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Inferential bridging relations reveal distinct neural mechanisms: Evidence from event-related brain potentials

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Abstract

This study investigates the online comprehension of Determiner Phrases (DPs) as a function of the given-new distinction in two-sentence texts in German and further focuses on DPs whose interpretation depends on inferential information (so-called 'bridging relations'). Previous reaction time studies report an advantage of given over new information. In the present study, this difference is reflected in distinct neural mechanisms: event-related potentials reveal that previously introduced (i.e., *given*) *DPs* elicit a reduced N400, while *new DPs* show an enhanced N400 followed by a P600. Crucially, *inferentially bridged DPs*, which are hypothesized to share properties with new and given information, first pattern with given DPs (showing an attenuated N400) and then with new DPs (showing an enhanced P600). The data demonstrate that salience relations between DPs and prior context ease DP integration and that additional cost arises from the establishment of independent reference. They further reveal that processing cost associated with the interpretation of bridged DPs results from the anaphoric complexity of introducing an independent referent.

Keywords: Reference; Familiarity; Inferences; Mental model; Anaphora resolution; Anaphoric complexity; Sentence processing; Event-related potentials; N400; P600

1. Introduction

During sentence comprehension, a mental model is constructed and information about participants, objects, states, events is stored and maintained so that new incoming information can be related to previously processed information. When Determiner Phrases (DPs)—such as *a dancer*, *the farmer*—are comprehended, they enter the (comprehender's) mental model as new or given information (cf. e.g., Chafe, 1976; Clark & Haviland, 1974; Haviland & Clark, 1974; Prince, 1981, 1992). This has consequences for integration: new information introduces an independent discourse referent into the mental model, suggesting that integration and storage cost arise, while given information forms a dependency relation with previously established information which is accessible within the mental model. One cue to this given-new distinction of DPs is definiteness marking, as for instance suggested by Christophersen (1939), Hawkins (1978), and Heim (1982).[1] According to this view, a definite DP signals that the corresponding referent is familiar within the current mental model. This is certainly true for an example like (1) where *the girl* refers to a familiar entity, which was introduced in the initial sentence of the brief paragraph (*a girl*), and enters into an identity relationship with this particular referent. In contrast in (2), *the groom* fails to have a previously introduced discourse

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[1] The characterization of definiteness remains a controversial issue in the theoretical literature and notions of familiarity, uniqueness, inclusiveness, identifiability, among others have been advocated to formalize the functional basis of definiteness marking (see Abbott, 2004 for an overview). However, a discussion is beyond the scope of the present paper, and I follow the familiarity approach herein. Nevertheless, the findings presented in this paper illustrate that bridged definite DPs carry properties of familiar *and* novel entities, weakening a strict correspondence between definiteness and familiarity.

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referent in the mental model, but integration is easily resolved through activation of inferential knowledge (e.g., a groom is a salient participant in a wedding, hence the definite DP is interpreted as *the groom at the wedding Natalie went to*), which results in the establishment of a linkage between *groom* and *wedding* that licenses the introduction of a new discourse entity for *groom*.

(1) Sean met a girl yesterday. **The girl** talked about a recent trip to Boston.
(2) Natalie went to a wedding in Italy. **The groom** looked nervous and jumpy.

Inferences as required for the comprehension of *the groom* in (2) are made when information that is not explicitly stated is recruited to support interpretation and when situational or world knowledge is activated to establish a connection between units of information. Inference drawing is particularly essential for reasons of conversational coherence and general well-formedness conditions that control the comprehension process and state that efficient language use is guided by the notion that qualitatively and quantitatively sufficient information is provided (cf. e.g., Grice, 1975). One particular type of inferences are the so-called *bridging inferences* (see also 'associative' DPs)—as required in (2)—that license critical dependency relations to establish a coherent interpretation (cf. Clark, 1975; Heim, 1982; Lewis, 1979). Inferential bridging relations require a certain level of relatedness between a newly introduced entity and an entity already present in the mental representation, such as part-whole relations (e.g., *room—ceiling*), causal relations (e.g., *accident—fracture*), or salient roles (e.g., *wedding—groom*). Nevertheless, in contrast to dependency relations that support identity interpretation—as described for *the girl* in (1)—bridged entities, in addition to forming a linkage with given information, also represent discourse-new information and are predicted to require the establishment of an independent discourse referent in the mental model. In the present study, I therefore investigate the neural mechanisms underlying the interpretation of bridging relations in order to test the hypothesis that bridged DPs share properties with both given and new discourse referents.

The framework adopted herein proposes a mental model theory that distinguishes between dependent and independent discourse entities, expanding on the Syntax-Discourse Model initially formulated for pronominal-antecedent relations (cf. Avrutin, 1999; Burkhardt, 2005). Dependent discourse entities are subject to a dependency relation with either a previously introduced discourse referent (yielding an *identity* relationship) or through an inferentially licensed relationship, which can be based on situational or world knowledge (yielding a *bridging* relationship). A prerequisite for these dependency relations is the existence of a salient entity in the mental model, which serves as anchor. In contrast, independent discourse entities are not subject to a dependency relation with information made available by the mental model, but form a new discourse referent (i.e., *independent reference*), which results in an increase of working memory load and storage cost. As a consequence, two functionally distinct processes relevant for the integration of DPs are proposed: dependency formation and the establishment of independent reference. The former is predicted to emerge during the interpretation of given DPs, the latter during the interpretation of new DPs. Critically, bridged DPs are hypothesized to show effects of *both of these integration processes*, because they have the potential to relate to previous information through a bridging dependency, yet also represent an independently available discourse referent. In fact, DPs that are subject to a bridging dependency must obligatorily find an anchor in the mental model for proper integration. This is related to the observation that bridged DPs generally carry a definite marker in languages that distinguish between indefinite and definite markers, and as pointed out above, the definite article signals the familiarity or identifiability of the respective entity, which in turn requires the establishment of a dependency with information available in the mental model. The present research therefore seeks to disentangle the different kind of discourse relations—i.e., identity, bridging, and independent reference—to obtain a finer-grained characterization of the processes carried out by the language processor during the interpretation of DPs. It further provides insights into the processing of anaphoric complexity, with identity relations representing the least complex anaphor resolution mechanisms.

Previous sentence comprehension studies indicate that given information is integrated more easily than new information (e.g., Haviland & Clark, 1974; Yekovich & Walker, 1978; inter alia). Furthermore, it has been shown that inferential information affects integration immediately and that the establishment of a bridging relationship, in contrast to the establishment of an identity relationship, results in processing cost (e.g., Haviland & Clark, 1974; Keefe & McDaniel, 1993). However, these studies only provide end-of-sentence measures and they cannot assess the time-course of sentence processing. In contrast, the present study addresses these issues by examining at what point during real-time sentence comprehension inferential knowledge influences the referential interpretation of DPs and what the nature of the underlying processes is. To inform these questions, analyses of event-related brain potentials (ERPs) were recorded during a reading comprehension study in German in order to capitalize on the fact that ERPs are sensitive to the time-course of processing and supply additional information about the latency, polarity and topography of the electrophysiological responses that can be linked to specific cognitive processes. The two ERP components that figure most prominently with respect to the current research question—the N400 and the P600—are introduced in the following section.

Many studies that measured ERPs have reported a negative deflection with a latency of about 400 ms (N400) for semantic implausibilities and contextual incoherence (cf.

e.g., Friederici, Pfeifer, & Hahne, 1993; Hagoort, Hald, Bastiaansen, & Petersson, 2004; Kutas & Hillyard, 1980, 1984; Kutas & Federmeier, 2000; van Berkum, Hagoort, & Brown, 1999; Van Petten & Kutas, 1991). A reduction of the N400 has been registered in response to semantic and repetition priming (cf. Kutas & Federmeier, 2000; Rugg, 1985; Weisbrod et al., 1999). These findings illustrate that the amplitude of the N400 varies as a function of the degree of plausibility and relatedness, which arise from discourse-semantic and -pragmatic as well as lexical considerations. The N400 effect has further been observed during the formation of pronominal-antecedent dependencies (cf. Burkhardt, 2005; Streb, Rösler, & Hennighausen, 1999; Streb, Hennighausen, & Rösler, 2004), and it has also been characterized as an index of inference drawing. For example, St. George, Mannes, and Hoffman (1997) report a reduced N400 for passages that required bridging inferences compared to passages that did not depend on the retrieval of inferential information. For present purposes, these findings suggest that the N400 is a relevant measure for DP integration and in particular for the establishment of dependency relations, which represents one of the processes that is postulated by the present model with respect to the interpretation of given and bridged DPs.

Furthermore, a positive deflection around 600 ms (P600) has recently been analyzed as an index for increased processing demands during integration arising from either syntactic or conceptual complexity (cf. e.g., Fiebach, Schlesewsky, & Friederici, 2002; Friederici, Hahne, & Saddy, 2002; Kaan, Harris, Gibson, & Holcomb, 2000; Kaan & Swaab, 2003; Phillips, Kazanina, & Abada, 2005). For instance, Kaan et al. (2000) observed a posterior positivity to the verb in *who*-sentences, which require the integration of the *who*-phrase with the argument structure of the verb, in comparison to less complex *whether*-sentences. This indicates that the positivity is an index of integration cost, which Kaan and colleagues interpreted as syntactic integration, but could alternatively be interpreted as cost arising from anaphoric complexity, since an antecedent is anaphorically accessed in *who*-phrases. In subsequent studies, Kaan and Swaab (2003) identified two functionally distinct positivities, a frontal P600, which they attribute to processes of ambiguity resolution and/or increasing discourse demands due to an increase in the presence of additional discourse referents, and a posterior P600, which indexes syntactic repair and revision processes proper. Friederici et al. (2002) also report a frontally distributed positivity as an index of increasing sentence complexity in fronting constructions. In a more recent investigation, a posterior P600 has been registered during the interpretation of independent, discourse-new proper names in contrast to referentially dependent pronominal elements, which further supports the notion of processing cost from anaphoric complexity (Burkhardt, 2005). Overall, these findings suggest that the P600 is a marker of processing cost arising from integration operations and that the distinct topographical distributions might be revealing of functionally dissociable integration processes. For the current research question, this indicates that the P600 is a marker of integration cost, possibly associated with the establishment of new information and the resulting increase of anaphoric complexity in the mental model. This represents the second process hypothesized in the current model and is predicted to affect new and bridged DPs alike.

The N400 and the P600 therefore mark distinct processes relating to the given-new distinction, which can be characterized as dependency and independence, respectively. In the following study, these two ERP components are hence useful measures to investigate the processing of new and given discourse referents as well as to identify the specific processes involved in the interpretation of inferentially licensed entities.

2. The present experiment

The main goal of the present study was to examine the processes involved in the integration of bridging relations. It is hypothesized that DPs that require the formation of a bridging dependency share properties with new *and* given information and that this should be observable in online sentence comprehension. On the one hand, bridged DPs represent *new information* since they introduce a new discourse referent that is not presently available in the mental model, and on the other hand, they relate to *given information* through an inferentially licensed relationship with information previously introduced into the mental model. This study therefore contrasted the integration of inferentially licensed bridged DPs with that of new and given DPs. The critical experimental conditions are illustrated in Table 1.

Table 1
Sample experimental items per condition (critical DP in bold)

Condition	Example stimulus
Context A: BRIDGED DP	Tobias besuchte ein Konzert in Berlin. "*Tobias visited a concert in Berlin.*"
Context B: GIVEN DP	Tobias besuchte einen Dirigenten in Berlin. "*Tobias visited a conductor in Berlin.*"
Context C: NEW DP	Tobias unterhielt sich mit Nina. "*Tobias talked to Nina.*"
Target sentence (following Context A–C)	Er erzählte, dass **der Dirigent** sehr *he said that* ***the conductor*** *very* beeindruckend war. *impressive was* *"He said that* ***the conductor*** *was very impressive."*
Sample verification questions:	War der Dirigent laut Tobias sehr beeindruckend? "*Was the conductor, according to Tobias, very impressive?*" (expected answer: *yes*) War der Dirigent laut Tobias sehr übernächtigt? "*Was the conductor, according to Tobias, very tired out?*" (expected answer: *no*)

First, the neural mechanisms underlying the interpretation of new and given DPs were assessed, which then formed the basis to test the predictions of the hybrid interpretation pattern of bridged DPs. With findings from semantic and repetition priming (cf. Kutas & Federmeier, 2000; Rugg, 1985; Weisbrod et al., 1999; among others), a reduction of the N400-component is predicted for the anaphoric integration of given DPs. Similarly, new DPs are expected to register an enhanced N400 due to absence of a linking anchor as well as lack of coherence between the context and the target sentences (e.g., Hagoort et al., 2004; Kutas & Hillyard, 1984; van Berkum et al., 1999). Furthermore, assuming that the P600 reflects increased integration demands arising from the establishment of an independent discourse referent, this effect is predicted to emerge in response to the processing of new DPs (e.g., Burkhardt, 2005; Fiebach et al., 2002; Kaan et al., 2000; Phillips et al., 2005).

Second, the study addressed how bridged DPs pattern with respect to the interpretation of new and given DPs and whether these novel ERP data can shed light onto the source of the additional processing demands that have been reported in previous reaction time studies of inferential dependencies. Bridged DPs are first predicted to show effects of dependency—similar to given DPs—which should be reflected in the N400 component. In particular, bridged DPs are expected to show a reduction of the N400 in comparison to new DPs reflecting the inferential linkage available through the anchor (hence patterning with given DPs in terms of forming a dependency). In the direct comparison with given DPs, a further gradation of the N400 is likely to emerge revealing the force of the respective linking relations (cf. Fiebach et al., 2002; Friederici et al., 2002; Kutas & Federmeier, 2000; Weisbrod et al., 1999): bridged DPs establishing an inferential relationship should show a weaker reduction than given DPs entering into an identity relation. In sum, the N400 is predicted to be most reduced for given DPs, followed by bridged DPs, and then new DPs. One potential confound with respect to the interpretation of N400 effects is that the N400 has previously been reported for lexico-semantic and discourse-based dependencies, which are both active during the integration of given and bridged DPs. Yet, this study seeks to investigate first and foremost the hybrid nature of the interpretation of bridged DPs and in showing that bridged DPs share processes with given DPs during the dependency formation stage (i.e., they establish a linkage with information provided by the mental model), the hypothesis under investigation would be confirmed. Future research should then seek to address the question of the exact nature of the dependency formation processes during the establishment of identity and inferential bridging, respectively. In addition, bridged DPs are further hypothesized to show effects of independence—similar to new DPs—since an independent discourse representation must be introduced and maintained resulting in an increase in anaphoric complexity. This complexity is expected to surface as an enhanced P600 for bridged and new DPs.

2.1. Methods and materials

2.1.1. Participants

Twenty-four students (12 female) from the University of Leipzig participated in this experiment. Their ages ranged from 21 to 29 years ($M = 24.3$, $SD = 2.6$). All participants were right-handed (Lateralization Quotient: $M = 93.37$, $SD = 7.72$), native speakers of German, and reported normal or corrected-to-normal visual acuity. They received monetary compensation for their participation.

2.1.2. Stimuli

Forty experimental stimuli were constructed per condition. They were designed in triplets and consisted of a context and a target sentence as illustrated in Table 1. Target sentences were kept constant across triplets while context sentences manipulated the degree of salience of the critical DP (GIVEN, BRIDGED, NEW). A questionnaire study was conducted prior to stimuli creation with thirty native speakers of German to obtain association ratings for the critical DPs and their licensing DPs required for the bridging condition (e.g., *Dirigent-Konzert*—'*conductor-concert*'). Participants were asked to rate the relatedness of ninety noun pairs on a 7-point-scale and the most strongly associated pairs were selected from the questionnaire (all of which received an average rating of 6.0 and higher) for the creation of the context-target sentence pairs of the BRIDGING condition. As a consequence, the critical DPs in the BRIDGING condition represent very salient roles (in relation to the introductory context sentence) and the establishment of an inferential bridging dependency should hence take place easily. The NEW and GIVEN context sentences were subsequently constructed to precede the target sentences with the critical DP. In addition to the 120 experimental stimuli, 160 sentence pairs served as distractor items, which matched the experimental stimuli in length. Moreover, in the present ERP experiment, participants had to complete a comprehension task following each stimulus item. For this task, questions were constructed that equally probed content information from context or target sentences across items (see Table 1 for an example). To make it easier for the participants to base their answers only on the information provided by the context-target sentence pair, rather than drawing their own conclusions, verification questions included a phrase like *laut Tobias* ('according to Tobias'). Two versions of stimulus-question pairings were created that were evenly distributed across all participants.

2.1.3. Procedure

Participants sat comfortably in a sound-attenuating booth and were instructed to read the stimuli material for comprehension. Experimental stimuli were presented visually in the center of a computer screen in yellow letters against a blue background. DPs were presented phrase by phrase (for 500 ms) and all other elements word by word (for 400 ms) with an inter-stimulus interval of 100 ms each. Following the presentation of the two successive sentences of a stimulus (i.e., context and target sentence), a verification question was presented on the computer screen in its entirety and participants were asked to respond as quickly as possible by pressing the left or right mouse button on a response box. 'Yes' and 'no' responses were equally distributed across all items. Asterisks were presented at the beginning of each stimulus and prior to the verification question, and participants were asked to only blink during the presentation of the verification task and until the presentation of the asterisks for the next stimulus. Each session started with two brief practice blocks. The experimental session consisting of 280 pseudo-randomized stimuli was carried out in six blocks with short breaks between blocks.

The electroencephalogram was recorded from 26 Ag/AgCl scalp electrodes mounted in an elastic cap (*Electro-Cap International*), which conformed to the standard 10–20 system for electrode positioning (Jasper, 1958). The following positions were recorded: FPZ, FZ, CZ, PZ, FP1, FP2, F3, F4, F7, F8, FC3, FC4, FT7, FT8, C3, C4, T7, T8, CP5, CP6, P3, P4, P7, P8, O1, and O2. All scalp electrodes were referenced to the left mastoid and re-referenced offline to linked mastoids. In order to control for artifacts resulting from ocular movements, horizontal and vertical eye movements were monitored by means of two sets of bipolar electrode pairs, placed above and below the participant's left eye and at the outer cantus of each eye. Electrode impedances were kept below 5 kΩ. All channels were amplified with a *Twente Medical Systems International* amplifier with a band pass from DC to 70 Hz (3 dB cutoff) and signals were recorded continuously with a digitization rate of 250 Hz. The grand-average ERPs were filtered off-line with 8 Hz low pass for the plots only, while all statistical analyses were calculated using unfiltered data.

2.1.4. Data analysis

The analysis of the behavioral data is based on the responses to the verification task. Error percentages were averaged over false responses and timed-out responses (i.e., responses that failed to be registered 4000 ms after the verification questions were presented). Analyses of variance (ANOVAs) for error rate by condition as well as mean reaction time by condition for the correct responses were calculated.

Average ERPs were time-locked to the onset of the critical definite DP and computed per condition per participant, before grand averages were calculated over all participants. A 200 ms baseline before the critical DP was utilized during averaging. Trials that registered an incorrect or timed-out response to the verification task (9.71%) or that contained ocular, amplifier-saturation, or other artifacts (13.37%) were excluded from averaging. Data points from one participant had to be excluded in their entirety due to excessive artifacts. For the statistical analysis of the ERP data, repeated measures ANOVAs were performed with the factor CONDITION (NEW/BRIDGED/GIVEN). All statistical analyses are based on the mean amplitude value per condition in predetermined time-windows: the N400 window was determined to range from 350 to 550 ms based on the findings from Weisbrod et al. (1999), but as Fig. 1 demonstrates, this temporal window reflects two distinct patterns of electrophysiological responses and therefore, after visual inspection, statistical analyses were performed on two 100 ms-windows separately (350–450 ms and 450–550 ms). The P600 window ranged from 600 to 900 ms. The analysis was carried out in a hierarchical manner, i.e., only statistically significant interactions ($p < .05$) were resolved. To control for potential type I errors due to violations of sphericity, the data were corrected using the Huynh–Feldt procedure whenever the analysis involved factors with more than one degree of freedom in the numerator (Huynh & Feldt, 1970). Electrodes were grouped by location and entered the ANOVA as factors: the midline analysis included the factor ELECTRODE with three midline electrodes as levels (FZ/CZ/PZ). The lateral analysis included the topographical factor REGION OF INTEREST [ROI]: left anterior (F3/F7/FC3/FT7), right anterior (F4/F8/FC4/FT8), left posterior (C3/CP5/P3/P7), and right posterior (C4/CP6/P4/P8). If pairwise comparisons were justified, the probability level was adjusted using the modified Bonferroni procedure (Keppel, 1991), setting the significance level to $p < .033$. Only significant effects are reported below.

2.2. Results

2.2.1. Behavioral data

The repeated measures analysis of the reaction times to the comprehension task showed a significant effect of CONDITION ($F(2,46) = 4.06$, $p < .04$), which resulted from significantly longer reaction times for the NEW condition over both the GIVEN and the BRIDGED condition (see Table 2). The repeated measures analysis of the error rates did not reach significance ($F < 1.1$), but the mean error rates support the reaction time pattern and registered the largest number of errors in the NEW condition. Overall, the BRIDGED condition recorded the smallest error rate and the fastest response times.

2.2.2. ERP data

Grand-average ERPs are shown in Fig. 1 for DPs referring to new, bridged, and given discourse referents depending on the information provided by the context sentence. In the 350–450 ms window, the amplitude of the N400 varies as a function of the salience relation between the DP and preceding context: NEW DPs registered the most negative deflection, followed by BRIDGED DPs and GIVEN DPs. In addition, NEW DPs showed a broadly distributed negativity reaching into the 450–550 ms window, followed by a positivity between 600–900 ms, while GIVEN DPs only show an attenuation of the negative deflection and no positivity. Critically, the BRIDGED DPs pattern first with the GIVEN DPs, showing a reduced negative potential between 350–450 ms and 450–550 ms in contrast to the NEW DPs, and then with NEW DPs, evidenced by a positivity from 600 to 900 ms.

Statistical analyses for the time window spanning from 350 to 450 ms revealed a main effect of CONDITION for

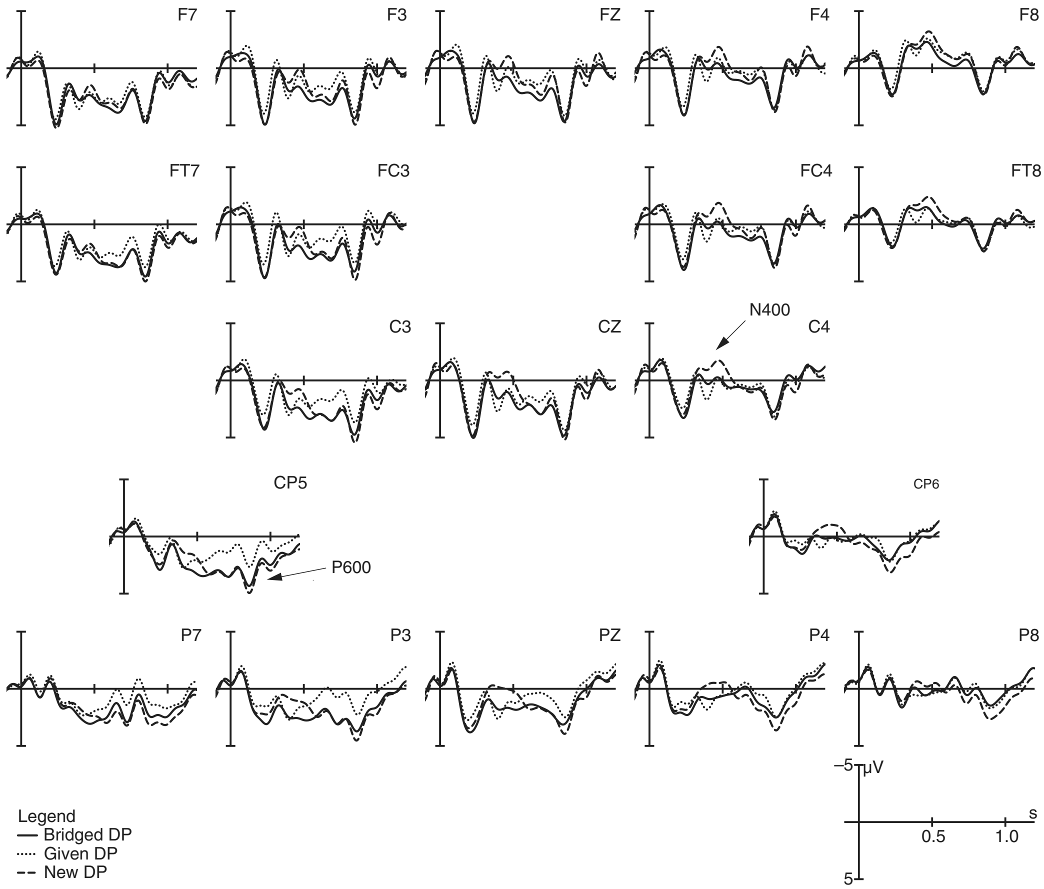

Fig. 1. Grand average ERPs ($n = 23$) recorded to the onset of the critical DP (onset at the vertical line) for given DPs (dotted line), new DPs (dashed line), and bridged DPs (solid line). Window presentation spans from 200 ms before until 1200 ms after the onset of the DP. The voltage scale ranges from −5 to 5 μV and negative voltage is plotted upwards.

Table 2
Behavioral data: mean reaction times and mean error rates to the verification task

	BRIDGED	GIVEN	NEW
Mean reaction times (SDs)	1648 ms (299 ms)	1662 ms (336 ms)	1693 ms (319 ms)
Mean error rates (%)	3.61 (9.02%)	3.83 (9.56%)	4.22 (10.54%)

midline sites ($F(2,44) = 16.49$, $p < .0001$), main effects of ROI ($F(3,66) = 24.46$, $p < .0001$), and CONDITION ($F(2,44) = 7.98$, $p < .001$) for lateral sites, as well as an interaction of ROI × CONDITION ($F(6,132) = 2.27$, $p < .05$). This interaction was resolved in main effects of CONDITION in the right anterior ($F(2,44) = 4.91$, $p < .01$), right posterior ($F(2,44) = 18.62$, $p < .0001$), and left posterior ($F(2,44) = 8.32$, $p < .001$) ROIS. Pairwise comparisons in these ROIS revealed a significant difference between NEW and GIVEN DPs (right anterior: $F(1,22) = 9.29$, $p < .005$; right posterior: $F(1,22) = 27.44$, $p < .0001$; left posterior: $F(1,22) = 10.53$, $p < .003$), and between NEW and BRIDGED DPs over right posterior ($F(1,22) = 19.04$, $p < .0002$) and left posterior sites ($F(1,22) = 14.29$, $p < .001$) (right anterior: $p < .07$). The comparison of BRIDGED and GIVEN DPs registered a significant difference only in the right posterior ROI ($F(1,22) = 7.33$, $p < .01$). These data suggest that the information provided by the context sentence, and following from this the level of salience of the different DPs, impact integration in this early time window (particularly in the right posterior region).

An ANOVA for the window between 450 and 550 ms showed a main effect of CONDITION for midline sites ($F(2,44) = 6.19$, $p < .004$), main effects of ROI ($F(3,66) = 32.67$, $p < .0001$) and CONDITION ($F(2,44) = 5.42$, $p < .007$) for lateral sites, as well as an interaction of ROI × CONDITION ($F(6,132) = 2.38$, $p < .04$). This interaction was resolved in main effects of CONDITION in all ROIS: left anterior ($F(2,44) = 4.38$, $p < .01$), right anterior ($F(2,44) = 5.02$, $p < .01$), left posterior ($F(2,44) = 5.57$, $p < .007$), and right posterior ($F(2,44) = 8.02$, $p < .001$). Pairwise comparisons in these ROIS revealed no significant differences between BRIDGED and GIVEN DPs, suggesting that these two conditions pattern alike in this time range. In contrast, a significant difference was registered between NEW and GIVEN DPs over right lateral sites (right anterior: $F(1,22) = 4.39$, $p < .04$; right posterior: $F(1,22) = 10.03$,

Table 3
Overview over main effects. *F* values per time window in pairwise comparisons (for ROIs that were statistically resolved on the basis of hierachical analysis)

Time Window	ROI	new vs. given	bridged vs. given	bridged vs. new
350–450 ms	RA	9.29**	—	—
	LP	10.53**	—	14. 29***
	RP	27.44***	7.3**	19. 04***
450–550 ms	LA	—	—	9.9**
	RA	4.39#	—	11.13**
	LP	—	—	13.01***
	RP	10.03**	—	14.12***
600–900 ms	LA	5.27*	4.86*	—
	LP	17.86***	14.46***	—

LA, left anterior; RA, right anterior; LP, left posterior; RP, right posterior.
* $p < .033$ (modified Bonferroni).
** $p < .01$.
*** $p < .001$.
\# $p < .05$.

$p < .004$), but not over the left anterior and left posterior ROIS ($F < 1.4$). For the comparison of NEW and BRIDGED DPs the following main effects of CONDITION were observed: left anterior ($F(1,22) = 9.79$, $p < .004$), right anterior ($F(1,22) = 11.13$, $p < .003$), left posterior ($F(1,22) = 13.01$, $p < .001$), right posterior ($F(1,22) = 14.12$, $p < .001$). The data demonstrate that new DPs elicit the most negative electrophysiological responses in this temporal window, suggesting that the unavailability of an anchor/antecedent results in processing cost.

An ANOVA for the P600-window (600–900 ms) yielded main effects of ROI ($F(3,66) = 12.82$, $p < .0001$) and CONDITION ($F(2,44) = 5.96$, $p < .005$), as well as an interaction of ROI × CONDITION ($F(6,132) = 3.85$, $p < .01$), which was most pronounced at left anterior ($F(2,44) = 3.67$, $p < .03$) and left posterior sites ($F(2,44) = 10.96$, $p < .0001$). Pairwise analyses in these two ROIS show significant differences between NEW and GIVEN DPs (left anterior: $F(1,22) = 5.27$, $p < .03$ and left posterior: $F(1,22) = 17.86$, $p < .0003$) and between BRIDGED and GIVEN DPs (left anterior: $F(1,22) = 4.86$, $p < .03$ and left posterior: $F(1,22) = 14.46$, $p < .001$), but critically no difference between BRIDGED and NEW DPs ($F < 1$). These effects are reflected in enhanced positivities for both the new and bridged DPs, revealing that these DPs share similar processes, which is here connected to the need to establish independent reference. The critical effects are sketched out in Table 3 for the pairwise comparisons in the three windows of interest.

3. Discussion

The purpose of this ERP experiment was to investigate first the processes underlying the integration of new and given definite DPs and second the comprehension of DPs that depend on an inferentially licensed relationship. The results show a dissociation of the mechanisms required for the comprehension of DPs. First, the degree of the salience relation between a DP and prior context impacts integration leading to the most reduced negativity for the most salient (i.e., identical) DPs, followed by bridged DPs, which form an inferential relationship with a familiar entity in the mental model, and resulting in the most pronounced negativity for unfamiliar, new DPs. This difference is most pronounced between 350 and 450 ms post DP-onset and continues in the 450–550 ms window distinguishing the two dependent entities given and bridged DPs on the one hand from new DPs on the other hand. Second, the establishment of an independent discourse referent gives rise to a positive potential between 600 and 900 ms, which groups together new and bridged DPs.

Turning first to the referential interpretation of given and new DPs, the current results reveal that previously introduced DPs elicited an attenuated negativity with an onset latency of 350 ms, while new DPs gave rise to an enhanced N400 followed by a left posterior positivity between 600 and 900 ms. These ERP findings generally converge with previous psycholinguistic studies that report an advantage of given over new information and demonstrated that additional processing resources are required during the integration of new DPs. The present data show that the interpretation of a dependent entity is resolved more easily than that of an independent discourse referent, and furthermore that distinct neural mechanisms are associated with these processes. Interestingly, bridged DPs clearly show a reduction of the N400 resembling the effect observed for dependent, given DPs, while also being distinct from given DPs in the 350–450 ms time window, in addition to a pronounced P600 similar to the effect registered for independent, new DPs. These findings reveal that the interpretation of bridged DPs patterns first with given and then with new information: on the one hand, representing a salient role with respect to a previously introduced entity, (inferential) dependency formation associated with the bridged DPs takes place relatively effortlessly (as reflected by the reduced N400); on the other hand, a new discourse entity must still be integrated into the mental model resulting in additional processing cost (evidenced by the P600). In general, these novel data reveal that processes associated with the drawing of inferences and the formation of dependency can be dissociated from the integration of independent information, and crucially that bridged DPs are subject to both of these processes.

The data thus indicate that distinct sources of information influence the integration of DPs. Around 350 ms after the onset of the critical DP information reflecting lexico-semantic and coreferential relations is available, which results in a reduced N400 for given and bridged DPs and an enhanced N400 for (unrelated) new DPs. Combined with previous evidence from the N400, the gradation of the N400 between 350 and 450 ms suggests that lexical-level relations or discourse-level dependencies are activated during the processing of given and bridged DPs, but as pointed out in the introduction, the present experiment was not explicitly designed to identify and isolate lexico-semantic from discourse-based cues and vice versa. The observed reduction of the N400 reflects facilitation effects and is taken as a general index of dependency formation, but future research will have to decide whether this process is purely lexical or conceptual or both. Most critical for the current research question is that the observed N400 effects demonstrate that both given and bridged DPs differ significantly from new DPs. The contrast between given and bridged DPs in the early time window is further revealing of the ease of the dependency in the case of identity over inferential bridging (cf. Weisbrod et al., 1999 on repetition priming). The pronounced signal observed for the new DPs in this temporal window could further be interpreted as a reflex of the unavailability of a dependency (or failure to form one). The main effects in the subsequent window ranging from 450 to 550 ms provide an indication that given and bridged DPs pattern alike in this temporal window.[2]

The integration of given DPs is completed with the formation of an identity relationship. Around 600 ms post-onset, an enhanced positivity to both types of new discourse referents (i.e., new and bridged DPs) suggests that the respective discourse units are fully integrated at this point, indicating that an independent discourse referent is identified to be stored and maintained in discourse representation. On the basis of these findings, I suggest that during the online comprehension of DPs, the P600 is an index of anaphoric integration cost due to the establishment of an independent, new discourse referent. The observed P600 effect does not merely reflect general acceptability difficulties that could be attributed to the relative incoherence of context and target sentences in the new condition. This is mainly based on the fact that the bridged DPs also elicit a P600. First, sentences with bridged DPs are judged more natural than sentences containing new definite DPs (which make the context-target sentence pair appear incoherent).[3] Moreover, it could be argued that the sentences with the bridged DPs are the most coherent, as evidenced by the fast response times and the low number of errors in the verification task. Second, the naturalness of bridged DPs is supported by corpus studies that revealed that these DPs occur frequently in natural language (e.g., Fraurud, 1990; Poesio & Vieira, 1998). This implies that unacceptability cannot be the source of the observed positivity, as it is found for both new and bridged DPs. In terms of the ERP data, the incoherence of the new condition is more likely displayed in the pronounced N400, while the acceptability and the ease of integration of the bridged condition is reflected in the attenuated N400, which confirms previous findings from recall and reaction time studies that report facilitation effects related to inferential and causal coherence (e.g., Black & Bern, 1981; McKoon & Ratcliff, 1981, 1986). Thus from a functional perspective, the common property shared by bridged and new DPs is that they make available an independent discourse referent for future referential processing, and this is neurally reflected by the positivity. In line with previous findings (Fiebach et al., 2002; Friederici et al., 2002; Kaan et al., 2000; Kaan & Swaab, 2003; Phillips et al., 2005), the P600 hence emerges as a measure of processing cost from integration. As pointed out, there is an ongoing debate in the literature over the functional dissociation of the P600. In terms of its latency, the positivity to the new and bridged condition generally supports the idea that the P600 indexes integration processes. But what kind of integration is indexed by the P600? The current data cannot address the notion that the P600 marks syntactic complexity and integration processes (Fiebach et al., 2002; Friederici et al., 2002; Phillips et al., 2005), since syntactic information is not manipulated in the present study. With respect to the topography of the P600, the claim that discourse integration effort is reflected in a frontally distributed positivity (Kaan & Swaab, 2003) is also not supported by the data. Instead, the present experiment registered a left-lateralized positivity with a posterior maximum (cf. Burkhardt, 2005; Kaan et al., 2000), suggesting that the system taps into a new type of integration related to anaphoric complexity. In this respect, the P600 findings provide new evidence for the multi-faceted nature of the P600, and the notion of integration cost is here extended to the level of discourse representation such that the P600 indexes increased computational demands arising from the establishment of an independent discourse referent and successive storage demands. Irrespective of the functional nature of the effect, the findings suggest that latency and polarity are good predictors for the P600 as a complexity measure, but that topographical information is not.

Finally, the behavioral data also support the general notion of the given-new distinction. The responses to the verification task indicate that the integration of new information is more costly than that of given information, as evidenced by a significantly higher reaction time to the new DPs. This finding is in line with previous reports (cf. e.g., Yekovich & Walker, 1978). However, the behavioral data do not reveal a significant difference between the bridged and the given DPs, which does not converge with the results discussed by Haviland and Clark (1974). Yet, this difference can be explained by the fact that the different reaction time measures were elicited using varying experimental designs and tasks. What the current offline results suggest is that coherence and plausibility considerations affect the decision required in the verification task, such that the most incoherent context-target sentence combinations (in the new DP condition) elicited significantly longer reaction times. More importantly, the ERP data, which provide online measures of sentence comprehension, support the general observation put forth by Haviland and Clark and point to increased computational demands during the comprehension of bridged DPs in

[2] The effects in the 450–550 ms window are further influenced by the onset of the positivity observed in the 600–900 ms, resulting in the absence of a significant difference between new and given DPs over left sites.

[3] Along these lines, in the case of given DPs, it would be more coherent to use a pronoun instead of a repetition of a given DP (cf. e.g., Ariel, 1990; Gordon, Grosz, & Gilliom, 1993; Grosz, Joshi, & Weinstein, 1995).

contrast to given DPs. They suggest that the anaphoric complexity ascribed to the interpretation of bridged DPs arises most robustly from the need for independent reference.

The present investigation therefore provides new evidence from online sentence comprehension in multi-sentence text for a dissociation of interpretive processes on the basis of the given-new distinction, and it supports the view that the establishment of dependency relations and that of independent reference represent electrophysiologically and functionally distinct processes. The findings demonstrate that the establishment of identity and independent reference are guided by separate neural subsystems, providing a window to language processing at the level of discourse representation. Moreover, the data illustrate that inference-based processes such as bridging occur immediately during comprehension and facilitate the integration of (bridged) DPs, suggesting that the cost observed during the integration of bridged DPs —reflected by the positivity—results most prominently from the need to establish independent reference, rather than from the formation of inference-based relations.

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