7

Decomposing Gradience: Quantitative versus Qualitative Distinctions

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7.1 Introduction

Psycho- and neurolinguistic research within the last three decades has shown that speaker judgements are subject to a great deal of variability. Thus, speakers do not judge all sentences of a given language equally acceptable that are assumed to be grammatical from a theoretical perspective. Likewise, ungrammatical sentences may also vary in acceptability in rating studies conducted with native speakers. These findings stand in stark contrast to the classical perspective that grammaticality is categorical in that a sentence is either fully grammatical or fully ungrammatical with respect to a particular grammar.

This apparent contradiction has, essentially, been approached from two different directions. On the one hand, it has been proposed that judgement variability—or gradience—results from extra-grammatical ‘performance factors’ and that it therefore has an origin distinct from linguistic ‘competence’ (Chomsky 1965). Alternatively, the gradience of linguistic intuitions has been described in terms of varying markedness of the structures in question. Rather than appealing to variation in grammaticality, this latter approach introduces and appeals to an additional grammar-internal dimension. The idea that structures can vary in acceptability for grammar-internal reasons has found expression in the use of question marks, hash marks, and the like to describe the perceived deviation from the endpoints of the grammaticality scale.

Importantly, it must be kept in mind that judgements of acceptability—whether they are binary judgements or numerical ratings—represent unidimensional assessments of what is inherently a multidimensional signal. In essence, intuitions of acceptability reflect the endpoint of a complex sequence of processes underlying sentence comprehension or production. Consequently, it is possible that two sentence structures judged to be equally unacceptable may be unacceptable for rather different reasons. Consider, for example, the following three German examples:

(7.1a) Dann hat der Lehrer dem Jungen den Brief gegeben.
then has [the teacher]NOM [the boy]DAT [the letter]ACC given
'Then the teacher gave the letter to the boy.'

(7.1b) Dann hat der Jungen dem Brief der Lehrer gegeben.
then has [the boy]DAT [the letter]ACC [the teacher]NOM given
'Then the teacher gave the letter to the boy.'

(7.1c) Dann hat der Lehrer dem Jungen gegeben den Brief.
then has [the teacher]NOM given [the boy]DAT [the letter]ACC

Example (7.1a) illustrates the canonical argument order in German: nominative > dative > accusative. In (7.1b), two argument permutations have resulted in the order dative > accusative > nominative. Argument serializations of this type are typically analysed as grammatical, but are highly marked. Example (7.1c), by contrast, is ungrammatical because of the positioning of the participle, which should be clause-final. Interestingly, structures such as (7.1b) and (7.1c) are consistently judged to be equally (un-)acceptable in rating studies of various types, including questionnaire studies (Pechmann et al. 1996) and speeded acceptability ratings (Röder et al. 2002; Fiebach et al. 2004). Thus, it is not possible to discriminate between the two sentence types by relying on linguistic intuitions alone.

Fortunately, however, other measures can effectively discriminate between the structures in (7.1). In a recent study using functional magnetic resonance imaging (fMRI) to map the brain areas involved in the processing of sentences such as (7.1), Fiebach et al. (2004) showed that the observed pattern of acceptability can be traced back to two distinct sources of neural activation (Figure 7.1). Whereas complex grammatical sentences (e.g. 7.1b) gave rise to an enhanced activation in Broca’s area (the pars opercularis of the left inferior frontal gyrus, BA 44), ungrammatical structures (e.g. 7.1c) engendered activation in the posterior deep frontal operculum. The data reported by Fiebach et al. (2004) thus provide a compelling demonstration that overt judgements of sentence acceptability (or grammaticality) may not provide an adequate means of determining the underlying differences in acceptability of various sentence structures.
7.2 The phenomenon: argument order in German

Argument order variations in German are typically classified along several dimensions. First, a permuted argument may occupy either the sentence-initial position (the *Vorfeld*) or reside in a clause-medial position (in the *Mittelfeld*).2 Secondly, the type of permuted argument (wh-phrase, pronoun, etc.) is also of crucial importance. In this way, four permutation types are distinguished: topicalization (7.2a), wh-movement (7.2b), scrambling (7.2c), and pronoun ‘movement’ (7.2d).

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1 It has been shown, for example, that the final interpretation of a sentence may vary interindividual as a function of general cognitive capacity. Thus, researchers have distinguished between fast and slow comprehenders (e.g. Mecklinger et al. 1993), good and poor comprehenders (e.g. King and Kutas 1993), high and low verbal working memory capacity as measured by the reading span test (King and Just 1991) and individual alpha frequency (Bornkess et al. 2004b). However, a discussion of these factors is beyond the scope of this chapter.

2 The *Mittelfeld* is the region of the German clause that is delimited to the left by a complementizer (subordinate clauses) or finite verb in second position (main clauses) and to the right by a clause-final participle or particle.

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(7.2) a. **Topicalization** (*Vorfeld*, -wh)

<table>
<thead>
<tr>
<th>Den Arzt</th>
<th>hat wahrscheinlich der Journalist</th>
</tr>
</thead>
<tbody>
<tr>
<td>[the doctor]_{ACC}</td>
<td>has probably [the journalist]_{NOM}</td>
</tr>
<tr>
<td>eingeladen.</td>
<td>invited</td>
</tr>
</tbody>
</table>

'The journalist most likely invited the doctor.'

b. **Wh-movement** (*Vorfeld*, +wh)

<table>
<thead>
<tr>
<th>Welchen Arzt</th>
<th>hat wahrscheinlich der Journalist</th>
</tr>
</thead>
<tbody>
<tr>
<td>[which doctor]_{ACC}</td>
<td>has probably [the journalist]_{NOM}</td>
</tr>
<tr>
<td>eingeladen?</td>
<td>invited</td>
</tr>
</tbody>
</table>

'Which doctor did the journalist most likely invite?'

c. **Scrambling** (*Mittelfeld*, non-pronominal)

<table>
<thead>
<tr>
<th>Wahrscheinlich hat den Arzt der Journalist</th>
</tr>
</thead>
<tbody>
<tr>
<td>probably has [the doctor]<em>{ACC} [the journalist]</em>{NOM}</td>
</tr>
<tr>
<td>eingeladen.</td>
</tr>
</tbody>
</table>

'The journalist most likely invited the doctor.'

d. **Pronoun ‘movement’** (*Mittelfeld*, pronominal)

<table>
<thead>
<tr>
<th>Wahrscheinlich hat ihn der Journalist eingeladen.</th>
</tr>
</thead>
<tbody>
<tr>
<td>probably has [him]<em>{ACC} [the journalist]</em>{NOM}</td>
</tr>
<tr>
<td>invited</td>
</tr>
</tbody>
</table>

'The journalist most likely invited him.'

In addition to these four theoretically motivated permutation types, psycholinguistic studies implicate an additional dimension, namely whether the permuted argument is unambiguously case marked (e.g. *den Arzt*, '[the (male) doctor]_{NOM}') or case ambiguous (e.g. *die Ärztin*, '[the (female) doctor]_{NOM/ACC}'). From a comprehension perspective, the difference between unambiguous and ambiguous case marking lies in the fact that the former immediately signals the presence of an argument order variation, while the latter does not. Empirical evidence indicates that, when faced with an ambiguity, German speakers initially pursue a strategy in which the first ambiguous argument is analysed as the subject of the clause (e.g. Frazier and d’Arcais 1989; de Vincenzi 1991; Bader and Meng 1999). Only when information contradicting this analysis is encountered is a *reanalysis* of the clause initiated. In this way, the processes leading to the recognition of an argument order variation differ qualitatively in unambiguous and ambiguous situations.

The various types of argument order variations in German have been subject to a number of empirical investigations using different types of acceptability measurements. From these findings, the four central generalizations in (7.3) emerge.
Generalizations with regard to the acceptability of argument order variations in German

(i) object-initial sentences are generally less acceptable than their subject-initial counterparts (Krems 1984; Hemforth 1993);
(ii) acceptability decreases with an increasing number of permutations (Pechmann et al. 1996; Röder et al. 2000);
(iii) the acceptability of object-initial sentences decreases when the permuted object is case ambiguous (Meng and Bader 2000a);
(iv) the acceptability difference between object- and subject-initial structures varies according to the following hierarchy: scrambling > topicalization > wh-movement > pronoun movement (Bader and Meng 1999).

The four generalizations summarized in (7.3) interact to produce the overt acceptability pattern seen in German argument-order variations, giving what appear to be a highly gradient set of linguistic intuitions. To cite just one example, Meng and Bader (2000b) report a 49 percent acceptability rate for the scrambling of ambiguous accusative objects. As participants were asked to provide yes–no judgements, this amounts to chance-level performance.3

However, the generalizations in (7.3) emerged almost exclusively from studies on the permutation of accusative objects in transitive sentences. By contrast, when the relative ordering between dative- and nominative-marked arguments is examined, at least two interesting exceptions to this general pattern become apparent. First, the severe drop in acceptability for scrambled (transitive) objects is attenuated when the object bears dative case marking: Schlesewsky and Bornkessel (2003) report an 86 percent acceptability rate for initially ambiguous dative-initial structures similar to those engendering a 49 percent acceptability rate for accusative-initial structures in the Meng and Bader (2000b) study. Secondly, in sentences with dative object-experiencer verbs—which project an argument hierarchy in which the dative-marked experiencer outranks the nominative-marked stimulus—the acceptability decrease for object-initial orders is neutralized or even tendentiously reversed (Schlesewsky and Bornkessel 2003; see Table 7.1).

Dramatic differences of this sort call for an explanation. We believe that an adequate explanation requires, as a first step, an accurate, fine-grained characterization of the output signal that constitutes an acceptability judgement.

Thus, we must examine how the judgement 'emerges' from the on-line comprehension process.

7.3 Sources of gradience

A natural first step in tracing the emergence of a linguistic judgement lies in the examination of the comprehension system's initial response to the variation under consideration, that is, for present purposes, to the argument order permutation. How does the system react when it encounters an object before a subject and is there evidence for an immediate differentiation between the different permutation types? A methodological approach optimally suited to answering this question is the measurement of event-related brain potentials (ERPs; see Appendix 1). Because of their very high temporal resolution and their multi-dimensional characterization of neuronal activity, ERPs allow for an exquisitely precise differentiation of various cognitive processes, and, not surprisingly, many researchers have capitalized upon these properties to explore language processing.

Most of the argument order variations discussed above have been subjected to examinations using ERPs, but we restrict our discussion to order permutations in dative constructions and how these contrast with those in accusative structures. Moreover, we will focus primarily on findings for initially ambiguous structures, as these reveal the influence of processing considerations on acceptability ratings most clearly. From the perspective of a strong competence versus performance distinction, these structures might be considered a 'worst case scenario' and are as such well-suited to examining the limitations of supposedly time insensitive linguistic judgements.

The exploration of ambiguous sentences provides fruitful ground for investigating these issues. Consider, for example, the sentence fragment in (7.4):
When confronted with an input such as (7.4), the processing system initially analyses the first argument Dietmar as the subject of the clause (e.g. Henning 1995; Schriefers et al. 1995; Bader and Meng 1999; Schlesewsky et al. 2000). Accordingly, the second argument Physiotherapeutinnen—which does not contradict the initial assignment—is analysed as an object. If, however, the clause is completed by a plural verb such as beunruhigen ('to disquiet'), the supposed subject of the clause no longer agrees with the finite verb. Thus, a reanalysis towards an object-initial order must be initiated in order for a correct interpretation to be attained. In terms of ERP measures, reanalyses are typically associated with a late (approximately 600–900 ms) positivity with a posterior distribution (P600; e.g. Osterhout and Holcomb 1992). Indeed, this component has also been observed for the reanalysis of argument order in German, for example in wh-questions (beim Graben et al. 2000), topicalizations (Frisch et al. 2002) and scrambled constructions (Friederici and Mecklinger 1996). Note, however, that all of these studies only manipulated the word order of accusative structures.

However, a qualitative difference emerges when the reanalysis towards a dative-initial order is examined and compared to the reanalysis towards an accusative-initial order in an otherwise identical sentence (i.e. completing sentence fragments as in (7.4) with either an accusative or a dative verb, e.g. besuchen ('to visit') versus danken ('to thank')). While the reanalysis in

![Figure 7.2](image-url)

Figure 7.2. Grand average ERPs for object- and subject-initial structures at the position of the disambiguating clause-final verb (onset at the vertical bar) for sentences with accusative (A) and dative verbs (B). Negativity is plotted upwards. The data are from Bornkessel et al. (2004a).
structures is measurable in ERPs even with dative object-experiencer verbs, while the difference between the two word orders is no longer visible in the acceptability rates. In order to precisely predict the relationship between the two types of measures we must fully understand how an overt judgement 'emerges' from the comprehension process. This requires tracing the development of the judgement from the point at which the problem is detected to later points when the system has settled on a final assessment of the acceptability of the structure.

The speed-accuracy trade-off procedure (SAT; see Appendix 2) is one experimental method that allows for an examination of how a linguistic judgement develops over time. This method traces the emergence of an acceptability judgement from its beginnings (i.e. from the point at which the judgement departs from chance-level) up to a terminal point (i.e. a point at which the judgement no longer changes even with functionally unlimited processing time). Under the assumption that ERPs characterize the processing conflict and its resolution, while time-insensitive linguistic judgements reflect the endpoint of a multidimensional set of processing mechanisms, SAT procedures provide a bridge between the two measures.

Let us first consider the SAT results for reanalysis towards a dative-initial order in sentences with dative active and dative object-experiencer verbs. The SAT functions for the four critical conditions are shown in Figure 7.4 (Bornkessel et al. 2004a).

The SAT data shown in Figure 7.4 were best fit with an exponential approach to a limit function (Eq. 1), that assigned a distinct asymptote ($\lambda$)

As Figure 7.3 shows, reanalyses initiated by a dative object-experiencer verb also engender an N400 component, rather than a P600. However, the N400 effect is less pronounced than for the analogous structures with dative active verbs. The difference between the two types of dative constructions is therefore quantitative rather than qualitative in nature. This suggests that reanalysis is more effortful in the case of dative active verbs, but that the same underlying processes may be assumed to take place with both verb classes.

To a large extent, the ERP patterns mirror the acceptability judgements described above. On the one hand, there is a general difference between dative- and accusative-initial sentences: the former are not only more acceptable than the latter, they also engage qualitatively different processing mechanisms in reanalysis. Secondly, there is also a difference within the dative verbs themselves such that reanalysis towards a dative-initial order is less costly when it is triggered by an object-experiencer rather than an active verb. Nonetheless, reanalyses with both dative verb types appear to proceed in a qualitatively similar manner.

However, despite this strong convergence of measures, it is unrealistic to expect a one-to-one mapping between the ERP data and the acceptability ratings. Indeed, not all the differences found in ERP measures are expressed in overt judgements. For example, the disadvantage for the object-initial
to each of the four conditions and distinct intercepts (\(\delta\)) to the subject-initial and object-initial conditions, respectively.

(Eq. 1) \(d'(t) = \lambda (1-e^{-\beta(t-\delta)})\) for \(t > \delta\), otherwise 0

The intercept difference between subject-initial and object-initial structures, with a longer intercept for object-initial structures, indicates that the final analysis of the object-initial sentences takes longer to compute than the final analysis of their subject-initial counterparts. This is the characteristic pattern predicted for a reanalysis operation: as reanalysis requires additional computational operations, the correct analysis of a structure requiring reanalysis should be reached more slowly than the correct analysis of an analogous structure not requiring reanalysis. The dynamics (intercept) difference occurs in exactly the same conditions as the N400 effect in the ERP experiment.

The asymptotic differences appear to result from two sources. First, the object-initial structures are generally associated with lower asymptotes than the subject-initial controls. This difference likely reflects a decrease in acceptability resulting from the reanalysis operation required to interpret the object-initial sentences. A principled explanation for this pattern, one that is consistent with the concomitant dynamics differences, is that, on a certain proportion of trials, the processing system fails to recover from the initial miscalculation, thus engendering lower asymptotic performance for an initially ambiguous object-initial structure as compared to a subject-initial structure. More interesting, perhaps, are the differences in asymptote between the two object-initial conditions: here, the sentences with object-experiencer verbs were associated with a reliably higher asymptote than those with active verbs. This difference may directly reflect the differences in the accessibility of the object-initial structure required for a successful reanalysis. Whereas the active verbs provide no specific lexical information in favour of such a structure, the object-experiencer verbs are lexically associated with an argument hierarchy calling for precisely this type of ordering. Thus, while a garden path results for both verb types, the object-experiencer verbs provide a lexical cue that aids the conflict resolution. Again, the correspondence to the ERP data is clear: the higher asymptote for the object-initial structures with object-experiencer verbs—which we have interpreted as arising from the higher accessibility of the object-initial structure in these cases—corresponds to the reduced N400 for this condition, which also reflects a reduction of the reanalysis cost.

Two conclusions concerning acceptability patterns follow from this analysis. First, despite the presence of an almost identical processing conflict in both cases, dative-initial structures with object-experiencer verbs are more acceptable than those with active verbs because only the former are lexically associated with an object-initial word order. Second, however, even the presence of an object-experiencer verb can never fully compensate the cost of reanalysis, as evidenced by the fact that an initially ambiguous dative-initial structure never outstrips its nominative-initial counterpart in terms of acceptability. From a surface perspective, therefore, the observed acceptability patterns are the result of a complex interaction between different factors. The observed gradience does not result from uncertainty in the judgements, but rather from interactions between the different operations that lead to the final intuition concerning acceptability.

Having traced the emergence of the acceptability judgements for the two types of dative structures, a natural next step appears to be to apply the same logic to the difference between accusative and dative structures and to thus examine whether similar types of parallels between the on-line and off-line findings are evident in these cases.

Recall that, while the reanalysis of a dative structure generally engenders an N400 effect in ERP terms, reanalysis towards an accusative-initial order has been shown to reliably elicit a P600 effect. In addition, the surface acceptability is much lower for the accusative than for the dative-initial structures. How might these findings be related? Essentially, the different ERP patterns suggest that the two types of reanalysis take place not only in a qualitatively different manner, but also in different phases of processing: while the N400 is observable between approximately 300 and 500 ms after the onset of a critical word, the time range of the P600 effect is between approximately 600 and 900 ms. Thus, the reanalysis of an accusative structure appears to be a later process than the reanalysis of a dative structure and, in terms of the SAT methodology, we might therefore expect to observe larger dynamics differences between subject- and object-initial accusative sentences than in the analogous contrast for dative sentences. As discussed above, dynamics differences can subsequently lead to differences in terminal (asymptotic) acceptability and the distinction between the dative and the accusative structures might therefore also—at least in part—stem from a dynamic source.

The difference between subject- and object-initial dative and accusative structures as shown in an SAT paradigm is shown in Figures 7.5.a and 7.5.b (Bornkessel et al. submitted).

As the accusative and dative sentences were presented in a between-subjects design, model fitting was carried out separately for the two sentence types. While the accusative structures were best fit by a \(\lambda - 2\beta - 2\delta\) model (adjusted \(R^2 = .994\)), the best fit for the dative structures was \(\lambda - 1\beta - 2\delta\) (adjusted \(R^2 = .990\)). Estimates of the composite dynamics (intercept + rate) were
acceptability disadvantage for the initially ambiguous accusative-initial structures—and the corresponding asymptote differences for the accusative sentences—results to a large extent from the highly pronounced dynamics difference between these structures and the corresponding subject-initial sentences. In other words, the likelihood that the correct analysis fails to be computed is much higher in the accusative-initial sentences because the computational operations required to obtain this analysis are much more complex for this sentence type. Consequently, accusative-initial sentences are rejected as unacceptable in a higher proportion of trials, thereby yielding a lower acceptability rate/ asymptote.

Again, SAT provides a principled means of establishing the correspondence between the ERP data and the acceptability ratings. The reanalysis mechanisms that are reflected in an N400 effect—those that enable reanalysis towards a dative-initial structure—are also associated with a smaller dynamics increase than those reflected in a P600 component—those that enable reanalysis towards an accusative-initial structure. Therefore, we might speculate that the difference in the underlying neural processes, which is reflected in the different ERP components, gives rise to the concomitant differences in SAT dynamics and, thereby, to the differences in surface acceptability.

If both of the SAT studies discussed here are considered together, an interesting difference between the two becomes apparent. In the first experiment, in which only dative structures were examined in a design identical to that used to obtain the acceptability rates in Table 7.1, there were reliable asymptote differences between dative- and nominative-initial structures with dative active verbs. In the second study, there were comparable dynamics differences, but the asymptote difference—although apparent in visual inspection—failed to significantly improve the model fit. How can we account for this variation or inter-experimental gradience? Assuming that the asymptotic acceptability measured using SAT reflects the endpoint of processing and, thereby, the time-independent acceptability of a given structure, one plausible explanation appears to lie in the different experimental environments in which the structures were presented. It is well-known that sentences judgements are influenced by various factors including context, filler sentence type, etc. (Bard et al. 1996; Schütze 1996). One crucial difference between the two SAT studies is that dative object-experiencer verbs were only included in the first experiment. It may therefore be the case that the acceptability ratings for the object-initial dative active sentences arise not only from a contrast with the corresponding subject-initial sentences but also with the object-initial sentences with...
experiencer verbs. In the face of more acceptable object-initial structures, the acceptability disadvantage for the object-initial active sentences may be 'overestimated'. If true, this observation suggests that terminal acceptability may result from the interaction of a variety of different factors. Whatever the source of this discrepancy, it serves to highlight the highly variable nature of acceptability judgements, and to contrast these measures with those that more directly reflect intrinsic properties of the underlying processing mechanisms, such as the dynamics difference between object- and subject-initial structures, which may be assumed to be more stable and less subject to environmental influences.

7.4 Final remarks

In this chapter, we have attempted to show how linguistic judgements arise from different facets of language comprehension. In particular, our data suggest the following caveats concerning the interpretation of acceptability judgements:

1. One-dimensional judgements often result from the interaction of a variety of factors, and hence are inherently multi-dimensional.
2. Superficially similar judgements may stem from qualitatively different sources, which should be disentangled. Differences that may appear quantitative, for example as different 'strengths' on a single dimension may nevertheless have qualitatively different origins.
3. Acceptability decreases may be dynamic or non-dynamic in nature.

Concerning gradience in linguistic judgements, these findings indicate that a considerable amount of variation in judgements may be accounted for by carefully considering factors that interact to produce the end state that constitutes an acceptability judgement. The question thus arises whether gradience should indeed be attributed to linguistic competence, or whether it is better described as a product of the language in use, that is of processing mechanisms—which may or may not be language specific—and of general cognitive factors (e.g. working memory, see footnote 1). From our perspective, the burden of the evidence rests with the advocates of gradient grammaticality, for it appears very difficult to mount a convincing argument in favour of grammar-internal gradience on the basis of acceptability judgements alone. Thus, when all possible alternative sources of surface gradience are considered, a categorical grammar still appears to be the simplest and therefore most appealing means of accounting for the data.

7.5 Appendix 1. Event-related brain potentials (ERPs)

Event-related brain potentials (ERPs) are small changes in the spontaneous electrical activity of the brain, which occur in response to sensory or cognitive stimuli and which may be measured non-invasively by means of electrodes applied to the scalp. The high temporal resolution of ERP measures is of particular importance for the examination of language comprehension. Furthermore, ERP patterns ('components') are characterizable in terms of the following parameters: polarity (negative versus positive); topography (at which electrode sites an effect is visible); latency (the time at which the effect is visible relative to the onset of a critical stimulus); and amplitude (the 'strength' of an effect). While a number of language-related ERP components have been identified (cf., for example, Friederici 2002), we will not introduce these here for the sake of brevity. For a more detailed description of the ERP methodology and how it has been applied to psycholinguistic domains of investigation, the reader is referred to the overviews presented in Coles and Rugg (1995), Garnsey (1993), and Kutas and Van Petten (1994).

**Figure 7.6.** Schematic illustration of the ERP methodology
The ERP methodology only provides relative measures, that is an effect always results from the comparison of a critical condition with a minimally differing control condition. For example, at the position of socks in *He spread the warm bread with socks* in comparison to the position of butter in *He spread the warm bread with butter*, a negativity with a centro-parietal distribution and a maximum at 400 ms post critical word onset (N400) is observable (Kutas and Hillyard 1980). Thus, in the experiments presented here, we always compare the response to a critical condition with that to a control condition at a particular (critical) position in the sentence.

A schematic illustration of the ERP methodology is shown in Figure 7.6.

7.6 Appendix 2. Speed-accuracy trade-off (SAT)

Reading time (eye-movement tracking or self-paced) procedures are often used as a natural and unintrusive measure of processing time. However, these measures do not provide an estimate of the likelihood that readers have successfully processed a sentence and, conversely, do not provide a direct estimate of the time it takes to compute an interpretation. A reading time difference can reflect the time needed to compute a particular interpretation, but it can also reflect the likelihood that readers can compute that interpretation or how plausible readers find the resulting interpretation (McElree 1993, 2000; McElree and Griffith 1995, 1998; McElree and Nordlie 1999; McElree et al. 2003). A standard solution to this problem is to derive a full time-course function that measures how the accuracy of processing varies with processing time (Wickelgren 1977). The response-signal, speed-accuracy trade-off (SAT) procedure provides the required conjoint measures of processing speed and accuracy.

The response-signal speed-accuracy trade-off task requires subjects to make their judgement of acceptability at particular times. This serves to chart the full time-course of processing, measuring when discrimination departs from a chance level, the rate at which discrimination grows as a function of processing, and the asymptotic level of discrimination accuracy reached with (functionally) unlimited processing time. Figure 7.7 presents illustrative SAT functions derived from this procedure. The accuracy of discriminating acceptable from unacceptable sentences is measured in $d'$ units (the $z$-transform of the probability of correctly accepting an acceptable sentence minus $z$-transform of the probability of falsely accepting an unacceptable sentence). Typical SAT functions display three distinct phases: a period of chance performance ($d' = 0$), followed by a period of increasing accuracy, followed by an asymptotic period where further processing does not improve performance. In a sentence acceptability task, the SAT asymptote provides a measure of the probability (across trials and materials) that readers arrive at an interpretation sufficient to support an 'acceptable' response. If two conditions differ in asymptote, as illustrated in Panel (a), it indicates that they differ in the likelihood that a meaningful interpretation can be computed or in overall acceptability/plausibility of the respective interpretation.

The point at which accuracy departs from the chance level (the intercept of the function) and the rate at which accuracy grows over processing time are joint measures of the underlying speed of processing. If one type of structure

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**Figure 7.7.** Illustrative SAT functions
can be interpreted more quickly than another, the SAT functions will differ in rate, intercept, or some combination of the two parameters. This follows from the fact that the SAT rate and intercept are determined by the underlying finishing time distribution for the processes that are necessary to accomplish the task. The time to compute an interpretation will vary across trials and materials, yielding a distribution of finishing times. Intuitively, the SAT intercept corresponds to the minimum of the finishing time distribution, and the SAT rate is determined by the variance of the distribution. Panel (b) depicts a case where the functions differ in rate of approach to asymptote, leading to disproportional dynamics; the functions reach a given proportion of their asymptote at different times.

Dynamics (rate and/or intercept) differences are independent of potential asymptotic variation. Readers may be less likely to compute an interpretation for one structure or may find that interpretation less acceptable (e.g. less plausible) than another; however, they may not require additional time to compute that interpretation (McElree 1993, 2000; McElree et al. 2003; McElree and Nordlie 1999).

Part II
Gradience in Phonology