pictures were pre-tested such that the depicted actions were equally recognisable across conditions.

**************** FIGURE 1 ABOUT HERE ****************

Each picture was paired with one of two versions of auditory sentences.[3] One version (henceforth the 'subject-object', or SO, condition) referred to the event in which the female character acted as the agent (1a,b) and the other version (henceforth the 'object-subject', or OS, condition) referred to the event in which the female character acted as the patient (2a,b). Sentences were always consistent with the displayed actions – the (a) and (b) sentence versions apply to the picture versions in Figure 1a and 1b, respectively.

(1) a. Die Krankenschwester föhnt offensichtlich den Priester.
The nurse [ambig.] *blow-dries apparently the priest* [acc].
b. Die Krankenschwester schubst offensichtlich den Sportler.
The nurse [ambig.] *pushes apparently the sportsman* [acc].

(2) a. Die Krankenschwester schubst offensichtlich der Sportler.
The nurse [ambig.] *pushes apparently the sportsman* [nom].
b. Die Krankenschwester föhnt offensichtlich der Priester.
The nurse [ambig.] *blow-dries apparently the priest* [nom].

The first NP in each sentence always referred to the central (female) character and was therefore ambiguous with respect to case marking (in German, nominative and accusative case feminine NPs are morphologically identical). Thus, locally, this NP could either be interpreted as the subject (typically, the agent) or the object (patient) of the sentence. The earliest point of disambiguation was the (present tense) verb region, which, combined with the visual context, unequivocally indicated the role being played by the central character. The verb was followed by an adverbial and an unambiguously case marked masculine NP referring to the remaining accusative (patient) or nominative (agent) NP in (1) and (2), respectively.

A cross-splicing procedure ensured that there were no prosodic differences between the SO- and OS-versions of the target sentences up to the onset of the second NP: the final OS-versions were actually generated from the SO-recordings (1) by replacing the original second NPs with the appropriate second NPs from the OS-recordings (2).

Priming Materials

The picture-sound target trials were immediately preceded by (lexically and semantically unrelated) prime trials in which participants had to read aloud one of three types of written sentences: SVO primes (P1), OVS primes (P2), or Neutral primes (P3). SVO primes consisted of a masculine singular nominative NP followed by a past tense verb, an adverbial, and a masculine singular accusative NP, resulting in an unambiguous subject-verb-object ordering of constituents. In OVS primes, the assignment of case to the relevant NPs was reversed, which resulted in an unambiguous object-verb-subject order. Neutral primes consisted of intransitive passive constructions, which were considered an unlikely trigger of a particular subject-object sequencing (thus, they provide a baseline with which the effectiveness of SVO/OVS primes can be compared).[4]

(P1) Der Regisseur lobte insbesondere den Produzenten.

The director [nom] *commended in particular the producer* [acc].

(P2) Den Regisseur lobte insbesondere der Produzent.

The director [acc] *commended in particular the producer* [nom].

(P3) Vor den Wahlen wurde im Fernsehen heftig gestritten.

Before the elections there was a lot of debate on TV.

Design and Procedure

For each picture version (Figure 1a vs. 1b), each type of prime (SVO, OVS, Neutral) was paired with each type of sentence condition (SO vs. OS), resulting in a 2 (picture version) × 3 (prime) × 2 (sentence condition) design. Twelve material files were generated such that (a) each of the 24 items appeared exactly once per file, but in different factor-combinations across files and (b) the number of items per factor combination was balanced within each file. In addition to the prime-target pairs of interest, each material file included 24 *visual-world* items (pictures combined with auditory sentences) and 12 written sentences (for reading) as fillers. For each of the 12 files, four different quasi-random orders of trials were generated, subject to the constraint that each prime-target sequence was preceded by at least one filler (visual-world or reading trial).

Participants were seated approximately 75 cm from the screen of a 21" colour monitor that was connected to the Subject-PC of an *SMI EyeLink* head-mounted eye-tracking system (spatial resolution: < 0.01°, sampling rate: 250Hz). The Subject-PC controlled the presentation of the stimuli and stored the eye-tracker output for later analysis. Connected to the sound card of the Subject-PC was a Labtec LCS-2414 satellite speaker and subwoofer system for auditory presentation. The stimulus display ran at 120Hz refresh rate in 1024 × 768 pixel resolution. Viewing was binocular, but only the participant's dominant eye was tracked.

In order to conceal the purpose of the study, the experiment was disguised as the training phase of a picture/sentence-recognition test. Participants were told that they would see a random series of trials comprising either written sentences (which they would have to read aloud on encounter) or pictures combined with auditory sentences (which they would just have to pay attention to). Their 'task' was to memorise as many of the presented pictures and sentences (written or auditory) as possible; at the close of the experiment, they would be tested on how many of the previously presented stimuli they would recognise from a list containing 'old' and 'new' stimuli. This testing phase actually never took place (participants were debriefed about the actual purpose of the experiment at the close of each session).

Each trial started with the presentation of a fixation cross in the centre of the screen. The participant fixated it so that an automatic drift correction could be performed (the trial would not proceed until the cross was fixated). Then the experimenter pressed the space bar of the Operator-PC keyboard, triggering the presentation of the relevant stimuli. In the case of a reading trial (prime or filler), a written sentence was presented for 5.5 seconds. The participant read it aloud, and then the next trial was initiated. In the case of a visual-world trial (target or filler), the picture appeared and the corresponding sentence was played 1000ms after picture onset (the relevant system time stamps were recorded in the tracker output). The participant had to pay attention both to the picture and to the sentence. The sounds typically ended about two seconds before the end of the corresponding picture presentation, which always lasted for 6.5 seconds before the next trial was initiated.

The eye-tracker continuously recorded the temporal onsets and offsets of fixations (as defined in the event-sampling routines of the tracker) together with (a) the corresponding spatial coordinates and (b) the relevant pupil size (video-frame area in pixels).

The experiment started with the camera set-up (which took about 1.5 minutes) followed by a brief calibration and validation procedure (ca. 30 seconds) during which the participant had to fixate a crosshair in nine different screen positions. Over the course of the experiment, calibration and validation was repeated once every 20 trials.

Data Analysis

The temporal onsets of the words in each target sound file were hand-coded in millisecond resolution using GoldWave. For later analysis, two critical time intervals were chosen, namely NP1 (from sentence onset until the onset of the verb) and V-ADV (from the onset of the verb until the onset of the determiner of NP2, comprising the verb and the adverbial). The average durations were 1105ms and 1289ms for NP1 and V-ADV, respectively. Due to cross-splicing (as explained earlier), OS-disambiguated target sentences were identical with their SO-disambiguated counterparts until the onset of the second NP.

The eye-tracking data were processed as follows. The temporal onsets and offsets of the fixations within a trial were re-calculated relative to the corresponding picture onset by subtracting the picture onset from the relevant fixation onsets and offsets. Extremely short fixations (less than 80ms between onset and offset, accounting for ca. 2.3% of all fixations) were pooled with the immediately preceding or following fixation if that fixation lay within a Euclidean distance of 12 pixels (ca. 0.5°), otherwise they were eliminated. The time for a blink was added to the immediately preceding fixation. Finally, the spatial coordinates of the fixations were mapped onto the objects in the picture by means of colour-coded bitmap templates (1024 × 768 pixels). The data were further processed such that all consecutive fixations on an object before the eyes moved to another object were accumulated into one *gaze*. Besides gaze duration (which will be a primary measure in our analyses), a mean pupil size per gaze was calculated (the *weighted average* of the log-transformed[5] pupil size scores of the constituent fixations – longer fixations contributed proportionally more to the mean pupil size per gaze than shorter ones). Furthermore, a mean X/Y-coordinate per gaze was calculated (the *weighted average* of the X/Y-coordinates of the constituent fixations – again, longer fixations contributed more to the mean X/Y-coordinate per gaze than shorter ones). The mean X/Y-coordinate per gaze will be used as an auxiliary measure for analysing pupil size (see details below).

In a first set of analyses (focusing on gaze duration), we were interested in the effects of *prime type* (SVO, OVS, Neutral) and *target disambiguation* (SO vs. OS) on looks to the male patient (the priest in Figure 1a and the sportsman in Figure 1b) and looks to the male agent (the sportsman in Figure 1a and the priest in Figure 1b) in each of the critical sentence regions (NP1 and V-ADV). As already discussed in the introduction, the rationale behind this was that longer looks to the male patient would indicate a preference for the ambiguous first-NP referent (the female character) to be interpreted as the subject/agent of the target sentence (anticipation of an upcoming object/patient), whereas longer looks to the male agent would suggest that the ambiguous first-NP referent is interpreted as the object/patient of the target sentence (anticipation of an upcoming subject/agent). More specifically, our analyses considered mean gaze durations per target object (a) for gazes launched within NP1 and (b) for gazes launched within V-ADV. In case a picture object was not inspected within a given trial and sentence region, the corresponding gaze duration was scored as missing value; in case a picture object was inspected more than once within a given trial and sentence region, the relevant gazes were treated as separate observations (i.e., the individual gaze durations were averaged). Hence, our measure represents the average uninterrupted viewing time spent on a given picture object in response to the linguistic (and visual) information available in the relevant sentence region.[6] Inferential analyses were based on three-factorial ANOVAs including *prime type* (SVO, OVS, Neutral), *target disambiguation* (SO, OS), and *picture object* (patient, agent) as repeated-measures factors. The data were summarised by participants and items for $F1$- and $F2$-analyses, respectively.

In a second set of analyses, we were interested in *garden-path effects*, specifically, in how difficult the OS-disambiguated versions of the auditory target sentences are in comparison to their SO-disambiguated counterparts, and whether such differences in processing difficulty are modulated by the type of the previously read prime sentence. Obviously, an analysis of looks to different target objects in the scene is not very informative in this respect (it reveals early interpretational preferences rather than processing difficulty associated with the auditory linguistic input). We therefore used the pupil size measure as an indicator of the garden-path effects of interest (cf. Just & Carpenter, 1993; Hoeks & Levelt, 1993; Hyönä & Pollatsek, 2000; Hyönä, Tommola, & Alaja, 1995). Pupil dilation has long been known to correspond with mental processing load (e.g. Beatty, 1982; Kahneman, 1973): an increase in the mental effort associated with a task is typically accompanied with an increase in pupil size. Thus, we expect that sentence conditions which are 'hard' to process will be associated with more dilated pupils. Note that changes in pupil size are relatively slow (with a latency of about 200-400ms), but still fast enough to enable the identification of their triggering events in the sound stream. Further details of the pupil size analysis will be given in the relevant results-section below.

Results and Discussion

Gaze Durations

The analysis of gazes starting within NP1[7] revealed a reliable *prime type* × *picture object* interaction in gaze duration ($F1(2,94) = 3.67$; $p < .03$; $F2(2,46) = 5.16$; $p < .01$, see Figure 2), but no effect of *target disambiguation* (Fs < 2). The latter was expected because SO and OS target sentences were identical during this interval. We further resolved the *prime type* × *picture object* interaction by comparing the gaze duration difference between looks to the male patient and looks to the male agent across prime conditions (*Newman-Keuls Tests* by participants and items). These tests revealed a reliably stronger patient preference after SVO rather than OVS primes ($p_1 < .01$; $p_2 < .03$), a marginally stronger patient preference after Neutral rather than OVS primes ($p_1 < .03$; $p_2 < .10$), and no reliable effect (*p*s > .30) between SVO and Neutral primes, despite a numerical trend towards a smaller patient preference after Neutral primes (cf. Figure 2). Thus, on the assumption that longer gaze durations on the male patient indicate a preference for the ambiguous (female) NP1-referent to be interpreted as a subject/agent, we conclude that OVS-primes substantially reduced the expectation of a subject-first structure during the NP1 region.

**************** FIGURE 2 ABOUT HERE ****************

The analysis of gazes launched within V-ADV (these gazes ended about 77 ± 35ms [95% c.i.] before the onset of the determiner of the case-unambiguous second NP) revealed a significant main effect of *picture object* (longer looks to the male patient rather than agent, $F1(1,47) = 71.66$; $p < .001$; $F2(1,23) = 70.51$; $p < .001$, see Figure 3). This could reflect a general subject/agent-first preference in interpretation, or alternatively, a visual bias favouring the character that is being faced by the NP1-referent (cf. Scheepers et al., 2003) – note that in all of our target pictures, the female character was visually oriented towards the male patient character.

Importantly, there was also a reliable *target disambiguation* × *picture object* interaction ($F1(1,47) = 45.37$; $p < .001$; $F2(1,23) = 59.45$; $p < .001$), due to longer gazes on the male patient in the SO rather than OS target disambiguation condition ($F1(1,47) = 37.40$; $p < .001$; $F2(1,23) = 51.73$; $p < .001$) and longer gazes on the male agent in the OS rather than SO condition ($F1(1,47) = 16.72$; $p < .001$; $F2(1,23) = 18.61$; $p < .001$), see Figure 3. This suggests that verb information, in combination with the visual context, already allows for proper disambiguation of the target structure: participants are obviously able to anticipate the appropriate forthcoming argument (i.e. the object/patient in the SO condition and the subject/agent in the OS condition) before this argument and its case marking are available in the sound stream (cf. Kamide et al., 2003; Scheepers et al., 2003). Effects of prime type were not detected during the V-ADV region (*F*s < 1.5).

**************** FIGURE 3 ABOUT HERE ****************

Pupil Size

In order to be able to use changes in pupil size as an indicator of on-line processing difficulty, some potential confounds need to be controlled for. As lighting conditions were basically constant across conditions, the most important of these factors was the absolute gaze position of the eye: the eye-monitoring camera was always located at an angle slightly below and further to the outer rim of the dominant eye; hence, the video image of the pupil became systematically smaller as the dominant eye moved further upwards or towards the nose. To account for this, we performed a series of multiple regression analyses (separately for each participant) with mean X and Y gaze position as predictors and mean pupil size per gaze as the criterion, and subtracted the pupil size predicted from the relevant regression equations from the actual pupil size scores. (Recall from the data analysis section that the pupil size measure was already mapped onto a linear scale via log transformation). The calculation of this adjusted pupil size measure not only neutralised any influences of absolute gaze position, but also compensated for inter-individual differences in pupil size by subtracting the participant-specific intercept.

Figure 4a shows a continuous plot of the adjusted pupil size measure over a period of 0–5000ms after sentence onset (by time steps of 100ms), separately for SO- and OS-disambiguated target sentences. Figure 4b and Figure 4c show the difference between the two curves (positive values indicate more dilated pupils in the OS condition), and mark the time steps at which repeated-measures ANOVAs (by participants and items, respectively) revealed a significant (or marginal) main effect of *target disambiguation*. As can be seen, the OS condition was associated with a significant increase in pupil size relative to the SO condition. This can be regarded as the replication of an already well-established garden-path effect for

OS-disambiguated structures in German (e.g. Hemforth, 1993; see also Hemforth & Konieczny (Eds.), 2000). Interestingly, the effect started to emerge even before the second NP became available in the auditory input, namely, towards the end of the adverbial region (approximate word onsets are marked in the plots as well).[8] This suggests that it was triggered, at least during this early time period, by a combination of verb information plus visual context rather than case marking at the second NP (recall that in the given experimental set-up, the verb-region already provided all the information necessary to disambiguate the role of the first NP). Also, this seems consistent with the gaze duration findings reported earlier (*target disambiguation* × *picture object* interaction within the V-ADV region).

**************** FIGURE 4 ABOUT HERE ****************

Effects of *prime type* on pupil size did not approach significance at any of the considered time steps. However, a suggestion of a priming effect was found within a time period of 700-1200ms after the onset of the second NP's determiner (i.e., the time period around which pupil dilation reached its overall peak in the OS condition, see Figure 5): ANOVAs treating *time step* (five levels, corresponding to the five 100ms-bins of interest) and *target disambiguation* (SO vs. OS) as repeated measures factors revealed a reliable OS garden-path effect after SVO primes ($F1(1,47) = 5.37$; $p < .03$; $F2(1,23) = 9.17$; $p < .006$, Figure 5a), no effect of *target disambiguation* after OVS primes ($F1 < 1$; $F2 < 2$; Figure 5b), and a nearly significant OS garden-path effect after Neutral primes ($F1(1,47) = 5.36$; $p < .03$; $F2(1,23) = 4.04$; $p < .06$, Figure 5c). Thus, at least within this restricted time period, OVS primes seemed to have reduced the garden-path effect for OS-disambiguated structures relative to the other prime conditions. Effects of *time step* were not reliable within this period (Fs < 1.5).

**************** FIGURE 5 ABOUT HERE ****************

GENERAL DISCUSSION

The present experiment suggests that language comprehenders make rapid and exhaustive use of various sources of linguistic and non-linguistic information in order to resolve a temporary constituent order ambiguity associated with a case-ambiguous NP in sentence-initial position. The gaze duration findings around the sentence region containing the verb and the adverb (V-ADV), for example, strongly suggest that visual context information (the actually displayed actions) and the verb (referring to one of those actions) enable the prediction of the appropriate forthcoming argument referent, which, in turn, suggests that the role of the case-ambiguous first NP (as either subject or object) is likely to have been resolved at this point (crucially, before the case-marked second NP is available; see Knöferle et al., 2003, for very similar findings).

Interestingly, the target disambiguation effect showed up not only in gaze durations on the critical unambiguous scene-characters, but also in pupil size changes towards the end of the adverbial region (again, before the case-marked second NP became available): when the verb and the visual context made it clear that the ambiguous first NP must be the object of the sentence (OS-disambiguation), pupils became reliably more dilated than when the verb and the visual context supported the subject-interpretation of the first NP (SO-disambiguation). This is consistent with a garden-path effect for OS-disambiguated structures in German, an already well-documented finding in the literature. The present study is presumably the first to have shown this effect being triggered by visual context and verb information (and crucially, in the absence of a morphological case marker).

The main findings concern the effect of previous (short-term) linguistic exposure. The present experiment was able to demonstrate that the kind of constituent ordering being processed in a prime trial (where participants had to read unambiguous sentences) reliably affected the constituent ordering preferences in an immediately following target trial (where participants had to listen to temporarily ambiguous sentences). First, gaze durations upon hearing the case-ambiguous first NP in the target trial suggested a substantially reduced tendency to interpret this NP as the subject (or agent) of the sentence after having read an OVS rather than SVO or Neutral prime (as evidenced in reliably shorter gazes on the male patient after OVS primes), suggesting that at least very early interpretational preferences are subject to priming (recall that there were no comparable effects of prime type during the 'disambiguating' V-ADV region). Second, changes in pupil dilation revealed that processing difficulty associated with OS-disambiguated target structures tended to be reduced after having read an OVS rather than SVO or Neutral prime (at least within a time frame of about 700-1200ms after the onset of the case-marked second NP), which, albeit not being a very pronounced effect, appears to indicate that garden-path strength can be modulated through prior linguistic exposure (i.e., via some sort of priming mechanism).

A point that is worth further discussion is that relative to the Neutral prime condition only OVS primes appeared to elicit substantial priming effects. SVO primes, on the other hand, merely induced a numerical but non-significant trend in the expected direction (especially in gaze duration around NP1) when compared with Neutral primes. We interpret this as evidence for a general reduction in the magnitude of priming when the prime is consistent with a *preferred* structure. In fact, comparable observations have been made in experiments on priming in production, focusing on rather different syntactic alternations (e.g. Hartsuiker & Westenberg, 2001; Scheepers, in press): if there was a preference for a given syntactic alternative in the baseline ('neutral condition'), then the effect associated with 'preferred structure' primes was smaller than the effect associated with 'non-preferred structure' primes. There are at least two plausible reasons for this observation: either 'non-preferred structure' primes are more effective because they are more surprising (and thus *salient*) to the language processing system, or they achieve stronger priming effects because they are being processed in a more elaborate fashion (requiring more processing time) than 'preferred structure' primes. At present, it seems too early to decide between these explanatory alternatives. However, we note that priming in comprehension and production may be related at a rather general level.

CONCLUSION

Of course, a single experiment will hardly be able to give definitive answers to all the questions that we have raised in this paper. For example, are the observed priming effects truly *syntactic* in nature? One potential problem with our present study is that most of the employed priming sentences could have triggered the assumed ordering of syntactic functions (subject-before-object vs. object-before-subject) *as well as* a particular sequencing of thematic roles (agent-before-patient vs. patient-before-agent). Hence, we are currently preparing a follow-up experiment in which 'functional order priming' and 'thematic order priming' will not be confounded in this way (the verbs in the primes will systematically differ in their thematic role assignment properties from the verbs in the targets; cf. Scheepers, Hemforth & Konieczny, 2000, Bornkessel, Schlesewsky, & Friedericy, in press).

Nevertheless, the bottom line conclusion from the present findings is that on-line sentence comprehension is susceptible to some kind of constituent order priming, either in the form of maintaining syntactic function sequences over consecutive trials or in the form of maintaining thematic role orderings. Hence, the phenomenon of sentence-level priming (i.e., persistence of abstract sentence representations over consecutive trials) does not seem to be confined to language production only.

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FIGURE CAPTIONS

Figure 1 Example picture (a) with left-to-right direction of action (b) with right-to-left direction of action.

Figure 2 Mean durations (in ms, with standard errors) of gazes launched within NP1, by levels of *prime type* (SVO, OVS, Neutral) and *picture object* (male patient, male agent).

Figure 3 Mean durations (in ms, with standard errors) of gazes launched within V-ADV, by levels of *picture object* (male patient, male agent) and *target disambiguation* (SO, OS).

Figure 4 Adjusted pupil size over time (10Hz resolution): (a) plotted by levels of *target disambiguation* (SO, OS); (b) and (c) plotted as OS – SO difference scores.

Figure 5 Adjusted pupil size over time (10Hz resolution), by levels of *target disambiguation* (SO, OS): (a) after SVO primes; (b) after OVS primes; (c) after Neutral primes.

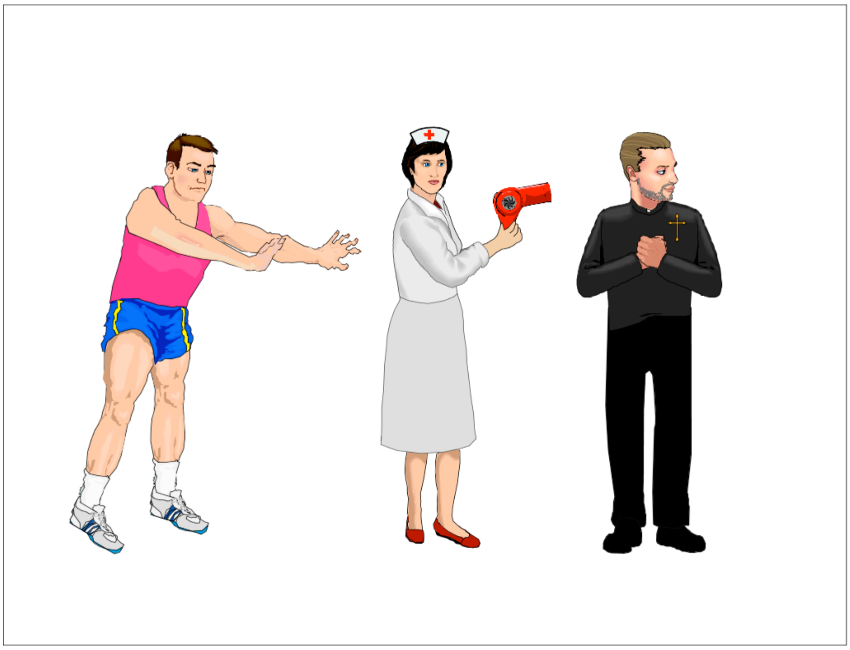

Figure 1a

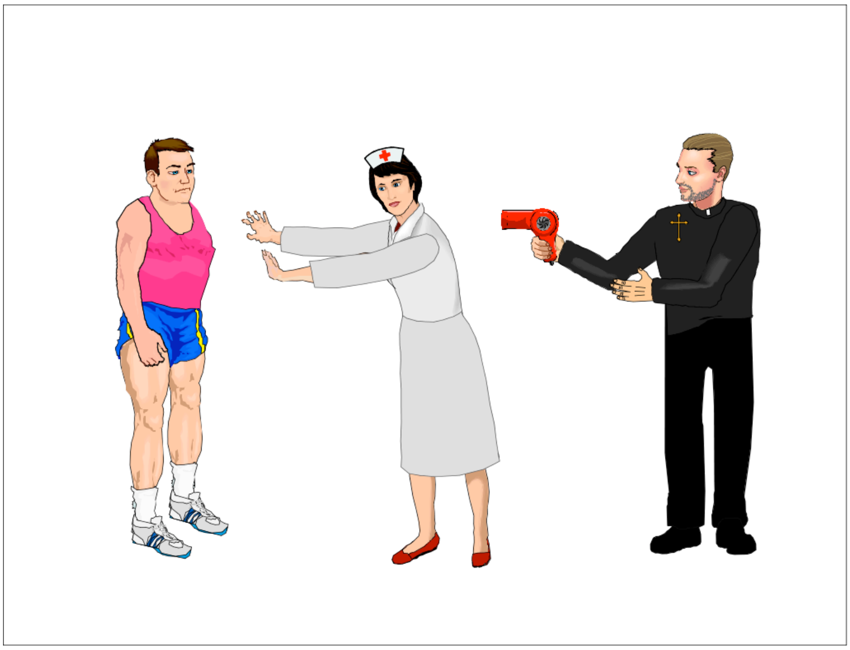

Figure 1b

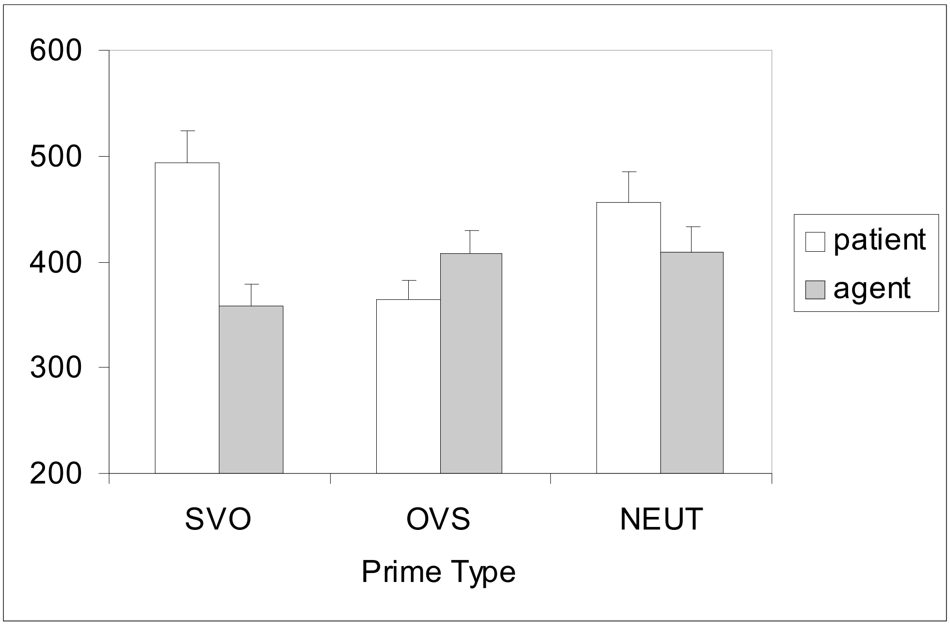

Figure 2

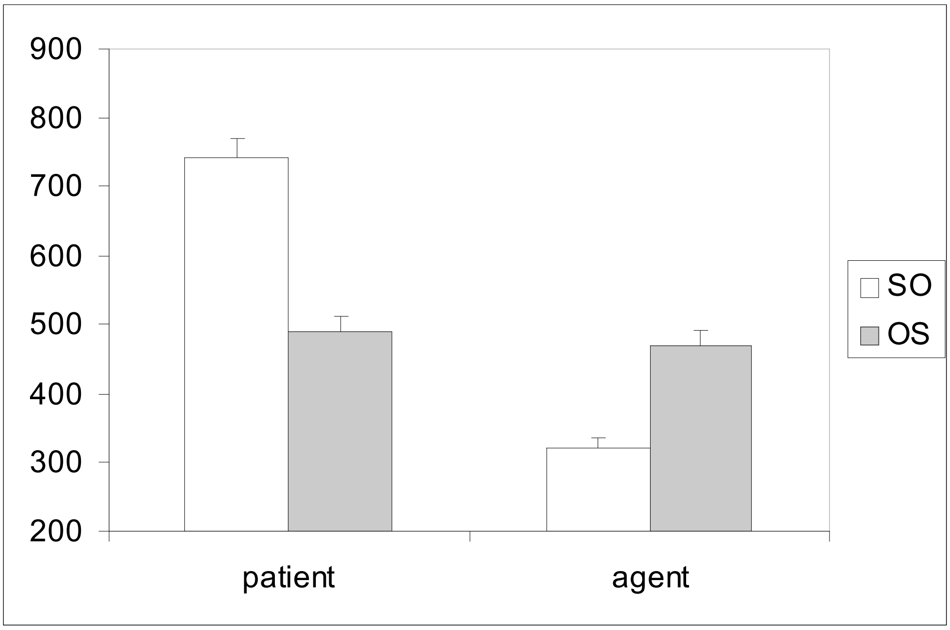

Figure 3

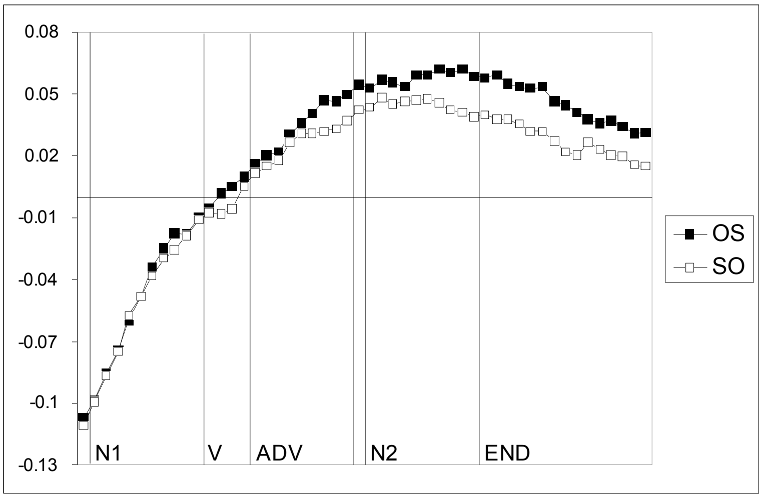

Figure 4a

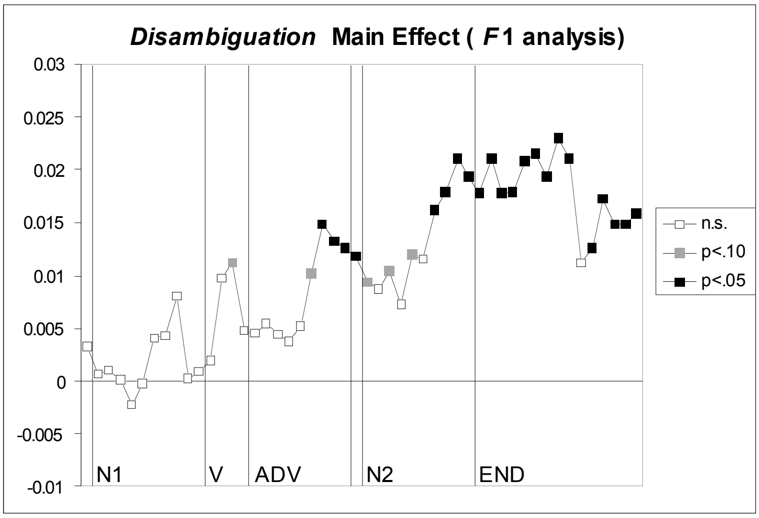

Figure 4b

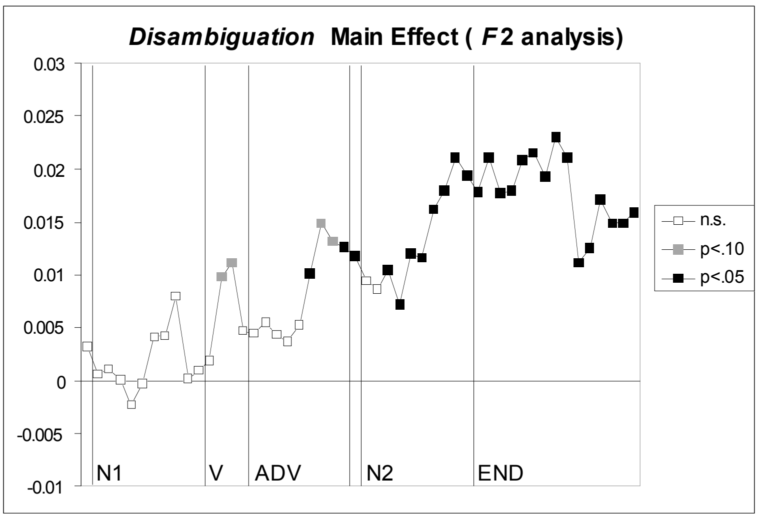

Figure 4c

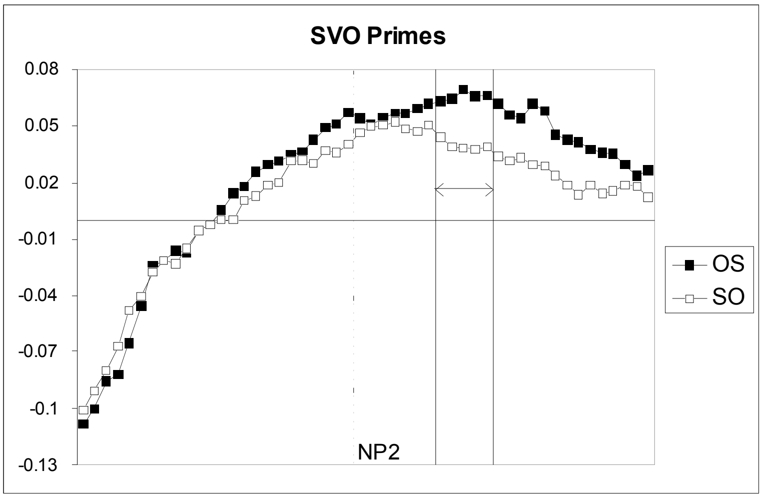

Figure 5a

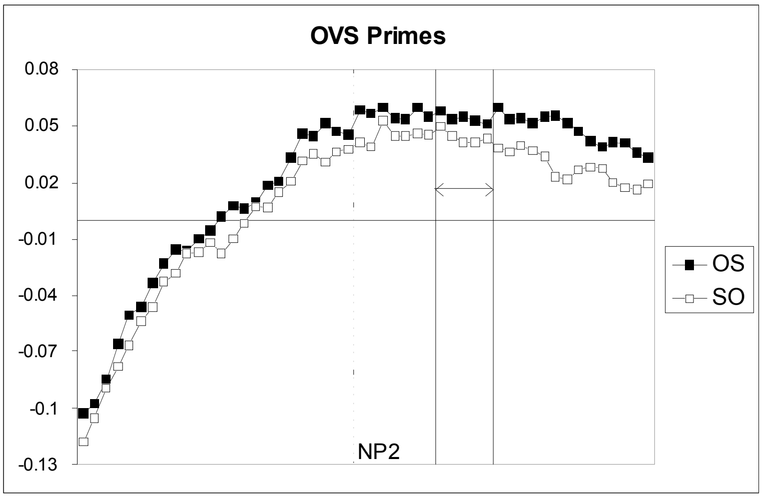

Figure 5b

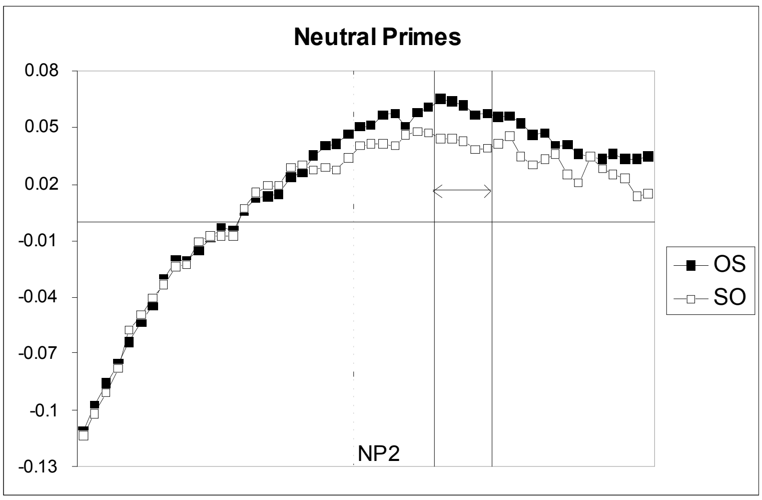

Figure 5c

FOOTNOTES

[1] For a more detailed empirical as well as theoretical motivation of the underlying rationale see Knöferle, Crocker, Scheepers, and Pickering (2003) which, in fact, forms the starting point of the present study.

[2] We are especially grateful to Pia Knöferle for permission to use her visual-world materials.

[3] The recordings were made on MiniDisk (44.1KHz, mono) in one session by a male native German speaker (CS). They were transferred to a PC via TOSLINK for further editing (see below) and re-mastered into 16KHz wave files before presentation. The latter had no audible effect on sound quality, but saved a considerable amount of disc and memory space.

[4] To avoid confusion, we will use the labels SVO, OVS, and Neutral to refer to *prime* conditions, and the labels SO and OS to refer to *target disambiguation* conditions.

[5] The log-transformation translates proportional pupil size changes into linear ones.

[6] Previous findings have shown that this measure corresponds well with gaze frequencies in a visual-world task. The main difference, if any, appeared to be that average gaze durations were more sensitive to linguistic variation and less affected by the visual salience of individual picture objects than gaze frequencies (see Scheepers et al., 2003).

[7] On average, these gazes ended about 183 ± 35ms (95% c.i.) before the onset of the verb. Effects in the relevant gaze durations are therefore unlikely to be affected by disambiguating material becoming available further downstream.

[8] To ensure that the early onset of this effect was not an artefact of the rather crude averaging procedure, we carried out an additional analysis focusing only on gazes that ended 1-400ms before the onset of the NP2-determiner (a subset of the gazes that are responsible for

the effect at the end of the adverbial region in Figure 4). These gazes revealed mean pupil size scores of 0.029 ± 0.007 (*SE*) for the SO condition and 0.049 ± 0.006 (*SE*) for the OS condition. The difference was reliable by participants and marginal by items ($t_1(47) = -2.02$; 2-tailed $p < .05$; $t_2(23) = -1.71$; 2-tailed $p < .11$), which confirms a trend towards an OS garden path effect well before information about the NP2-determiner became available.