Time to Speak: Cognitive and Neural Prerequisites for Time in Language

Editors Peter Indefrey and Marianne Gullberg

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Peter Indefrey and Marianne Gullberg, Editors

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Foreword

The articles in this issue are the result of a conference held at the Max Planck Institute for Psycholinguistics in Nijmegen, The Netherlands, in October 2007. The conference, entitled "The Cognitive and Neural Prerequisites for Time in Language," was the second in the A. Guiora Roundtable Conference Series in the Cognitive Neuroscience of Language, jointly initiated and cosponsored by the journal *Language Learning* and by the Max Planck Institute for Psycholinguistics.

We wish to express our thanks to the former and the current Board of *Language Learning* and to the directorate of the Max Planck Institute for Psycholinguistics for their generous support to this enterprise. We also wish to thank the other members of the steering committee of the Conference series, Nick C. Ellis, John Schumann, *Language Learning*; Peter Hagoort, director of the F.C. Donders Centre for Cognitive Neuroimaging, Nijmegen; and Wolfgang Klein, director of the Max Planck Institute for Psycholinguistics. We gratefully acknowledge the help provided by Nanjo Bogdanowicz and Evelyn Giering in organizing the conference. Finally, we thank Frauke Hellwig for meticulous editorial help.

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Peter Indefrey and Marianne Gullberg

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Time in Language, Language in Time

Wolfgang Klein
Max Planck Institute for Psycholinguistics

The Linguist's Daily Bread

Many millenia ago, a number of genetic changes endowed our species with the remarkable capacity

- to construct highly complex systems of expressions—human languages;
- to copy such systems, once created, from other members of the species;
- to use them for communicative and perhaps other purposes.

This capacity is not uniform; it is actually a set of interacting capacities, which are rooted somewhere in the brain of the individual. However, each of the three processes made possible by this set of capacities also involves social interaction with other individuals. The creation of a language, its acquisition—be it as a child or as an adult—as well as its use in communication are fundamentally social in nature. We do not know how the first language came into existence. However, it is not very likely that a particularly gifted member of our species thought it out and then passed it on to his or her family and some of his or her best friends; languages grow in steady interaction among humans. The creation of, acquisition of, and communication by means of a linguistic system are processes that have a *biological* as well as a *social* side. The tradition of linguistic research from antiquity to the end of the 20th century has always been aware of these two dimensions. What it has been much less aware of is their *temporal* side. What linguists normally care for is not so much the properties of the three *processes* but the properties of the *products* that they bring forth. Linguists try to uncover the characteristics of linguistic systems

Pages 1 to 8 of this article are a somewhat expanded version of my introduction to the round table. The remainder is (with minimal changes) the brief text that was sent in advance to the participants of the round table on which this volume is based.

Correspondence concerning this article should be addressed to Wolfgang Klein, Max Planck Institute for Psycholinguistics, P.O. Box 310, 6500 AH Nijmegen, The Netherlands. Internet: wolfgang.klein@mpi.nl

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(i.e., of what the ensemble of our genetically given language capacities have brought forth in social interaction) and they try to understand the properties of the utterances (i.e., of what these systems, in turn, bring forth when put to use in a concrete situation). Thus, linguists normally deal with the lexical or grammatical features of Greek or Tagalog, and they deal with the structural and functional characteristics of a sentence or a text in these languages. Both tasks—in Saussure's terms, *la linguistique de la langue* and *la linguistique de la parole*—are closely linked to each other. In fact, the second task is most often seen as somehow subordinate to the first task: The properties of a particular utterance are often not studied in their own right but in order to find out the properties of the underlying system. This preference is clearly stated in the famous last sentence of Ferdinand de Saussure's *Cours de linguistique générale* (1917): "La linguistique a pour unique et véritable objet la langue envisagée en elle-même et pour elle-même" (The unique and true object of linguistics is language viewed in and for itself). We now know that this sentence is not by Saussure himself but was added by the editors. However, it is true that for most linguists, the "language as such" is the primary object of concrete work. They look at a structure, not at a process, and even if they study concrete utterances that are deployed in time, they are interested in their grammatical and lexical properties, not in the way in which they are produced or understood in real time. Traditional linguistics is mostly time-free.

This picture of the tradition is simplified on a number of grounds. First, from Herakleitos to Chomsky, there has always been a strong interest in what is common to all human languages—in universal grammar—and, second, parallel to this concern, in how these linguistic universals relate to other capacities of the human mind—in particular, to what is called thinking. Third, many have been and are fascinated by the question of "the origin of language." Herodotos tells the story of the Egyptian king Psammetikh who let a newborn grow up without any linguistic input in order to find out what the "original language" is (it is Phrygian). Fourth, there has always been considerable interest in the principles of efficient communication and, thus, in the social side of the language capacities. Fifth, toward the second half of the 18th century, linguists also became interested in the way in which linguistic systems change over time (i.e., in a special type of linguistic process). However, the three first issues—universal grammar, the relationship between language and thought, and the origin of language—have primarily been topics of—sometimes wild, sometimes intriguing—philosophical speculation, rather than of solid, fact-based research. The fourth issue—the role of language for efficient communication—has primarily been a challenge to teachers of rhetoric and, later, to social psychologists.

None of these concerns have been at the very heart of what language experts do in their daily work. This is different for the fifth issue—the interest in the history of languages. In fact, historical considerations have ruled the field for at least one century; but historical linguistics had its culminating point around a century ago, and it is now almost a niche within the wider field of language studies. I will come back to this in a moment.

In a nutshell, what linguists have done and still mainly do is to analyze grammatical structures and lexical meanings. They write (parts of) grammars and they compile (parts of) dictionaries. In both cases, this work may include diachronic aspects. Thus, linguists are typically concerned with questions like the following:

(1)
1. What is the position of the verb in English, compared to the verb position in Latin or Turkish?
2. What is the meaning of *to eat*, compared to the meaning of *to drink*?
3. What is the meaning of *the*, compared to the meaning of *this* or of *a*?
4. What is the meaning of *still*, compared to the meaning of *already*?
5. What is the difference among *He is running, he was running, he ran, he has run*, and *he has been running*?
6. How does the meaning of *He was still eating the soup* result from the meaning of its parts?

Questions of this type are typical, they are straightforward, and they are the kind of questions the ordinary person expects a linguist to be able to answer. One might assume, therefore, that after so much research—thousands of publications dealing with them appear year after year—linguists are able to do that. However, in actual fact, we know remarkably little about the lexical and grammatical properties of human languages. At present, there are about 6,000–8,000 languages on Earth; it is impossible to give a precise figure, first because there are no clear boundaries between languages and dialects and, second, because most of them have never been studied in any depth. If we qualify a language as well described if there are at least three grammars and three dictionaries—a very modest criterion by any standard—then maximally 3% of the world's languages are well described. About those, we surely know a lot. However, if you look at what even the best available dictionaries of English say about the meaning of familiar items such as *to drink, the*, or *still*, you may begin to wonder whether the most common words of the best studied language on Earth are well described.

The reasons for this slightly humiliating state of affairs are, on one hand, the enormous complexity of any human language and, on the other hand, certain limitations of the methods that are normally used to analyze the grammatical and lexical properties of such a language. English, for example, has at least 300,000 lexical items such as *eat, drink, the, still*, or *this*, and many of these items have a whole range of meanings (as any look in a comprehensive dictionary immediately demonstrates). Suppose that a lexicographer needs one day to describe the lexical meaning(s) of such an item. Then it would take him or her about 1,500 years of work to describe the vocabulary of English, a never-ending task. The second problem, the scarcity of analytic tools, is no less difficult to overcome. Practically all claims about the lexical and grammatical features of a human language are based on two elementary methods that are typically used in combination with each other:

- looking at specimens of actual language production, usually written or spoken (and then transcribed) sentences;
- appealing to the linguistic *intuitions* of someone who speaks the language (very often the linguist himself or herself); this appeal can have the form of a grammaticality judgment (e.g., *Can you say that in Inuktitut?*) or a question about the meaning (e.g., *What do you use this word for?*).

Take, for example, the first of the six questions mentioned above: *What is the position of the verb in English, compared to Latin or Turkish?* The usual way to answer such a question is to look at a corpus of sample sentences. An initial inspection of such a corpus shows that the position of the verb in Latin is relatively free; it can appear at the beginning, at the end, and somewhere in between. In Turkish, it is predominantly at the end, although other positions are found as well. In English, it also appears in various positions: *John closed the window. Did John close the window? Close the window, John!* Other positions are not observed; no one seems to say *John the window closed*. Both findings—the positions that are observed in the data and the positions that are not observed in the data—are not fully satisfactory to answer the question. It could be accidental that certain positions are not observed (especially if the corpus of sample sentences is small). Additionally, as to the positions that are in fact observed, they yield a somewhat inconsistent picture. It is easy to see that the various positions are not random but correlate somehow with functional differences. However, what are these differences? Here, the linguist appeals to the intuitions of someone who speaks the language. In this particular example, one might be able to correlate varying positions with varying types of speech situations in which the utterance is used and then relate the different positions to different functions.

Such an observational approach is hardly possible when it comes to lexical meaning. In theory, one might try to determine the meaning of *to eat* or *to drink* by observing all types of situations in which these words are used by someone. However, first, this is practically impossible if more than a few words are to be described: It would take 15,000 rather than 1,500 years to describe the vocabulary of English. Second, it is not very telling, because one cannot easily determine which aspect of the situation is related to that particular word. Third, it is plainly impossible for words such as *the*, *still*, or *or*. In practice, and sometimes in principle, there is so far no other way than to appeal to the intuitions of a competent speaker of the language in question; this appeal is supported by the clever use of specimens of the language when used in production. This applies to the determination of lexical meaning; it applies to the determination of syntactic or morphological properties; it applies to the way in which the meaning of compound constructions results from the meaning of its elements.

This is not nice. Is there any way, any instrument, any measurement, or any procedure that would allow us to go substantially beyond what these two methods can provide us? So far, no one has found such a method. However, there are two interconnected developments which raise hopes.

Language in Time

The first of these developments is what one might call the "discovery of the time dimension." Ever since Aristotle, linguists have been aware of the fact that human languages allow their speakers to express time—for example by the inflectional morphology of the verb ("tense") or by adverbials; we will come back to this in the next section. However, they have hardly considered the fact that language itself is crucially "in time." The average linguist used to see, and still sees, a language as a static system. However, what is so special about the *zoon logon echon* "the word-bearing animal" are certain properties of the brain (and, to a lesser extent, peripheral organs) that allow him to create such systems, to copy them from others, and to use them for various other purposes. These are processes that go on in time, and if one wants to understand the linguistic nature of humans, one must also look at these processes, and more generally speaking, one must also look at the *dynamic side* of language. This was hardly done before the end of the 18th century. In that regard, the scientific study of language was not very different from any other area of scientific study. Up to that time, the way in which things evolve over time played a very limited role in the eye of the researcher. This has changed in many disciplines; biology and geography are well-known cases. It has also changed for the study of language; in fact, this field may be the first in which this development played a crucial role. Although the study of "time-less" properties of the linguistic system is still the daily bread of the linguist, there are now at least three areas that are devoted to the study of "language in time":

- historical linguistics, which looks at the way in which the lexicon and the grammar of a system change over time;
- language acquisition, which looks at the development of language in the individual;
- language processing, which studies the actual time course of how utterances are produced and understood.

Historical linguistics is a child of the late 18th century; it grew rapidly, and within a century, it was firmly established as *the* scientific way of studying human language. In the preface to the second edition of his *Principien der Sprachgeschichte* (1886), Hermann Paul, not only a leading historical linguist but also a brillant theorist, bluntly denied that there could be any other truly scientific study of language than from a historical point of view. The reason was not that he loved the past more than the present but that without history, all we have are isolated facts. The inner connection between these facts becomes clear only when we look at history. It is the same line of reasoning that we find in the theory of biological evolution: Facts only make sense in light of development over time. In linguistics, this position did not prevail. One of the reasons is surely that we have so little evidence of earlier stages of languages. Normally, linguistic features develop slowly; but there are at most two dozen or so languages for which we have good records over more than a thousand years. So, most linguistic work nowadays is not, and simply cannot be, concerned with diachronic aspects. Historical linguistics somehow resembles a spectacular building erected within a century, on which currently much less is and can be built unless new material is discovered.

The scientific study of language acquisition and of language processing is much younger. There are—as always—admirable precursors in the 19th century (and maybe even before that); but only in the last five decades have these complex processes become a subject of intensive and systematic scientific investigation, largely under the label of "psycholinguistics." It is interesting to note that the initial incentive came primarily from psychologists, rather than from linguists, although both areas were fed by linguistic theories—in particular, by generative grammar. Currently, research in both fields is firmly established and fertile, and although it is perhaps fair to state that we are still far from fully understanding either, we know much more than one could have hoped for half a century ago.

The second important development is the advent of new methods that came with the study of language acquisition and language processing. Historical linguistics, by its very nature, is largely bound to the two classical methods mentioned in the previous section, namely looking at samples of written utterances and, albeit to a much lesser extent, appeal to intuitions. The latter may sound somewhat surprising; we have no native surviving speakers of Hittite or Tocharic B to consult. However, in fact, the linguist herself, when studying the remaining texts, to some extent becomes a speaker of these languages—with shaky intuitions perhaps, but sufficient to understand the meaning of words and constructions. Otherwise, historical linguistics would be impossible.

Thus, the study of how languages evolve over time did not augment the linguistic tool box. The study of language acquisition and of language processing did. Over the years, numerous experimental designs have been invented and successfully applied. They range from by now "classical" reaction time experiments to the most recent, and most spectacular, techniques of registering physiological processes in the human brain. In a way, the situation is reminiscent of what happened in the sciences, whose eminent progress is largely the result of new instruments and methods—the microscope, the telescope, spectral analysis, X-ray crystallography, and so forth. A great deal of what we now know about how humans produce and understand language would simply have been impossible without the new tools. The progress is perhaps a bit less obvious in language acqusition, where corpus analysis, combined with appeal to intuitions, is still the dominant way to proceed; but here too, experimental methods are steadily gaining ground.

What do these two developments in the study of human language—the turn toward temporal characteristics and the use of new methods—mean for the classical question of linguistic research: What are the grammatical and lexical properties of languages? A brief look at the development in the last few decades rapidly shows that many linguists are genuinely interested in questions of acquisition and processing. However, they only marginally relate them to their own work. I am not aware of any grammatical description or of any lexical analysis that has been substantially influenced by results from psycholinguistics. Sometimes, especially in the generative tradition, linguistic claims are tested against acquisition or processing evidence. However, I am not aware of any case in which conflicting evidence has led to a change of these claims. As a rule, psycholinguistic evidence is only mentioned when it supports the linguistic analysis, as gained by the classical methods. However, even those cases are quite rare.

The reason is not just human weakness—who wants to be refuted by evidence from some other field? It is simply that in many cases, one cannot easily tell how the "classical questions," such as exemplified in (1), can be approached by new methods. Can a reaction time experiment help us to decide what the verb position in English is? If fMRI studies show us convincingly that the lexical item *to drink* is stored in Brodmann's area 44, whereas the lexical item *to eat* is stored in Brodmann's area 45, what does this tell us about the meaning of these words? It is not the kind of information that you want to hear when you learn English. If acquisition studies demonstrate that children first learn the determiner *a* and only then the determiner *the*, whereas the demonstrative *this* comes last, what does this tell us about the syntactic and semantic properties of these little words? The answer in all of these cases is probably "not very much."

That is not encouraging. However, maybe we have not looked at these problems from the right angle, and we should not only think about how we can use new methods for old questions but rather change our way of *thinking* about these old problems. Our ideas of what linguistic systems are like are based on the two classical methods that we used to analyze them. New methods (those that include the time dimension of human language) might also be a chance to think in a new way about the properties of these systems.

In doing so, it would perhaps be wise not to begin with questions like those under (1), for which such a potential change in approaching the classical tasks seems particularly far-fetched. A better candidate might be the way in which time and temporal properties themselves are encoded in human languages. The reason is that time and its expression in language is fundamental to human cognition in general. Here, we have a natural relation between an important property of all known human languages, as conceived in the classical way, and the biological and social makeup of the human mind in general. In the next section, I will try to summarize the traditional picture of "time in language." At least for some languages, we know much about how the expression of time works. However, there are still many open questions. Can new methods, new tools, new ways to think about them help us find better answers?

Time in Language

Time is a fundamental concept of human cognition and action. It is not surprising, therefore, that all languages we know of have developed rich means to express the various facets of time: bare time spans, their position on the time line or their duration; "real" events that are actually experienced; imaginary events that could or should happen; events stored in memory, regardless of from which source; and specific temporal features of all of these types of events, such as length of duration or frequency. All of this must somehow be processed in the brain. In what follows, I will first sketch some basic ingredients of time expressions, as linguists understand them, and then raise a few questions at the crossroads of language, cognition beyond language, and brain.

Background

Roughly, there are six main devices to encode time in natural language:

A. *Tense*. Tense is an inflectional category of the verb (often in combination with an auxiliary); in its simplest understanding, it indicates a temporal relation ("earlier," "simultaneous," "later") between some event or state and some "temporal anchor," typically the moment of speech. There are many refinements, such as different types of simultaneity, or degrees of remoteness; these vary from language to language. Tense is not found in all languages, although all languages allow reference to present, past, and future.

B. (*Grammatical*) *Aspect*. Aspect is also an inflectional category of the verb (again often in combination with an auxiliary). In its simplest understanding, it indicates a particular viewpoint on the event: The speaker may "show" it as ongoing (imperfective) or as completed (perfective). As a grammatical category, it is as least as frequent as tense, with which it is often combined.

C. *"Aktionsarten"* (*Event Types, Lexical Aspect*). Events, as encoded in the verb meaning, differ by various temporal characteristics: They may involve end points or not; they express inherent changes or not; they may last for some time or be punctual; and so forth. Accordingly, we distinguish among processes, actions, events, states, and so forth. Distinctions of this sort are found in all languages.

D. *Temporal Adverbials*. This is by far the richest category of temporal expressions. Structurally, there are different types: bare adverbs such as *now, later, then, shortly,* and *often*; prepositional phrases such as *after the autopsy, over the years, at first sight, for three hours,* and so forth; or subordinate clauses, such as *when the saints are marching in, before I come to the end*, and so forth. Functionally, temporal adverbials can express the position of some event on the time line, its duration, and its frequency.

E. *Temporal Particles*. Some languages (e.g., Chinese) use special particles to express temporality. Although this is somewhat rare, most languages have a type of expression that is somehow between particles and temporal adverbs, such as *still*, *yet*, and *again*.

F. *Discourse Principles.* The construction of texts typically follows certain temporal constraints, the best known of which is the "principle of chronological order": "Unless marked otherwise, the order of mention corresponds to the order of events." Thus, a sentence such as *He fell asleep and switched the light off* sounds distinctly odd because it violates this principle.

The literature on these issues is vast and impressive. Still, there are many gaps and shortcomings. In particular, we have the following:

(a) Research is strongly biased toward certain devices: By far most studies deal with the "verb devices" (i.e., tense, aspect, and Aktionsarten). There is much less work on temporal adverbials, particles, or discourse principles.
(b) Similarly, it is strongly biased toward certain languages: most work deals with the "classical" languages, such as Greek, Latin, English, or Russian. For most of the world's languages, we have only vague ideas in this regard.
(c) It is strongly biased toward certain text types; most work deals with singular events in narratives. Other discourse types, if dealt with at all, are analyzed against this background.
(d) There is little agreement on many fundamental issues, such as the very notions tense and aspect.

The Questions

A. *How do our notions of time and our ways to express them change over the life span?*

It is obvious that children have to learn both the underlying concepts as well as the particular means to express them in their mother tongue. However, there is also some reason to assume that older people have different ways to talk about time than younger people.

B. *How culture-specific are our notions of time?*

Clearly, temporality is to some extent culture-specific. Calendric time, so important in our everyday life, is very rudimentary, or not found at all, in many cultures. The issue is therefore how "deeply" such differences are rooted in human cognition, whether they are determined or at least influenced by the structure of the language and whether they lead to different processing in the brain.

C. *How is the expression of time connected to the expression of other conceptual categories?*

Temporal expressions are often not just temporal. They may also encode, for example, evidentiality, likelihood, or causality. Thus,

- if an event is said to be have happened in the past, speakers often mark, or must mark, whether they have experienced it themselves or whether they know it from hearsay;
- if an event is placed into the future, then this statement often has a modal component: it is likely, but not certain, that it will happen;
- if event A is said to be after B, then B is often considered to be the cause of A (post hoc–propter hoc).

D. *If an event is located in time, then this can be done in relation to the speech act ("deictic"), in relation to some other event given in discourse ("anaphoric"), or in relation to some culturally important event ("calendric"). How is this difference reflected in other domains of cognition, and how is it reflected in the brain?*

The different "anchor points" come from different types of knowledge; the deictic anchor comes from perception, the anaphoric anchor comes from short-term memory in text processing, and the calendric anchor stems from overarching cultural knowledge *(the birth of Christ, the Hedjra,* etc.*)*. It cannot therefore simply be an issue of language.

F. *How do the various devices, in particular marking on the verb and temporal adverbials, interact?*

There are redundancies, as in *He departed yesterday at four*, where the past tense marking is vague and superfluous. There are incompatibilities, as in *He has departed yesterday at four*, where the time of the departure is clearly in the past, but one is not allowed to specify this time by an adverbial. Additionally, there are very complex interactions, as becomes clear from the difference between *Yesterday at four, he had departed* versus *He had departed yesterday at four.*

G. *How does temporality function in other text types, such as descriptions, instructions, film retellings, and legal texts?*

In all of these texts, we find temporal markings of all sorts. However, it often makes no sense to talk about deictic anchoring or a particular perspective on the "event."

H. *How are violations within the overall expression of time handled?*

Such violations are, for example, the combination of a future time adverbial with a past tense form, as in *Tomorrow, I came*. Under specific conditions, these combinations are tolerated, as in the famous "epic preterite" *Morgen war Weihnachten, und er hatte noch keine Geschenke* (tomorrow was Christmas, and he still had no gifts). Similarly, there are deviations from the normal temporal organization of texts, as determined by the "principle of chronological order" and related constraints. Somehow, these violations are either felt to be nonsense or they require a kind of reinterpretation. Either process must have counterparts in the way in which the brain interprets these structures.

A Concluding Remark

As a linguist who has worked a lot on the expression of time in language and on the way in which learners acquire the relevant devices in a new system, I am quite skeptical that new methods, as the ones mentioned in the section Language in Time, can help us answer these and similar questions. However, it would be arrogant to say that it is impossible, and it is surely worth trying. In the words of Pliny: *Quam multa fieri non posse, priusquam sint facta, iudicantur* (How many things were not considered impossible before they happened).

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Time in Language, Situation Models, and Mental Simulations

Rolf A. Zwaan
Erasmus University Rotterdam

The purpose of this article is to propose a view of language processing, and particularly the role of aspect therein, from a mental-simulation perspective. I argue that situation model theories can account for the flow between and interconnectedness of event representations but that mental simulation theories are needed to account for the internal structure of event representations. The article concludes with some speculative thoughts on how simulation theories might accomplish this intellectual feat.

Introduction

As with so many things, the study of the role of time in language dates back to Aristotle, who, in his *Poetics*, decreed how events should be reported in fictional versus historical narrations. Cognitive psychological research on the topic is much more recent, originating in the 1980s. Research on the role of temporal markers in language comprehension became "timely" with the advent of the notions of mental model (Johnson-Laird, 1983) and situation model (Van Dijk & Kintsch, 1983). The main thrust of these theories was that the essence of language comprehension is not to create a mental representation of the linguistic input per se, as had previously been thought, but to create a mental representation of the situation described by the linguistic input, a situation model. The building blocks of situation models are representations of individual events and actions. A central question in situation-model research became how these event representations are integrated in memory to represent the overall comprehension of a piece of discourse.

Situation Models

According to the Event-Indexing Model (e.g., Zwaan, Langston, & Graesser, 1995; Zwaan, Magliano, & Graesser, 1995; Zwaan & Radvansky, 1998; see

Correspondence concerning this article should be addressed to Rolf A. Zwaan, Department of Psychology, Erasmus University Rotterdam, Postbus 1738 3000, DR Rotterdam, The Netherlands. Internet: zwaan@fsw.eur.nl

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also Speer & Zacks, 2005; Speer, Zacks, & Reynolds, 2007), event representations formed during language comprehension are integrated into the unfolding mental representation on five dimensions: time, space, entity, causation, and intentionality. To the extent that an event shares an index with the active part of the current mental representation (e.g., the same time frame, the same spatial location, or the same goal/plan structure), it is easier to integrate and more strongly connected in the resulting long-term memory representation. Later research has shown the effects of dimensional overlap to be additive (Zwaan, Radvansky, Hilliard, & Curie, 1998; Rinck & Weber, 2004).

Zwaan (1996) provided evidence for the role of situational overlap on the temporal dimension. This study examined how readers' tracking of the passage of time, one of the five dimensions of the Event-Indexing Model, can affect online comprehension and long-term memory of text. Time shifts are common events in narratives (e.g., *Later that day* or *A few weeks later*). When they occur, the speaker or writer can use the shift to omit events that are deemed irrelevant to the plot (of course, Aristotle did not accord such poetic license to historians). For example, we usually do not need know that the main character in a novel has brushed his teeth or tied his shoes. We could not care less. In fact, when such mundane events are actually reported in a story, it is usually a clue that they will become relevant later (like Chekhov's proverbial gun). The omission of these types of events in a story can be signaled by a time shift such as *an hour later*.

Zwaan (1996) created stories that came in three versions. In the *moment* version, the temporal adverbial *a moment later* was used. The assumption was that "a moment" does not constitute a time shift of any temporal magnitude on a human scale and thus maintains the current time frame. In the *hour* and *day* versions, the critical phrases were *an hour later* and *a day later*, respectively. These adverbial phrases should engender a shift to a new time frame. Following one of these shifts, participants were asked to identify whether a probe word had appeared in the story. Probe words were selected from descriptions preceding the temporal adverbial. The findings were consistent with the previously described assumptions of the Event-Indexing Model. Responses to probe words were significantly longer in the *hour* and *day* versions than in the *moment* versions, suggesting that the time shift made the previous event less accessible. A primed-recognition task performed after all of the stories had been read showed that when events occurred within the same time frame, they showed more priming than when these same events were separated by a time shift (both in the *hour* and *day* cases). This suggests that events from the same time frame are more strongly connected in long-term memory than events from different time frames. Subsequent studies have provided more support for the Event-Indexing Model (see Zwaan & Rapp, 2006, for a recent overview).

Situation-model theories such as the Event-Indexing Model are useful in that they make predictions about the relations between and among event representations. As such, they are aimed at the macrolevel of event representation. However, they are silent about the microlevel of event representations: the internal temporal contour, or aspect, of the events in question. There have been several studies on the role of aspect in language comprehension (e.g., Carreiras, Carriedo, Alonso, & Fernandez, 1997; Ferretti, Kutas, & McRae, 2007; Madden & Zwaan, 2003; Magliano & Schleich, 2000; Zwaan, Madden, & Whitten, 2000). In the most detailed study of this kind, Ferretti and colleagues proposed that verb aspect highlights different elements of a basic event structure. Following Moens and Steedman (1988), they assumed that basic event structures consist of initiating conditions (which have agents and instruments associated with them), the actual event (which has agents, instruments, patients, and locations associated with it), and the resultant state (which has patients associated with it). Imperfective aspect (e.g., *was skating*) was thought to preferentially activate the actual event (and thus agents, instruments, patients, and locations), whereas perfective aspect (e.g., *had skated*) was hypothesized to highlight the resultant state (and thus patients). One directly testable prediction from this view is that event components associated with the actual event should be more strongly activated by the imperfective aspect than by the perfective aspect. Ferretti et al. found evidence for this and other predictions. In an eye-movement study, Altmann and Kamide (2007) obtained converging evidence. Upon hearing a perfective sentence while looking at a computer monitor displaying four objects, subjects looked at an empty glass upon hearing *He had drunk the beer* rather than at a full beer glass.

Mental Simulation

The notion of mental simulation provides a suitable theoretical framework for studying phenomena such as these. Whereas situation-model theories tend to treat events as empty nodes, simulation theories go "inside the node." An ecumenical approach would view the model-building perspective and the simulation perspective as complementary. The former provides insights into the flow between event representations and their interconnectedness in memory, whereas the latter provides insight into the internal structure of the event representations. A brief overview of mental simulation theories may help clarify this point.

Potentially important clues about the comprehension process come from a prima facie unlikely source: single-cell recordings in the brain of the macaque monkey. Rizzolatti and colleagues were measuring activity in area F5, for which hitherto no important function had been identified (Di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Gallese, Fadiga,Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Fogassi, & Gallese, 1996). They discovered that neurons in this area fired not only when the monkey performed an action but also when it observed the experimenter perform the same action (grasping food). This discovery gave rise to the idea that the firing pattern that occurred during action observation actually reflected the monkey's understanding of the experimenter's action (Rizzolatti, Fogassi, & Gallese, 2001). It was using its own motor program for performing the same action to understand what was going on. Mirror neurons can be narrowly or broadly tuned (Gallese et al., 1996). Broadly tuned mirror neurons not only respond when the observed action directly corresponds to the action for which they are coded but also when there is a looser correspondence—for example, when the observed action is performed by a conspecific (e.g., a human) or with or without a tool (Ferrari, Rozzi, & Fogassi, 2005). Thus, because of the presence of broadly tuned neurons, the mirror system can abstract away from specific features of the observed action. Because area F5 in the monkey brain is considered the homologue of Broca's area in the human left-frontal cortex, the link between the mirror system and language was readily made (Rizzolatti & Arbib, 1998). This has led to a flurry of behavioral and neuroimaging studies examining the role of the motor system in the comprehension of language-mediated actions, either of single words or entire sentences. It is important to realize, however, that the role of the motor system in language comprehension is studied from a variety of theoretical perspectives, rather than exclusively from the perspective of mirror system theory (see Fischer & Zwaan, in press; Kemmerer, 2006; and Wilson & Knoblich, 2005, for recent reviews).

Paralleling this development was a more perceptually oriented development ignited by Barsalou's (1999) theoretical proposal of concepts as multimodal mental simulations, based in part on earlier work by Damasio (1989) (see also Rubin, 2006; Zwaan, 2004). Briefly, the idea is that thinking about a concept, or exposure to a corresponding word, will reactivate prior experiences with the concepts. Traces of these experiences are stored multimodally in the brain (e.g., visual experiences in the visual areas, tactile experiences in the tactile areas, and motor experiences in the motor cortex). Higher association areas, which Damasio dubs "convergence zones," code for which brain areas were simultaneously active, such that activation of neurons in these areas will activate the primary areas, thereby reactivating the multimodal experience. At the level of behavior, this should lead to interactions between sensorimotor performance and more "cognitive" tasks, such as language processing. As with mirror system theory, Barsalou's perceptual-symbol theory has given rise to a rapidly increasing number of empirical studies yielding support for the general tenets of the theory (e.g., Dijkstra, Kaschak, & Zwaan, 2007; Estes, Verges, & Barsalou, 2008; Goldberg, Perfetti, & Schneider, 2006; Kemmerer, Gonzalez Castillo, Talavage, Patterson, & Wiley, in press; Meteyard, Baharami, & Vigliocco, 2007; Pecher, Zeelenberg, & Barsalou, 2003; Richardson, Spivey, Barsalou, & McRae, 2003; Shintel, Nusbaum, & Okrent, 2006; Stanfield & Zwaan, 2001; Zwaan, Madden, Yaxley, & Aveyard, 2004; Zwaan, Stanfield, & Yaxley, 2002). Just to mention one example, Meteyard et al. (2007) found that incidental exposure to words implying vertical motion affected low-level vision of motion. Thus, there is considerable evidence for the role of sensorimotor representations in thought and language comprehension.

Linguistic Constraints on Mental Simulation

How can a simulation view on the unfolding of event representations inform us about language comprehension and, particularly, the role of aspect therein? Fischer and Zwaan (2008) noted that although it is tempting in light of the enthusiasm generated by the mirror system theory to view the comprehension of action sentences as a kind of action observation, it is important not to overlook the differences between the direct observation of an action and the comprehension of a linguistic description of that action. They listed three differences. First, directly observing an action provides analogue online temporal information about the action's unfolding, whereas language by virtue of its discrete nature (at the semantic level) does not. For example, in reading, the speed with which a described event is processed is codetermined by a number of factors unrelated to the manner of the action (lexical access, syntactic processes, etc.).

Second, even if it would take as long to hear or read, say, *He opened the door* as it would to physically carry out and/or observe the corresponding action, this would still not imply a close temporal correspondence between action observation and language comprehension. The action does not unfold in the comprehender's mind as each word is being processed. For example, we do not know what the protagonist is opening until we encounter the noun phrase. For all we know, he or she could be opening an envelope, his eyes, or a bank account, all of which involve different motor processes than opening a door (in fact, it is not even clear what kind of motor program would be relevant to understanding a sentence about opening a bank account, but more about this later). This means, in effect, that the relevant motor program cannot be accessed until a certain "uniqueness point" in the sentence has been reached at which sufficient motor-relevant information has accrued. Empirical evidence suggests that motor resonance occurs at such loci in the sentence rather than merely at verbs (Taylor, Lev-Ari, & Zwaan, in press; Taylor & Zwaan, 2008; Zwaan & Taylor, 2006). Does this mean, then, that no motor activation occurs when the verb is processed? Not necessarily. There is empirical evidence that action verbs produce motor activation in a somatotopic fashion; that is, verbs denoting hand actions activate the hand area, verbs denoting mouth words activate the mouth area, and verbs denoting leg words activate the leg area (Hauk, Johnsrude, & Pulvermüller, 2004). It would be in keeping with connectionist models of sentence processing to assume that this presumably diffuse activation of a set of motor programs is produced by the verb and is then narrowed down to a specific program when the uniqueness point of the sentence is reached. Although plausible, this hypothetical scenario still needs to be tested empirically.

The third difference between action observation and language comprehension identified by Fischer and Zwaan (2008) is that a great deal of information can be omitted from a linguistic description that is explicit during action observation. A sentence does not have to include a description of the actor or the patient, nor of the manner in which the action is being performed. For instance, the example sentence *He opened the door* does not specify who is opening the door other than that it is a male individual. Additionally, the sentence does not specify what kind of door we are dealing with: a house door, a room door, a car door. Importantly, this may be less of a problem than might be thought at first sight, given that sentences usually do not occur in isolation but in a context. For example, prior discourse context may sufficiently constrain the mental representation such that the nature of the action is clear once the verb is encountered, in which case it actually would be the uniqueness point. The following excerpt illustrates this point.

> Crouching down beneath the Cloak, he placed the Decoy Detonator on the ground. It scuttled away at once through the legs of the witches and wizards in front of him. A few moments later, during which Harry waited with his hand upon the doorknob, there came a loud bang, and a great deal of acrid, black smoke billowed from a corner. The young witch in the front row shrieked: ink pages flew everywhere as she and her fellows jumped up, looking around for the source of the commotion. Harry turned the

doorknob, stepped into Umbridge's office and closed the door behind him. (Rowling, 2007, p. 206)

Upon reading the phrase *Harry turned*, it is immediately clear what he is turning, because they reader has previously learned that Harry had his hand on the doorknob. Thus, if we extend the notion of mental simulation beyond the sentence level—a necessary move if we want the concept of mental simulation to have any relevance to language comprehension at all—then the uniqueness point should shift backward in the target sentence to the verb compared to when the sentence is seen in isolation. Predictions like these can and should be tested empirically.

A final problem with regard to equating language comprehension with action observation is that sentences are often mute on the manner in which an action is performed. For example, the sentence *He opened the door* does not specify how the action is performed (hesitantly, resolutely, furtively?). Again, as the example from *Harry Potter* shows, manner information may be readily available in a discourse context. Given that Harry tries to enter the office unnoticed, he is likely to turn the doorknob in a furtive manner.

How Aspect Might Constrain Mental Simulation

Speakers and writers have at their disposal a set of cues, which include verb tense and aspect, to *construe* (Langacker, 1990) the event in a certain way, thus offering a specific perspective on it. The interesting puzzle for researchers is how this might influence the activation of motor resonance during comprehension. Here are some speculations on this matter.

There are various analyses of the internal temporal contours of events and the ways to construe them linguistically. One of the most recent and comprehensive ones is Steedman (in press). Steedman summarized the extant literature on aspect by distinguishing two orthogonal dimensions of events—telicity and decomposability—which produces four categories. Achievements (e.g., *He started the car*) are telic (they achieve a specific goal) but cannot be further decomposed. Accomplishments (e.g., *He walked to the post office*) are telic but can be decomposed (e.g., there is a phase that has him walking and there is a phase that has him reaching the post office). Points (e.g., *He stumbled*) are neither telic nor decomposable. Finally, activities are not telic (e.g., *He walked*) but can be decomposed. As mentioned earlier, Moens and Steedman (1988) argued that the nucleus of an event always consists of a preparatory phase (akin to an activity), an event (akin to an achievement), and a consequent (e.g., as construed by the perfective). The overall nucleus is closely related to accomplishments.

What can be said about the role of motor resonance in the understanding of each of these categories? At first sight, it would seem that motor resonance is better suited to aid in the understanding of telic events than atelic ones. After all, motor programs are executed to achieve specific goals. A second issue to consider is the timescale of the events under consideration. As mentioned earlier, it is implausible to assume a close temporal correspondence between language and observed events. Nevertheless, it would seem that motor resonance is more useful for understanding instantaneous events than for understanding events of a longer duration (e.g., from slightly longer than the time it takes to understand a sentence to much grander timescales). Thus, motor resonance would seem to be the most useful with regard to achievements. The activation of the neural substrate for a right-hand clockwise manual rotation with a precision grip would be an important component of the mental simulation performed to understand *He started the car*. One might speculate that this motor program would be followed with the auditory simulation of a starting car.

Points are also short in duration, but they are not necessarily associated with motor programs. We do not have motor programs for stumbling. Rather, stumbling occurs when our motor program for walking or running is not executed well or is interfered with by some obstacle in the environment. Of course, clowns and mimes can develop motor programs for mimicking stumbling. Likewise (far too) many soccer players have developed motor programs that mimic being tripped or tackled. However, these are by definition not examples of stumbling or tripping. Thus, it would seem that a sentence such as *He stumbled* would activate memory traces of a situation in which a motor program failed to execute properly and the proprioceptive, perceptual, somatosensory, and emotional consequences thereof. In any case, activation of a motor program proper would not be central to the comprehension of this event.

How about accomplishments? Here the account is less straightforward. Take *He painted the wall*. It would be unrealistic to assume that the comprehender would pause on the sentence for half an hour while performing a real-time mental simulation of painting a wall. What happens instead? The literature on aspect suggests that what is central here is not the action but the resultant state. Thus, the simulation may be mostly visual. There might still be a fleeting activation of right-hand movement, but the simulation would quickly be dominated by a visual simulation of the result of the action.

Activities present problems of their own. Would activation of a motor program for walking be sufficient for understanding *He was walking*? Maybe. The difficulty of analyzing decontextualized sentences is particularly evident here. Perhaps the best idea would be to consider grammatical aspect and compare *He was painting the wall* with *He painted the wall*. The former describes an activity, whereas the latter describes an achievement. Possibly the difference between the mental simulations engendered by these sentences is that motor resonance is the dominant aspect of the mental simulation in the first sentence, whereas it is the nondominant aspect of the mental simulation in the second sentence. An empirically testable prediction would be that motor resonance persists until the end of the first sentence, but it is tied to the verb in the second one.

A category of nonevents that is typically considered outside of the realm of events are states (e.g., Steedman, in press). An example would be *He is a fast typist.* How is any state mentally simulated? Zwaan and Madden (2005) proposed that in connected discourse, a state is interpreted as a brief observation. Thus, *The car was red* is taken to mean *[The protagonist noticed that] the car was red.* As such, it activates the prior experience of seeing a red car. Analogously, *He types fast* activates motor traces of typing very fast as well as perceptual traces of seeing someone else type quickly or maybe of letters quickly materializing on a computer screen. It could be argued although that this is not the whole story. The sentence does not merely convey that there was an instance at which the protagonist could be observed typing really fast. Rather, it conveys that typing fast is a trait of the protagonist—he always displays this level of dexterity when typing. This generalization is exactly how the meaning of *He types fast* differs from *He is typing fast.*

How can this difference in meaning be captured in a mental simulation? As a first step, it is important to note (again) that sentences never occur in isolation, except in linguistics articles and in psycholinguistic experiments. So let us imagine a scenario in which Tom and Dick observe a third individual, Harry, who is typing fast. If Tom expresses his amazement about Harry's typing speed by uttering *Wow, he is typing fast*, then, on some level, he would be stating the obvious. The simulation derived from the sentence would have a great deal of overlap with the observation and understanding of the perceived situation. Given this redundancy, Dick, a follower of Gricean maxims, would infer that Tom's utterance was an expression of amazement or admiration. In response, he could say, *Yeah, he types fast*. Importantly, this comment is neither redundant with the observed situation nor a meaningless echo of Tom's comment. It means that Harry does not merely type fast in the current situation but also in other situations. As such, it is not a statement about the situation per se but rather a statement about Harry. Thus, typing fast should become unbound to the here-and-now and bound to Harry. In a mental simulation, this could be achieved by way of attentional focus on Harry and his manual dexterity at the keyboard. Because of this binding (e.g., via a Hebbian learning mechanism), typing speed now becomes associated with Harry in Tom's long-term memory, such that it has a high likelihood of being retrieved whenever he thinks about Harry. Because in the case of *He is typing fast*, focus is more distributed across a situation, typing speed does not become as closely associated with Harry, although there will still be an association. With regard to what I will simplistically call the "components" of the mental simulation, it could be hypothesized that motor resonance occurs during the comprehension of both sentences, but that the perceptual simulation is more extensive when an activity is described compared to when a state is described.

A similar mechanism of unbinding might occur when iterative actions are described, such as *He is slicing an onion* versus *He is slicing onions.* Both sentences could be uttered in a situation in which someone asks "What's Harry doing?" Both sentences would give rise to motor resonance (covert activation of the motor programs for small-tool use). The differences between the simulations would again presumably be perceptual in nature. In the first case, focus would be on the action of slicing an onion. In the second case, focus would be more distributed across the situation and would include the perception of other onions, whole and sliced, lying on the counter or the cutting board. Thus, the iterative nature of the action is not represented in terms of iterative motor resonance but in terms of the attentional scope of the perceptual simulation.

States and iterations are more abstract than accomplishments and especially than achievements; they necessitate some degree of abstraction from the currently observed or described situation. It is therefore interesting to note that these analyses dovetail nicely with Barsalou and Wiemer-Hastings's simulation account of abstract concepts (Barsalou & Wiemer-Hastings, 2005). They argued that both concrete (e.g., BOTTLE) and abstract concepts (e.g., JUSTICE) are essentially representations of situations, the difference being that concrete concepts have a focal object, whereas abstract concepts do not. As a result, there is a great deal of consistency within and across individuals in how they define concrete concepts, but a great deal of variability in how they define abstract concepts. Accounts such as these still await rigorous empirical tests, but there does not appear to be any a priori reason to think that mental simulation theories are not equal to the task of accounting for the comprehension of narrated events and actions.

Conclusions

The goal of this article was to review the research on the role of time in language through the prism of contemporary theorizing about comprehension. Situation models can account for the flow of events during comprehension and their interconnectedness in memory. However, they do no account very well for the internal structure of the described events. Mental simulation theories may be able to fill this conceptual void, but they face considerable theoretical and empirical challenges. Meeting these challenges will bring us that much closer to understanding how the flow of events, captured in static language by a speaker, can be returned to its fluid state by the comprehender.

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Simulation Semantics and the Linguistics of Time. Commentary on Zwaan

Vyvyan Evans
Bangor University

Recent work addressing the phenomenon of perceptual simulation offers new and exciting avenues of investigating how to model knowledge representation (e.g., Barsalou 1999, 2003; Barsalou & Wiemer-Hastings, 2005). From the perspective of language, the simulation approach has given rise to new impetus to work on models of language understanding (e.g., Zwaan, 2004, and references therein), and provides a way of recasting recent work in the psychology of language on *situation models* (Zwaan, this volume). Carried out by Zwaan and others, I refer to this work as *simulation semantics*. Simulation semantics is concerned with modeling the mechanisms involved in language understanding. More specifically, a fundamental claim of this approach is that semantic representation in language prompts for *simulations*: a rehearsal of a previously stored perceptual experience. Zwaan refers to such sense-perceptory experiences as *motor resonances*. The development of a simulation semantics offers the potential for understanding part of the interaction between language and conceptual structure in meaning-construction.

Here, I respond to Zwaan's article in this volume, in which he provides preliminary proposals for how a simulation semantics might address the relationship between aspects of temporal representation in language, and how such are interpreted in language understanding. In particular, he focuses on the way in which a simulation semantics might account for the semantic representation of the distribution of action through time: the assortment of grammatical and lexical means of encoding what is known as aspect.

In general terms, my point is as follows. Before we can speculate on the relationship between the role of visuo-motor simulations in language understanding in the domain of time, we must first get some basic issues straight with

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Correspondence concerning this article should be addressed to Vyvyan Evans, School of Linguistics & English Language, Bangor University, Gwynedd, LL57 2DG, United Kingdom. Internet: v.evans@brighton.ac.uk

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respect to (a) language, (b) the relationship between language and temporality, and (c) the role of language in meaning-construction. My overall purpose is to highlight some constraints on the nature and extent of the applicability of a simulation semantics, as it applies to temporal representation in language and to semantic representation in language more generally. Nevertheless, my comments are meant to facilitate the simulation semantics agenda, by placing it on a firmer footing.

There are a number of prerequisites for a simulation semantics: (a) We need to understand the ways in which time is encoded in language; (b) we need to understand how language is organized, in terms of the nature of meaning types that it encodes, and how these *lexical concepts* (Evans, 2006) relate to nonlinguistic aspects of knowledge (e.g., perceptual knowledge); (c) we need to know how the process of meaning-construction takes place, as mediated by language, and, crucially, the way it interfaces with nonlinguistic (e.g., perceptual) knowledge; and (d) we need to understand the nature of temporal experience.

The Expression of Time in Language

There is a wide range of ways in which language encodes temporal representation (see Klein, this volume). A simulation semantics must be clear on the complexity involved in the temporal representation of time in language.

One way in which language encodes time relates to the range of linguistic phenomena often referred to, variously, as aspect. This is the focus in Zwaan's article. In general terms, aspect relates to the way in which action is distributed through time, as encoded by language. Nevertheless, aspect is not a homogenous category, and even an individual language (such as English, for instance) has a range of ways of encoding the distribution of action through time. By way of illustration, I identify three distinct sorts of ways in which the distribution of action through time is encoded in English.

First, there is what we might refer to as *grammatical aspect*. This is illustrated by (1a) and (b):

(1) a. He is drinking the beer [progressive]
b. He has drunk the beer [bounded]

These examples relate respectively to what is traditionally referred to as imperfective aspect (1a) and perfective aspect (1b). Imperfective aspect encodes a schematic progressive (or continuous) reading: The event in question was in progress at the time-reference indicated by the tense system. Perfective aspect encodes a schematic bounded reading: The event in question occurred (or was initiated) at an earlier point and is complete, but still relevant, at the more recent time-reference, as indicated by the tense system. Hence, the meaning of the utterance in (1a) is that the drinking of the beer is ongoing at the time of speaking; that is, progressive aspect reveals that, in terms of the time period covered by the utterance, the drinking event is unbounded. The meaning of the utterance in (1b) is that the drinking of the beer was initiated at an earlier point in time and was completed prior to or at the moment of speaking; that is, perfective aspect reveals that, in terms of the time period covered by the utterance, the drinking event is bounded (see Comrie, 1979; Langacker, 1987).

Second, in addition to grammatical aspect, aspectual meaning is also "bundled" with verbal meaning. We might refer to this phenomenon as *lexical aspect*. For example, consider (2a)–(2e), and corresponding terminology, drawn from Talmy (2000):

(2) a. (to) die [One-way nonresettable]
b. (to) fall [One-way resettable]
c. (to) flash [Full cycle]
d. (to) breathe [Multiplex]
e. (to) sleep [Steady state]

The verbs represented in (2) encode, in part, different sorts of distribution of action through time.

Third, Vendler (1957) proposed a highly influential taxonomy of the distribution of action through time. Vendler's taxonomy relates to verb phrases and, hence, might be referred to as *utterance-level aspect*. Vendler distinguished between what he referred to as *activities*, *accomplishments*, *achievements*, and *states*, as illustrated in (3a)–(3d):

(3) a. He was pushing a cart [Activity]
b. He ran a mile [Accomplishment]
c. He reached the top [Achievement]
d. I love her [State]

Whereas an activity involves an event without a specific end point, an accomplishment does feature an inherent end point. An achievement represents a punctual event, whereas a state does not involve an event at all.

Aspect is a complex and multifaceted phenomenon. A simulation semantics must be clear on which sort of aspectual phenomenon it is addressing, and which part of a given utterance is encoding the aspectual phenomenon under investigation.

How Meaning Is Organized in Language

Semantic representation in language is encoded by two systems: a *lexical system* and a *grammatical system* (Talmy, 2000; see also Evans, in press; Evans & Green, 2006). Whereas the meaning encoded by the lexical system is (perceptually) rich in nature, the meaning associated with the grammatical system is more schematic in nature. The point, for a simulation semantics, is as follows. The grammatical system is unlikely to afford access to rich, perceptual rehearsals of experience ("simulations"). This follows as the grammatical system encodes schematized parameterizations abstracted away from rich, perceptual experience. As such, a simulation semantics must carefully select the sorts of temporal linguistic phenomena for which it seeks to account. The schematic meanings associated with grammatical phenomena such as grammatical aspect are unlikely to be tractable (in their own right) from the perspective of a simulation semantics.

Recent research in cognitive linguistics reveals that a speaker's knowledge of language is represented as a structured inventory of conventional symbolic units that subsumes both open-class and closed-class symbolic units (Croft, 2001; Langacker, 1987; Talmy, 2000). These represent qualitatively distinct end points on a *lexicon-grammar continuum* between specific (content) meaning and schematic (grammatical) meaning. Talmy modeled this distinction in terms of bifurcation between distinct lexical and grammatical systems that contribute to meaning in distinct, albeit complementary, ways (although, see Croft, 2007). On this account, schematic meaning is encoded by closed-class elements and has a structuring function. In contrast, content meaning is a function of open-class symbolic units, which are "draped," so to speak, across the "scaffolding" provided by the grammatical elements of language. To illustrate, consider (4):

(4) **These** cowboy**s** **are** ruin**ing** **my** flowerbed**s**. (Evans & Green, 2006, p. 503)

In (4), the closed-class elements are highlighted in bold. For instance, the meaning of the closed-class elements can be glossed as "These somethings are somethinging my somethings," which can be paraphrased as "more than one entity close to the speaker is presently in the process of doing something to more than one entity belonging to the speaker." The point is that although the meaning encoded by these closed-class elements is highly schematic, it is meaning nonetheless.

In summary, the meaning associated with closed-class forms (the grammatical system) (a) encodes highly schematic aspects of experience and (b) provides a means for encoding recurrent "digitized" parameters of humanly relevant experience in an efficient way, and, as such, (c) may not, of themselves, give rise to simulations: perceptually rich experience. In contrast, meaning elements associated with open-class forms (a) encode rich aspects of experience, including visuo-motor information, and, as such, (b) are likely to give rise to simulations.

In essence, it is not clear that closed-class forms, such as grammatical aspect, are likely to relate to specific and/or discrete simulations. Rather, their contribution is likely to facilitate a structuring function, and thus the construction of a situation model, in the sense of Zwaan (this volume). Hence, some types of aspect (or tense) may not be amenable to a simulation semantics at the level of the individual morpheme or word.

Lexical Semantics Versus Utterance/Discourse-Level Meaning

In this section I argue that word meaning is, crucially, a function of the utterance context in which a word is embedded. Hence, meaning is constructed: the result of integration with the closed-class schematic system at the utterance and discourse levels. Put another way, words do not "mean" in their own right but rely on the conceptual "scaffolding," the schematic meaning, afforded by the closed-class elements associated with the grammatical system. From the perspective of a simulation semantics, the simulation that an open-class element gives rise to is likely to be a function of the utterance and discourse context in which it is embedded, rather than being due to a context-independent semantic representation. To illustrate, consider the various meanings of *open* in (5a)–(5h):

(5) a. John opened the window
b. John opened his mouth
c. John opened the book
d. John opened his briefcase
e. John opened the curtains
f. The carpenter opened the wall
g. The surgeon opened the wound
h. The sapper opened the dam

In these examples the semantic contribution of *open* is slightly different. This follows as the nature of the event associated with *open* involves, in each case, different means, including different tools, differences in the nature of the aperture, and differences in the purpose of the opening event in each case. The meaning of *open* then, is, in a nontrivial sense, created, in part, by the utterance context in which *open* is embedded and the discourse event in which the utterance is embedded. Hence, the motor resonances (i.e., simulations) associated with *open* in each example will be different.

In essence, simulations are likely to arise due to integration at (or above) the level of the utterance. Moreover, closed-class elements contribute to the structuring of parameters, which serve to facilitate the precise specification of the simulation semantics associated with open-class meaning elements. Finally, aspect, insofar as it can be identified as being associated with distinct forms (e.g., grammatical aspect), contributes to the structuring function of language, rather than being relatable to distinct simulations.

The Nature of Temporal Experience

Recent research has revealed that temporal experiences are complex, multifaceted, and subjectively real, which is to say directly experienced (see Evans, 2004, for a review, and references therein). Indeed, types of temporal experience include the experience of duration (e.g., protracted duration and temporal compression), instantaneity, synchronicity, sequentiality, and so on. Moreover, temporal experience is neurologically instantiated (e.g., Mauk & Buonomano, 2004; Walsh, 2003). In short, whereas temporal experiences do not have a veridical sensory-motor dimension in the same way that, say, a motion event has, they are nevertheless phenomenologically real. As temporal experiences (and hence representations) appear to be of a distinct kind from visuo-motor experience, it is not clear that these can be fully captured in terms of a simulation semantics that is based on motor resonances alone.

Summary

A simulation semantics approach to language understanding (simulation semantics) represents an exciting and promising area of enquiry. However, a simulation semantics needs (a) to pay attention to the differential semantic contribution of grammatical and lexical subsystems of language and (b) to take account of the fact that meaning is a function not of monotonic composition but of situated language use. Hence, meaning arises from integration at, or above, the level of the utterance. As such, simulations are always contextualized. In terms of aspect, which is the specific focus of Zwaan's article, it is clear that this constitutes a complex phenomenon, which is encoded by virtue of both the grammatical and lexical (sub)systems. Hence, some aspectual phenomena may not be directly relevant, in the sense of not being tractable from the perspective of a simulation semantics. Moreover, the neural implementation of time, in language, relates to perceptual experience, which is not limited to visuo-motor experience. Hence, a simulation semantics, which encompasses time, needs to include those aspects of phenomenological experience uniquely relevant for time.

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Processing Temporal Constraints: An ERP Study

Giosuè Baggio
Radboud University Nijmegen

This article investigates how linguistic expressions of time—in particular, temporal adverbs and verb tense morphemes—are used to establish temporal reference at the level of brain physiology. First, a formal semantic analysis of tense and temporal adverbs is outlined. It is argued that computing temporal reference amounts to solving a constraint satisfaction problem. Next, the results of an event-related potential (ERP) study are presented, which suggest that violations of verb tense ("Last Sunday Vincent *paints* the window frames of his country house.") evoke larger left-anterior negativities (LANs) compared to sentences in which verb tense is correct. The semantic analysis is finally combined with a computational, unification-based model of parsing to provide a functional account of the ERP data.

Introduction

Reference to time is ubiquitous in natural languages, to the point that nearly every assertion involves the location of some event within a temporal coordinate system. Much attention has been paid to the expressions used to encode temporal information, which range from prepositional phrases (e.g., *before the dawn*) to verb suffixes (e.g., "–ed" in the English regular simple past), to measure phrases borrowed from mathematics (e.g., "10^{-35} s into the expansion phase"). Linguists have provided detailed accounts of the functioning of these devices, often using the formal tools made available by modern logic. However, comparatively little is known about how expressions of time are represented

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Correspondence concerning this article should be addressed to Giosuè Baggio, F. C. Donders Centre for Cognitive Neuroimaging, Radboud University Nijmegen, P.O. Box 9101, NL-6500 HB Nijmegen, The Netherlands. Internet: g.baggio@fcdonders.ru.nl

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and used to compute temporal reference at the level of brain physiology. My aim here is to contribute to this line of research by combining a formal analysis of temporal expressions with event-related potential (ERP) data on tense processing.

A Semantic Analysis of Tense and Temporal Adverbs

In this section I will be concerned with a formal semantic analysis of sentences in which tense is correctly or incorrectly used, such as

(1) a. Last Sunday Vincent painted the window frames of his country house.
    b. *Last Sunday Vincent paints the window frames of his country house.

These sentences recognizably form a minimal pair of the kind customarily used in language processing experiments, and the formal treatment of tense outlined below is precisely intended to drive the interpretation of the ERP data reported later. The main theoretical claim will be that processing sentences such as (1a) involves solving a constraint satisfaction problem in which the relevant temporal constraints are introduced by the semantics of the adverb *last Sunday* and of the verb *painted*. Conversely, processing a sentence such as (1b) is claimed to lead to a failure to simultaneously solve such constraints. Although the analysis developed here brings semantics center stage, tense has ramifications in morphology that can hardly be ignored. Before I turn to semantics, some notes on morphology are therefore in order.

Morphology

Comrie (1985) defined verb tense as the "grammaticalization of location in time." Unpacked, this definition reads that tense is concerned with the location of events in time—or, possibly, a cognitive representation of time—and that the expression of time is (a) obligatory and (b) morphologically bound on verbs. However, this can only be taken to imply that verbs obligatorily carry temporal information via morphemes, though not that there are morphological rules that determine, for any given verb form, whether tense is correctly used. Let me try to clarify this point with reference to (1).

The verb forms *painted* in (1a) and *paints* in (1b) convey, via the suffixes "–ed" and "–s," the information that the painting event is located respectively in the past and in the present of the moment of speech. Importantly, both verb forms are morphologically correct, in the sense in which, for instance, the overregularized verb form *goed* (past of "to go") is not. What makes *paints* incorrect in the context of (1b) is a mismatch between its semantics—that is, the fact that it refers (at least in this context) to a present event—and that of the adverb *last Sunday*, which defines a temporal window in the past of the moment of speech in which the main event is to be located.

From these considerations, two views on the processing consequences of the violation in (1b) ensue. Under the first, (1b) is perceived by the language system as a semantic violation, not as a morphological one, because, as we have seen, *paints* is in fact morphologically well formed. Under the second, *paints* in (1b) is perceived as a morphological anomaly, even though its origin is semantic. This option entails the additional hypothesis that the system is endowed with an interface component (Jackendoff, 2002) mediating between semantics and morphology, which, on the basis of the meaning of *last Sunday*, constrains the set of suffixes that the verb stem *paint-* (or any other verb stem for that matter) can take. In this article I wish to remain neutral with respect to this issue, despite its obvious importance. Instead, I will consider the processing consequences of the observation that, regardless of whether (1b) is perceived as containing a semantic or a morphological anomaly, it is the mismatch between the *semantic* features of the adverb and the verb that determines that tense is used incorrectly.

Semantics

In the following paragraphs I will outline an analysis of sentences like (1a) and (1b), trying to add some formal detail to the claim that tense violations are semantic in nature. The analysis is based on a lightweight adaptation of the mathematical theory of tense and aspect of van Lambalgen and Hamm (2004). The formalism they present and apply is an Event Calculus, reformulated using Constraint Logic Programming, which has its origins in the design of agents capable of planning in robotics. The result is something quite different from the event calculi of the Davidsonian tradition, such as those used by Parsons (1990) and Larson and Segal (1995).

The Event Calculus of van Lambalgen and Hamm is a many-sorted predicate logic which sorts for eventualities viewed either perfectively, called *events*, or imperfectively, called *fluents*. As we will soon see, fluents can be used to represent processes and temporal intervals, such as the period denoted by *last Sunday*. Temporal and causal relations are formalized using *predicates* and *constraints*, combined in formulas called either *clauses* or *integrity constraints*. Here I will use two predicates only: $Happens(e, t)$, which means that event type e has a token at time t, and $HoldsAt(f, t)$, meaning that the fluent f holds at time t. Constraints are either equalities ($x = y$) or inequalities ($x \leqslant y$) relating the values of the temporal variables that occur as arguments of the predicates.

Discourse comprehension involves the construction of a model making discourse true (Stenning & van Lambalgen, 2005; van Lambalgen & Hamm, 2004). As each word is processed, an *estimate* of the meaning intended by the speaker is computed (i.e., a representation making what is heard or read true and consistent with the grammar and world knowledge). The process is incremental, in that each new incoming word may result in an update of the model computed during the preceding stage. Whereas lexical meanings are formalized as sets of clauses, of which an example will be given soon, semantic updates are regimented by integrity constraints. These are statements that can take the form of either obligations "?Φsucceeds," forcing an update of the model satisfying Φ, or prohibitions "?Φ fails," blocking updates of the model satisfying Φ.

The tenses can be treated as integrity constraints instructing the system to update the current discourse model so as to locate the relevant event in the past, present, or future of the moment of speech (van Lambalgen & Hamm, 2004). The following integrity constraints may serve as a first approximation of the meaning of the past tense:

(2) a. ? $Happens(e, t) \wedge t < now$ succeeds
b. ? $Happens(e, t) \wedge t = now$ fails

Whereas (2a) forces the system to update the current discourse model such that e is located at t, in the past of the moment of speech *now*, (2b) captures the implicature that the event e lies entirely in the past. However, as has often been observed (Partee, 1973), the past tense is anaphoric, for it requires an anchor expression, such as a temporal adjunct, in the preceding discourse context. (Forward-looking temporal reference seems possible too, but let us ignore this possibility here.) The sentence *Vincent painted the window frames of his country house*, uttered without a prior temporal context, would seem underinformative (Grice, 1989). This suggests that (2) should be refined as follows:

(3) a. ? $HoldsAt(f, t) \wedge Happens(e, t) \wedge t < now$ succeeds
b. ? $HoldsAt(f, t) \wedge Happens(e, t) \wedge t = now$ fails

The meaning of the present tense is captured by the following integrity constraint (see van Lambalgen & Hamm, 2004, for a more careful analysis):

(4) ? $HoldsAt(f, t) \wedge Happens(e, t) \wedge t = now$ succeeds

The fluent f in (3) and (4) has to be unified with material from the preceding discourse context; for instance, a temporal adverb. *Last Sunday* can be analyzed as follows (Hamm, Kamp, & van Lambalgen, 2006). To begin with, the time line is partitioned in seven segments of equal length, corresponding to the days of the week: *fSu*, *fMo*, . . . , *fSa*. Next, the meaning of the adverb is given as in (5), where *fCPSu* denotes the closest past Sunday:

(5) $HoldsAt(fSu, s) \wedge s < now \wedge |now\text{-}s| \leq 7\ days \rightarrow HoldsAt(fCPSu, s)$

Unification works as follows. Upon encountering a sentence such as (1a) or (1b), the system is incrementally confronted with a constraint satisfaction problem. Consider (1a) first. Processing the adverb *last Sunday* results in a model in which the query *?HoldsAt(fCPSu, t)* succeeds—that is, in which the antecedent of (5) holds. When the verb *painted* is processed, the system tries to satisfy (3). This is done by unifying f in (3) with *fCPSu* in (5) ($f = fCPSu$) and t in (3) with s in (5) ($s = t$). All constraints introduced by (1a) can be satisfied, and no inconsistency follows. Let us now turn to (1b). Processing the adverb *last Sunday* leads, once again, to a model in which the antecedent of (5) holds. When the verb *paints* is processed, the system tries to satisfy (4). However, unifying s with t ($s = t$) now leads to an inconsistency: Whereas $s < now$ has been satisfied when processing the adverb, (4) requires, on the contrary, that $t = now$ (or, equivalently, under the proposed unification, $s = now$) succeeds; the two constraints cannot be satisfied simultaneously. This suggests a precise definition of "tense violation": There is a mismatch between an adverb and verb tense, or two verb tenses, when the unification of the temporal variables set up by the relevant expressions fails.

Consequences for ERP Studies of Tense

The definition just proposed can be used in a critical assessment of the ERP literature on tense. The first attempt to investigate tense violations using ERPs was made by Kutas and Hillyard (1983). In this experiment, a group of English speakers was presented with sentences like the following:

(6) a. Most of the earth's weather happens in the bottom layer of the atmosphere *called* the troposphere.
b. *Most of the earth's weather happens in the bottom layer of the atmosphere *calls* the troposphere.
c. The eggs and meat of this turtle are *considered* choice food by many people.
d. *The eggs and meat of this turtle are *consider* choice food by many people.
e. This allows them to *stay* under water for a longer period.
f. *This allows them to *stayed* under water for a longer period.

Incorrect sentences elicited a positive shift peaking at about 300 ms following the verb and approaching significance at parietal sites, and a negative wave in the 300–400-ms window, suggestive of an N400 effect (Kutas & Hillyard, 1980). Regardless of the functional meaning of these effects, there appear to be two problems with this study. First, (6b), (6d), and (6f) do not instantiate tense violations, as none of these sentences contains a temporal expression, such as a temporal adverb or a temporal preposition phrase, with which verb tense fails to agree. Second, anomalies are realized in quite different ways. In (6b) the present indicative *calls* replaces the past participle *called*, in (6d) the infinitive *consider* replaces the past participle *considered*, and in (6e) the past participle *stayed* replaces the infinitive *stay*.

Osterhout and Nicol (1999) investigated the ERP correlates of "verb tense violations" in modal constructions, presenting to a group of English speakers sentences like the following:

(7) a. The cats won't *eat* the food that Mary leaves them.
b. *The cats won't *eating* the food that Mary leaves them.
c. The expensive ointment will *cure* all known forms of skin disease.
d. *The expensive ointment will *curing* all known forms of skin disease.
e. The new fighter planes can *fly* faster than anyone had expected.
f. *The new fighter planes can *flying* faster than anyone had expected.

In the 300–500-ms window, incorrect sentences were more positive at posterior sites of the mid-line, whereas the LAN (left-anterior negativity) elicited by anomalous verbs did not differ significantly from the effect evoked by correct verbs. In the 500–800-ms time interval, incorrect sentences were more positive at mid-line and posterior sites, consistent with the distribution of the P600 (Hagoort, Brown, & Groothusen, 1993; Osterhout & Holcomb 1992). ERPs elicited by sentence-final words in the violation condition were more negative-going compared to those observed in correct sentences; they started 200 ms following the sentence-final word and continued throughout the epoch. Also in this case, it should be noted that sentences (7b), (7d), and (7f) do not contain tense violations: All main verbs lack an anchor point in the preceding discourse with respect to which tense agreement can be evaluated.

In an ERP study by Allen, Badecker, and Osterhout (2003), "syntactic (tense) violations" were investigated in sentences containing either high-frequency (HF) or low-frequency (LF) verbs:

(8) a. The man will *work* on the platform. (HF)
b. *The man will *worked* on the platform. (HF)

c. The man will *sway* on the platform. (LF)
d. *The man will *swayed* on the platform. (LF)

Correct LF verbs elicited a larger N400, ungrammatical verbs elicited a larger P600, and LF anomalous verbs elicited a biphasic increase of N400 and P600. In the 500–900-ms window, a significant main effect for grammaticality was found, maximal on posterior sites as is typical of the P600. Again, (8b) and (8d) do not contain tense violations, contrary to the authors' claim that the "sentences 'He will walked' and 'He will swayed' are equally and unconditionally ill-formed with respect to tense" (Allen et al.).

In summary, the studies of Kutas and Hillyard (1983), Osterhout and Nicol (1999), and Allen et al. (2003) did not bring into play genuine tense violations. In none of these experiments were stimulus sentences such that the anomalous verb located the event described by the main clause outside a frame specified by an anchoring temporal expression.

Genuine tense violations have been investigated in at least two ERP studies. Fonteneau, Frauenfelder, and Rizzi (1998) presented a group of French speakers with sentences like the following:

(9) a. Demain l'étudiant *lira* le livre.
"Tomorrow the student will read the book."
b. *Demain l'étudiant *lisait* le livre.
"Tomorrow the student read the book."

The adverb *demain* "tomorrow" specifies a temporal frame within which the eventuality denoted by the main clause is taken to occur. Because the lapse of time denoted by *demain* "tomorrow" is located after the moment of speech, the tense of the verb should be future as in (9a). In (9b) the verb *lisait* "read" locates the event in the past, thus outside the temporal frame specified by *demain* "tomorrow." Accordingly, based on the definition given above, (9b) is a genuine tense violation. Anomalous verbs evoked a biphasic wave in the 450–550-ms interval following the onset of the critical word, with a negative maximum at posterior sites and a positive anterior peak. Given current knowledge of ERP components modulated by linguistic processes, it is hard to make sense of these effects, as they do not fit neatly any of the (E)LAN, N400, or P600 classes. Moreover, the imparfait is typically used to describe a background eventuality (e.g., a state), against which a foreground event is described using the passé simple. The imparfait in (9b) might introduce, on top of the tense violation itself, a background/foreground structure, with an expectation for a foreground event to be mentioned later in discourse. The passé simple *lut* "read" would have been a more suitable candidate for realizing tense violations without such aspectual confounds.

Steinhauer and Ullman (2002) presented a group of English speakers with sentences like the following:

(10) a. Yesterday, I *sailed* Diane's boat to Boston.
b. *Yesterday, I *sail* Diane's boat to Boston.

In (10), *yesterday* specifies a past time frame for the occurrence of the main event. In (10b), *sail* locates the event in the present, thus outside the period denoted by *yesterday*. In the 400–900-ms time window following verb onset, tense violations elicited a consecutive LAN (400–500 ms) and P600 (600–900 ms), taken by the authors as signatures of morphosyntactic processing. Regardless of whether *sail* was perceived as semantically or morphologically anomalous (recall the remarks above), the LAN observed by Steinhauer and Ullman indicates that semantic information, in the form of temporal constraints—or something functionally equivalent—set up by the adverb, is used by the system as early as 400 ms after verb onset.

The study reported below was aimed at obtaining a more complete picture of the time course of the neurophysiological effects of tense processing. We sought to refine the results of Steinhauer and Ullman (2002) using Dutch stimuli, in which the position of the verb in the sentence structure immediately follows that of the temporal adverb. Dutch syntax affords a semantically less spurious measurement of the effects of tense violations, as the arguments of the verb are yet to be processed when the tense violation occurs. This fact might also allow us to estimate more accurately the onset of the LAN and, as a consequence, to address issues such as to what extent temporal constraint satisfaction is implemented in the brain as a feed-forward process (more on this later). Finally, we were interested in tracking more downstream ERP effects, such as those elicited by sentence-final words in narratives containing tense violations.

An ERP Study of Tense Violations

Materials

The Dutch materials used in the experiment were 80 critical sentences, 40 correct sentences and 40 with tense violations, and 240 fillers. All sentences had the same structure: A past temporal adverb was followed by the main, simple past or present tensed verb, a subject NP, and an object NP, in most cases modified by a PP. The following are examples of the stimuli used:

(S1) Afgelopen zondag *lakte* Vincent de kozijnen van zijn landhuis.
Last Sunday painted Vincent the window-frames of his country-house.
"Last Sunday Vincent painted the window frames of his country house."

(S2) Afgelopen zondag *lakt* Vincent de kozijnen van zijn landhuis.
*Last Sunday paints Vincent the window-frames of his country-house.
"Last Sunday Vincent paints the window frames of his country house."

The temporal adverbs were *vorige week* "last week," *vorige maand* "last month," *vorig jaar* "last year," *vorige eeuw* "last century," and *afgelopen N* "last *N*" for each day of the week, each month, and each season. Each adverb was used at most three times. Eighty verbs were used, 40 regulars and 40 irregulars, 20 activities, 25 accomplishments, and 35 achievements (Vendler, 1957). The mean length of the verbs (correct: $M = 7.41$, $SD = 2.56$; violation: $M = 6.79$, $SD = 2.25$) and raw frequency (correct: $M = 6{,}898.34$, $SD = 34{,}220.5$; violation: $M = 7{,}174.91$, $SD = 44{,}939.35$) were normed using the CELEX corpus (Baayen, Piepenbrock, & Gulikers, 1996), ensuring that there were no differences between conditions (t-tests, $p > .9$ in all comparisons). Noncritical lexical items, including sentence-final words, and sentence length were identical across conditions. Fillers were 160 grammatically well-formed sentences containing the prepositions *after* and *before* and 80 verb-adverb sentences (40 correct, 40 tense violations) similar to critical items but constructed using different lexical material. Two test versions were constructed, consisting of pseudo-randomized lists of critical and filler items.

Participants

Twenty-five students participated in the experiment. Of these, one was left out of the final analysis due to a high number (>20%) of trials contaminated by artifacts. The remaining 24 participants (mean age: 24.6, 14 female) had no history of neurological, psychiatric, or cognitive disorders. Participants were selected from the database of the F.C. Donders Centre for Cognitive Neuroimaging at the Radboud University Nijmegen. They received €6 per hour or course credits for participating in the experiment.

Procedure

After applying the electrodes, participants were conducted into the experimental room and were asked to sit in front of a video monitor. The stimuli were presented on the screen word-by-word (300-ms word duration, 300-ms blank between words, white-on-black background), followed by a fixation cross lasting for 1,500 ms. Participants were instructed to read each sentence carefully and to blink or move only when the fixation cross was shown. The experiment took about 50 min to be completed and was divided into four blocks of 80 trials each.

Recording

The EEG/EOG was recorded from 32 sintered Ag/AgCl electrodes. Two electrodes were placed at the outer canthi of the left and right eyes. One electrode below the left eye monitored vertical eye movements (e.g., blinks). The remaining 29 electrodes were arranged according to American Electrophysiological Society conventions at the following locations: Fp1, Fp2, F7, F3, Fz, F4, F8, FC5, FC1, FCz, FC2, FC6, T7, C3, Cz, C4, T8, TP10, CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, O1, O2. The left mastoid electrode served as the true reference. All electrodes were re-referenced offline to a linked mastoid. Electrode impedance was kept below 5 kΩ throughout the experiment. The EEG/EOG was amplified by a multichannel BrainAmp DC system, with the following settings: 500-Hz sampling rate, a low-pass filter at 70 Hz, and a 10-s time constant.

Data Analysis

Data were analyzed using FieldTrip, a MATLAB package for processing EEG/MEG data. Several transforms were applied to each participant's dataset. Segments corresponding to the verb and the sentence-final word were extracted from the EEG with an interval of 200 ms before and 1,000 ms after stimulus onset. Baseline correction used the 200-ms prestimulus interval. Two FieldTrip procedures were applied for artifact rejection. The first rejected all trials containing activity exceeding a threshold of $\pm 100 \mu V$. The second algorithm discarded trials contaminated with eye movements or blinks based on thresholding the z-transformed value of the raw data in the EOG channels, preprocessed using a band-pass filter of 1–15 Hz. A 30-Hz low-pass filter was applied to the segmented, artifact-free data. ERPs were obtained for each participant by averaging over trials in each experimental condition. A 5-Hz low-pass digital filter was used to produce the waveforms shown in Figures 1 and 2. Topographical plots and statistical analyses used the 30-Hz low-pass filtered data. Statistical analyses were based on a nonparametric randomization procedure (Maris, 2004; Maris & Oostenveld, 2007) that took as input mean amplitude values in each condition in time bins of 100 ms, starting from the onset of the relevant word and ending 1,000 ms after, and produced as output a cluster of (1–28) electrodes in which the difference between the conditions was significant in each time bin, the sum of t-statistics in that cluster, and Monte Carlo estimates of p-values.

Results

A visual inspection of ERP waveforms elicited by the verb (Figure 1b) reveals a negative deflection peaking around 100 ms after verb onset, followed by a positive shift with a trough around 200 ms. The amplitude of these two components, often referred to as N1 (or N100) and P2 (or P200), respectively, appears not to be affected by the experimental manipulation: There are no electrode clusters between 0 and 200 ms after verb onset, at which the mean amplitude difference between tense violations and correct sentences is significant (Table 1). The P2 is followed by a negative shift, larger for tense violations over left-anterior scalp sites, starting around 200 ms from verb onset and lasting for approximately 200 ms (Figure 1b). There are clusters of electrodes in which the negativity is significant between 200 and 400 ms (Table 1, Figure 1a), and marginally significant between 400 and 500 ms. This effect is an instance of LAN. Around 600 ms following verb onset, the waveforms are characterized by a biphasic (positive-negative) response (Figure 1b), which, however, is not different between conditions in either the 500–600-ms or the 600–700-ms time bin (Table 1). A positive shift, larger for tense violations over right-posterior electrodes sets on at about 700 ms and lasts for the entire epoch (Figure 1): Only marginally significant positive clusters are found between 700 and 1,000 ms (Table 1). This effect can be taken as an instance of P600 (Hagoort et al., 1993; Osterhout & Holcomb, 1992).

The waveforms evoked by sentence-final words show similar N1-P2 complexes (Figure 2b). The amplitude of these early and largely endogenous components is not affected by verb tense (Table 1). The P2 is followed by a negative shift, peaking at about 400 ms following the onset of the sentence-final word (Figure 2b). There are no significant clusters between 200 and 400 ms, but the negativity becomes significantly larger for tense violations between 400 and 700 ms (Figure 2, Table 1). The effect bears some superficial resemblance with the N400, in particular as far as its polarity and distribution are concerned (Kutas & Hillyard, 1980). However, it has a later maximum and is more sustained compared to the N400. In what follows, I will refer to this effect as sentence-final negativity (SFN).

Tense at the Syntax-Semantics Interface

The link between linguistic theory and processing data is notoriously problematic (Poeppel & Embick, 2005). In particular, the notion that behavioral and brain data can constrain the form of linguistic theories—in somewhat more traditional terms: that the theory of "competence" can be shaped by

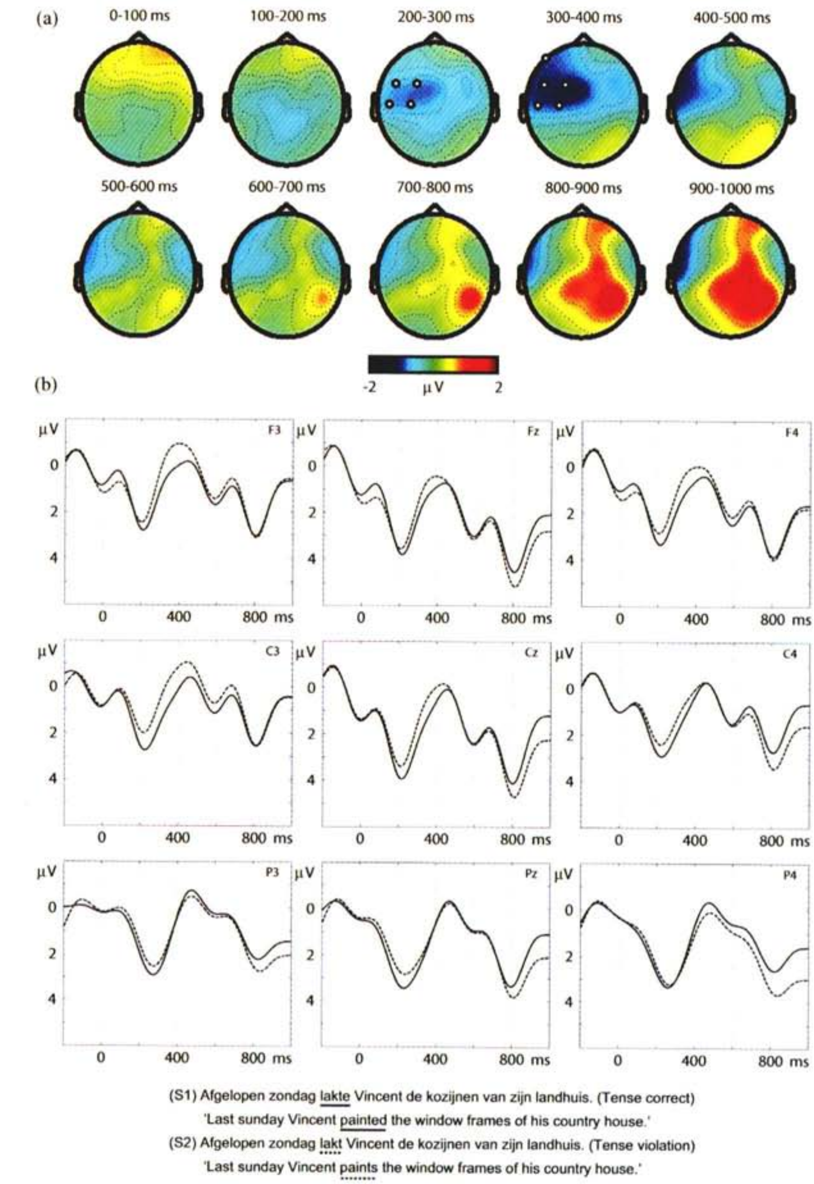


Figure 1 (a) Grand-average ($N = 24$) topographies displaying the mean amplitude difference between the ERPs evoked by the verb in tense violations and in correct sentences. (b) Grand-average ($N = 24$) ERP waveforms from frontal, central, and parietal electrode sites time locked to the onset (0 ms) of the verb in tense violations and correct sentences. Negative values are plotted upward.

Table 1 Summary of cluster-based t-statistics for the ERP data

	Verb		Sentence-Final Word	
Time	Negative Clusters	Positive Clusters	Negative Clusters	Positive Clusters
200–300 ms	$T(22) = -9.97$ $P = 0.046$			
300–400 ms	$T(22) = -14.46$ $P = 0.026$			
400–500 ms	$T(22) = -7.81$ $P = 0.056$		$T(22) = -15.33$ $P = 0.022$	
500–600 ms			$T(22) = -34.62$ $P = 0.006$	
600–700 ms			$T(22) = -6.66$ $P = 0.038$	
700–800 ms		$T(22) = 5.01$ $P = 0.09$		
800–900 ms		$T(22) = 4.44$ $P = 0.064$		
900–1,000 ms		$T(22) = 6.70$ $P = 0.05$		

Note. Tense violations and correct sentences are compared at the verb and at the sentence-final word in time bins of 100 ms starting from word onset. The first significant effects occurred at 200–300 ms. Empty cells denote the absence of (marginally) significant clusters.

"performance" data—is far from accepted (Jackendoff, 2002). Following Jackendoff (2007), I assume that a linguistic theory can be preferred over its competitors also based on its capacity to account for data on language processing and acquisition, at a fairly abstract level of analysis (Baggio & van Lambalgen, 2007; Marr, 1982). Below I will sketch a theory of tense at the syntax-semantics interface that meets, at least to some extent, this requirement. In particular, the model is consistent with the observation that the constraints set up by a temporal adverb are used to process a main verb as early as 200–300 ms after the onset of the latter.

Tense, Parsing, and Comprehension

An important missing ingredient from the semantic analysis of temporal expressions presented above is syntax. Here, I will adopt a lexicalist parser developed by Vosse and Kempen (2000) and applied by Hagoort (2003) to account for

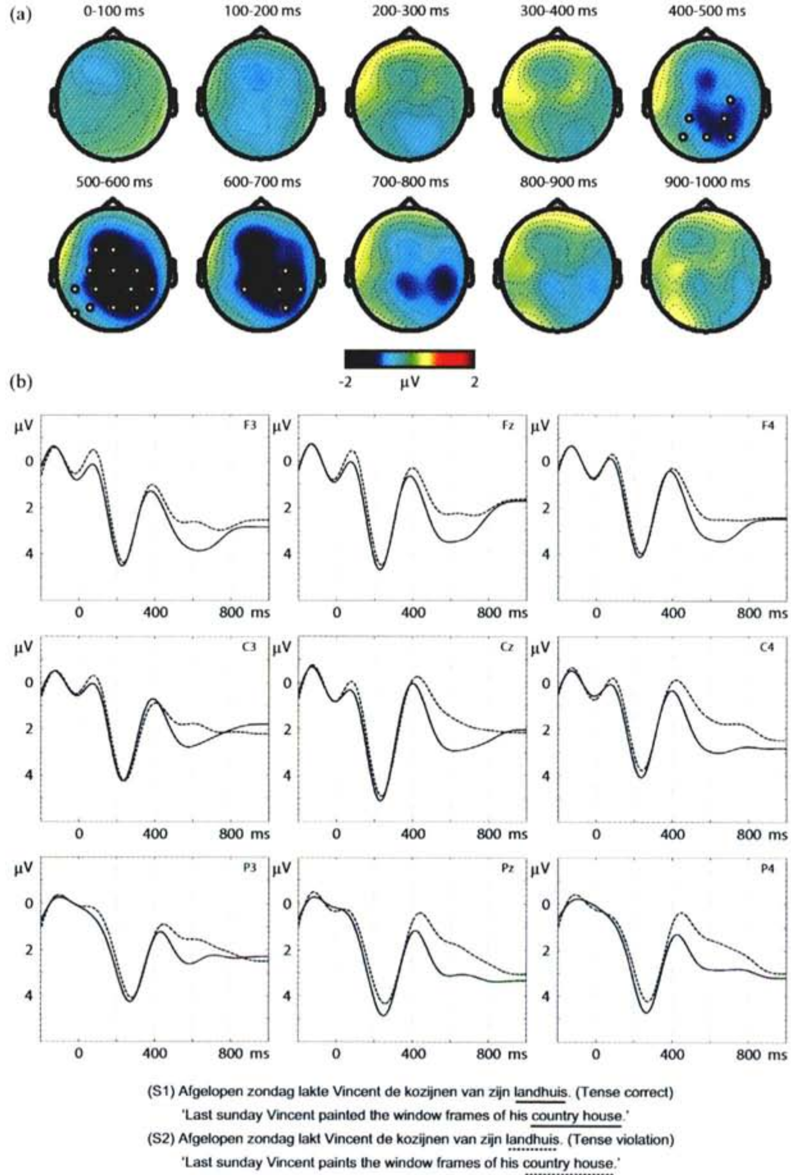
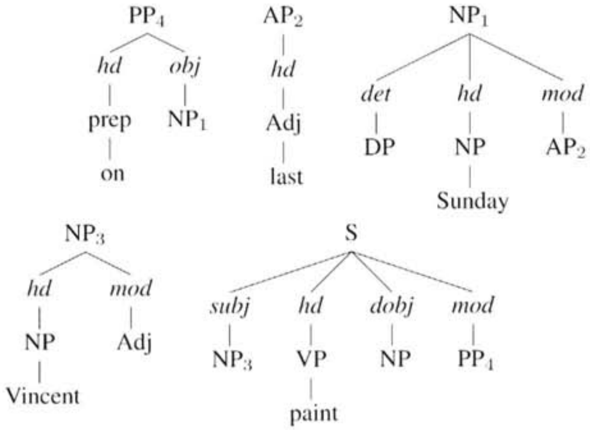


Figure 2 (a) Grand-average ($N = 24$) topographies displaying the mean amplitude difference between the ERPs evoked by the sentence-final word in tense violations and correct sentences. (b) Grand-average ($N = 24$) ERP waveforms from frontal, central, and parietal electrode sites time locked to the onset (0 ms) of the sentence-final word in tense violations and correct sentences. Negative values are plotted upward.

syntax-related ERP effects. The model assumes that syntactic information is stored in the mental lexicon as three-tiered unordered trees, or *syntactic frames*, which specify the admissible syntactic environment of each word. The syntactic frames associated with *last*, *Sunday*, *Vincent*, and *paint* are shown in (11), where *on* is assumed to be silent in examples (1a) and (b). The top tier of each frame is constituted by a single root node that contains phrasal information (NP, S, etc.) and that dominates a set of *functional nodes* in the second tier. For instance, an S node dominates four functional nodes: subject, head, direct object, and modifier; an NP node will have at most three functional nodes: determiner (if it is not associated with a proper name, at least in some languages), head, and modifier; and so forth. The third tier again contains phrasal nodes, called *foot nodes*, to which the root node of another syntactic frame can be attached.

(11)



Parsing consists in (a) checking agreement features of words such as number, gender, tense, and so forth, (b) checking word order, and (c) only if these checks are passed, unifying frames with identical root and foot nodes. Subscripts in the labels of root and foot nodes are used to indicate unification links in (11). Unifying root and foot nodes with the same subscripts yields the syntactic structure of (1) up to and including the verb *painted/paints*. Vosse and Kempen (2000) assumed that functional nodes carry features upon which the agreement checking (a) is based. For example, the subject node of *paints* carries the features *Case* = *nominative*, *Person* = *third*, and *Number* = *singular*. These are compatible with the features carried by the root node of the frame associated with *Vincent*. Therefore, the check yields a positive result and the two frames are unified. Tense could be treated analogously using an additional level of features in the frames of verbs and temporal prepositions. However, the resulting feature structure would then have to be interfaced with the semantics of verbs and temporal adverbs to ensure that the value of the *Tense* feature is consistent with that of the temporal variables in the semantic structures (3)–(5). This implies that at least three (sub)levels of representation have to be coordinated: the syntactic frame, the feature structure, and the semantic structure.

A more parsimonious option is to handle the check for temporal agreement entirely within the semantics. Consider (1a). Suppose that the parser has constructed a syntactic representation for *last Sunday* by unifying the NP foot and root nodes of *on* (which is silent) and *Sunday*, and the AP foot and root nodes of *Sunday* and *last*. Suppose, moreover, that the processor has constructed a semantic representation for the adverb *last Sunday* by forcing the query *HoldsAt(fCPSu, t)* to succeed. This leads to a model in which the antecedent of (5) holds; this model satisfies the constraint $s < now$. When *painted* is encountered, the syntactic frame of *paint* (which is tenseless) is retrieved from memory. Now, the PP root and foot nodes of *last Sunday* and *paint* are unified as soon as the agreement check is passed. This is carried out entirely within the semantics by simply updating the initial discourse model according to the integrity constraints (3). The unification $s = t$ can be made to succeed, so the temporal agreement check is passed, and the two frames are unified. Consider now (1b). In this case, when *paints* is encountered, the initial model is updated according to (4). The adverb satisfies the constraint $s < now$, but the verb satisfies $t = now$, which entails that s and t cannot be unified. The agreement check (a) is not passed, which results in a failure to unify the syntactic frames of *last Sunday* and *paints*.

Toward a Functional Account of the LAN

Negative shifts in the ERPs different from the N400 have been reported in several studies. Some of these effects are usually referred to as (early) left-anterior negativities or (E)LANs. The onset of (E)LANs ranges between 150 and 300 ms as a function of stimulus characteristics (Friederici, 2002). (E)LANs (150–200 ms) have been observed in response to rapidly detectable violations of word category. LANs (300–500 ms) are elicited by morphological anomalies such as case, number, and gender mismatches (Friederici, 2002; Hagoort, 2003). As the data show, tense violations result in LANs too, setting in between 200 and 300 ms from verb onset.

The theory of tense at the syntax-semantics interface presented above seems to be capable of accounting for the early response to tense violations. One key observation in this regard is that an effect that sets in between 200 and

300 ms after the onset of the stimulus arguably does not reflect feedback or recurrent computations. Rather, it is more likely related to the disruption of a largely automatic, feed-forward spread of activation from sensory areas (in this case, visual cortex), through brain regions subserving semantic memory (i.e., left temporal cortex), toward anterior language areas (i.e., left frontal cortex) (Hagoort, 2005). Hagoort (2003) suggested that (E)LANs might reflect the failure to bind two syntactic frames as a result of a negative outcome of the agreement check or of a failure to find two matching root and foot nodes. The LAN observed in the ERP experiment reported here can be taken as reflecting the failure in the tense agreement check—more precisely, a failure to simultaneously solve the temporal constraints set up by the adverb and the verb. This account appears to be consistent with the time course of the LAN, for it only requires that the constraint $t = now$, associated with the tense suffix of the verb *paints* (or *lakt* in the Dutch case), is active in semantic memory. Given the constraints set up by the adverb in the preceding processing stages, it follows that $s = t$ (a condition of temporal coherence within the sentence) cannot be satisfied. Note that this account does not require (a) that the full meaning (assuming there is anything like that) of the verb *paints* is reconstructed from semantic memory, for only the semantic contribution of the tense suffix "–s" is necessary, or (b) that any form of syntactic structure assembly takes place, for the constraint satisfaction stage actually precedes the unification of syntactic frames.

Although in-depth experimentation and modeling are still lacking, the temporal profile of the LAN can be taken to suggest that checking the satisfiability of a set of temporal constraints—or perhaps, if one can see a difference there, just detecting an inconsistency in such a set—might have a feed-forward neural implementation. This can be contrasted with processes such as the (re-)computation of a discourse model, which requires a recurrent network architecture (Baggio & van Lambalgen, 2007; Hitzler, Hölldobler, & Seda, 2004; Stenning & van Lambalgen, 2005) and gives rise to qualitatively different neurophysiological effects (Baggio, van Lambalgen, & Hagoort, 2008). This observation may constitute a starting point for an explanation of the SFN.

Toward a Functional Account of the SFN

A number of studies have reported negative shifts in the ERPs in response to sentence-final words in syntactically ill-formed sentences, even when the anomalous word does not occupy the sentence-final position (Hagoort et al., 1993; McKinnon & Osterhout, 1996; Osterhout, 1997; Osterhout & Holcomb, 1992, 1993; Osterhout, Bersick, & McLaughlin, 1997; Osterhout & Mobley, 1995). Osterhout and Nicol (1999) reported negativities in response to sentence-final words preceded by semantic as well as syntactic violations. Moreover, at some electrode sites, the SFN elicited by doubly (syntactically and semantically) anomalous sentences was approximately the sum of the SFNs evoked by syntactic and semantic violations.

Osterhout and Holcomb (1992) suggested that the SFN may be an electrophysiological marker of either (a) the perceived ungrammaticality of the sentence, or (b) the system's effort to find an acceptable syntactic structure for the sentence, or (c) the "message-level" consequences of the sentence-internal violation. As for the SFN elicited by tense violations, (a) seems to imply either that (i) the incorrect use of tense was not perceived when the verb was encountered, but only at the sentence-final word, or that (ii) the ill-formedness of the *sentence* (as opposed to that of the VP) was perceived at the sentence-final word, as only then it can be concluded that the entire sentence, which consists of a single VP, is ungrammatical. Now, both of these implications seem untenable. For one, the LAN elicited by the verb indicates that the violation *was* in some sense perceived, which rules out (i). Second, any sentence containing an ungrammatical phrase is itself ungrammatical, which makes (ii) untestable. Hypothesis (b) implies that, at the sentence-final word, the system computes a plausible syntactic representation for the anomalous sentence (1b), eventually unifying the PP root and foot nodes of "last Sunday" and "paint." However, computing a new syntactic representation does not solve the sentence-internal problem, which is semantic in nature. Either syntactic unification does away with the agreement check at the sentence-final stage, in which case the unification of frames does not guarantee that tense and other agreement features are consistent across the representation, or the agreement check is still required, in which case it is the semantic constraints that must be readjusted.

This brings us to (c), according to which the SFN would reflect either (i) the disruption of a process involved in computing a model of the sentence or (ii) the attempt made by the system to compute a model in which all constraints are satisfied. One key feature of the Event Calculus combined with Constraint Logic Programming is that satisfying a set of constraints actually *produces* a discourse model verifying the linguistic material given as input (van Lambalgen & Hamm, 2004). In this framework, the LAN can be taken as a physiological index of the failure to unify s and t (i.e., to add the constraint $s = t$ to the unification space), and thereby of the disruption of the processes that would otherwise have led to a discourse model. This rules out (i). According to (ii), the SFN would reflect the readjustment of constraints set up by the verb required to make the set of constraints satisfiable as a whole. In semantic terms, this process can be characterized as, for instance, forcing the integrity constraints (3) in the present tense case (1b), yielding a "narrative present" reading of the sentence. In terms of neural implementation, reworking a set of constraints to produce the desired output requires a recurrent architecture. Feed-back processes seem consistent with the temporal profile of the SFN (400–700 ms) and complete the picture sketched above where the LAN (200–400 ms) reflects a feed-forward computation instead.

Summary and Conclusions

The aim of the present article was to take a few initial steps toward an integrated account of temporal reference in terms of linguistic structure and neural processes. I tried to suggest that the bulk of linguistic computation in the brain, as far as temporal reference is concerned, is semantic. I argued that verb tense can be said to be used correctly or incorrectly only based on a semantic criterion, which can be captured in terms of temporal constraints using logical systems like the Event Calculus. Further on, I outlined an integrated model of parsing and comprehension in which the computation of temporal reference is entirely consigned to the semantic processor and acts as a preliminary stage of syntactic structure building. Under this view, the ERP data reported here, and the LAN in particular, suggest that the brain accesses and evaluates semantic information as early as 200–300 ms following word onset.

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Processing Temporal Constraints and Some Implications for the Investigation of Second Language Sentence Processing and Acquisition. Commentary on Baggio

Leah Roberts
Max Planck Institute for Psycholinguistics

Baggio presents the results of an event-related potential (ERP) study in which he examines the processing consequences of reading tense violations such as **Afgelopen zondag lakt Vincent de kozijnen van zijn landhuis* (*"Last Sunday Vincent paints the window-frames of his country house"). The violation is arguably caused by a mismatch between the semantics of the temporal adverb in the topic position *Afgelopen zondag,* which refers to the past time, and the present tense semantic feature as expressed by the morphological marking on the verb *lakt* "paints." Baggio reports that sentences with this type of tense violation elicited a left-anterior negativity (LAN) between 200 and 400 ms following the onset of the critical word (*lakt*), which was followed by a positive shift at about 700 ms (a so-called P600 effect), in comparison to conditions where there was no such temporal mismatch (*Afgelopen zondag–lakte*). Baggio's formal semantic analysis of tense and temporal adverbs underlies his view of the parsing of such violations and his functional account of these ERP data. Essentially, tenses are considered to be *integrity constraints*, which serve as instructions to the processing system to update the discourse model in order to locate the situation that is being talked about in (past/present/future) time. The LAN effect is argued to reflect the disruption in the system's attempt to satisfy the sentence's constraints. Baggio also finds a negative-going waveform between about 400 and 700 ms following the onset of the final word in the tense violation condition, which he identifies as a sentence-final negativity (SFN). He argues that this SFN reflects the system's readjustment of the sentence's

Correspondence concerning this article should be addressed to Leah Roberts, Max Planck Institute for Psycholinguistics, P.O. Box 310, 6500 AH Nijmegen, The Netherlands. Internet: Leah.Roberts@mpi.nl

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constraints in order to make them satisfiable. In other words, at least in this case, the LAN reflects the *detection* of the anomaly, and the SFN reflects its *correction*.

The fact that the LAN is elicited by a *semantic violation* might pose a challenge to comprehension models that see syntax as the driving force of the parse. Earlier ERP studies have found that a LAN effect is often elicited by the processing of word-category violations and morphosyntactic mismatches including subject-verb, gender, and case agreement violations (for an overview, see Hagoort, 2003). These findings have lent support to syntax-first models of comprehension (e.g., the three-stage model of Friederici and colleagues; e.g., Friederici, 2002), which view the building of syntactic structure as the autonomous first step of the parse and which, crucially, precedes semantic processes. Integration of syntactic and semantic processes is assumed to occur only later, in the 500–700-ms time window. The LAN effect has therefore been taken to indicate automatic, morphosyntactic processing. How can we reconcile the fact that Baggio finds a LAN effect for a *semantic violation*, and so early on in the processing of the critical item? One way is to appeal to the difference between Baggio's tense violation sentences and the types of violations that have been used in earlier studies. Specifically, the subject-verb and gender agreement violations used in earlier studies involve agreement between two *formal* (morphological) markers. In contrast, the tense violations used in Baggio's study concern agreement between the (lexical) semantic features of the adverb and the semantic feature as expressed by the verbal morphology. Therefore, both involve agreement, but of different types.

The view that tense violations are semantic (rather than strictly morphological) violations is unlikely to be a problem for most linguists. How else could it be that many languages effectively express complex temporal relations without having formal morphosyntactic marking (e.g., Moroccan Arabic, which has a large set of temporal adverbs)? The language of adult (particularly untutored) second language (L2) learners can be included in this group, as it is often characterized (at earlier stages) by a lack of productive tense/aspect morphology. Irrespective of language background, learners have been found to start out using temporal adverbs and general information structure principles to establish temporal relations, before they move toward a productive use of verbal morphology, which in fact some learners never do (Starren, 2001).

Baggio's article raises many other interesting questions. One concerns how adult L2 learners might process such tense violations and whether any differences observed can be attributable to specific properties of their first language (L1). Although there is an enormous body of research into the L2 acquisition of tense and aspect (see, e.g., Bardovi-Harlig, 2000, for an overview), there appear to be very few studies investigating L2 learners' real-time processing of tense (and aspect) violations. Some researchers investigating L2 processing claim that L2 processing differs from L1 processing in that, although applying lexical semantic knowledge online is no problem, learners are less able to compute nonlocal syntactic dependencies in real time (e.g., Clahsen & Felser, 2006; Marinis, Roberts, Felser, & Clahsen, 2005). Others claim that it is the integration of syntactic knowledge with other types of knowledge (semantic/pragmatic) that might be problematic for L2 learners, irrespective of language background (e.g., Roberts, Gullberg, & Indefrey, 2008). In fact, it is only in the domain of lexical-semantics and pragmatics that robust L1 effects on L2 processing have been found (see, e.g., Roberts, 2007, for a review). These L2 processing findings coupled with Baggio's semantic approach to the processing of tense predict that if an L2 learner has not acquired the semantic feature underlying the morphological marker of tense and/or aspect, then they should not be sensitive to a mismatch between a temporal adverb and such a morphologically marked verb. Furthermore, the semantic nature of the computational process predicts that a learner's L1 might influence their processing of the L2. Some recent L2 reading time data can be brought to bear on these questions.

The data that follow come from a word-by-word self-paced reading study by Roberts and Liszka (Roberts & Liszka, 2008), who looked at how French and German L2 learners of English processed present perfect (1) and past simple (2) sentences involving tense/aspect violations. As in Baggio's study, the critical sentences all contain a temporal adverb in the topic position, thus modifying the time being talked about (the Topic Time, TT; cf. Klein, 1994). The experimental manipulation (the tense violation) was created by having the immediately following verb either match in temporal features with the adverb [the *match* conditions: (1a) and (2a)] or not [the *mismatch* conditions: (1b) and (2b)].

(1) *Present Perfect*
  a. For months now, Jill has wanted to get married. *match*
  b. *Last year, Jill has wanted to get married. *mismatch*
(2) *Past Simple*
  a. Last year, Jill wanted to get married. *match*
  b. *For months now, Jill wanted to get married. *Mismatch*

Reading times were measured on the critical verb. Interestingly, the native English speakers showed an asymmetry in their sensitivity to these tense violations. Only in the present perfect sentences did they find the mismatch condition harder to process than the match condition. In contrast, in the past simple sentences, there was no reading time difference between the two conditions. This asymmetry in processing cost appears to be caused by the fact that the tense component of the present perfect condition includes the time of the utterance (TU), so it cannot be used with a temporal adverb that refers to a specific point in the past, as this would exclude the TU. In contrast, in the past simple condition, the time that is being talked about is situated earlier than the TU. Therefore, although it is pragmatically odd to use a temporal adverb that refers to a time span that includes the TU, the past time is not *excluded* as it is in the present perfect condition.

For the L2 learners, there seemed to be an effect of the learners' native language. In French, the compound past form (the *passé composé*) can express the present perfect interpretation like English, whereas in German the compound past mainly licenses the past simple interpretation. The French learners showed a mismatch effect for both the present perfect and the past simple conditions, unlike the German learners who showed no mismatch effect whatsoever. Therefore, for the German learners, the formal morphological marking on the verb did not affect their processing; that is, for the German learners, both sentence types were treated as merely *past tense*, and so there was no online conflict with the semantics of the temporal adverb, even for those German L2 learners who were able to produce the present perfect in the appropriate contexts, as measured by a cloze task. It seems that the German learners had metalinguistic knowledge that they could draw upon in the offline production task. This suggests that in many cases they were able to distinguish correctly the present perfect from the past (and present) simple but that this knowledge was not accessible during real-time processing.

Given these and Baggio's findings, it would be interesting to see the results of an ERP version of this study. For native English speakers, we would predict a LAN effect for temporal adverb mismatches in the present perfect condition. An interesting test case, however, would be the past simple conditions, where there was no behavioral difference in the reading time study. It is possible that because of the mismatch, the past simple items would elicit a LAN effect. On the other hand, they might induce a modulated SFN if one assumes that it is less costly to force the constraints so that they are satisfiable in this case. For the French L2 learners, a LAN and a SFN might be elicited by both sentence types and, in contrast, by neither type for the Germans. It should be noted here that very few ERP studies of L2 comprehension have in fact found LAN effects, and this has often been taken to suggest that early, automatic (morphosyntactic) processing is absent in L2 comprehension (Clahsen & Felser, 2006). However, the processing of this type of (semantic) anomaly has not been tested in L2 learners, so it may be that such violations *can* induce this effect in learners, but only for those whose L1 also encodes the relevant distinction (i.e., French vs. German L2 learners). Alternatively, it might be exactly this automatic, feed-forward process that is lacking in L2 processing, irrespective of the type of violation being processed. All of these interesting questions remain to be addressed.

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Who's Afraid of the Big Bad Whorf? Crosslinguistic Differences in Temporal Language and Thought

Daniel Casasanto
Stanford University

The idea that language shapes the way we think, often associated with Benjamin Whorf, has long been decried as not only wrong but also fundamentally wrong-headed. Yet, experimental evidence has reopened debate about the extent to which language influences nonlinguistic cognition, particularly in the domain of time. In this article, I will first analyze an influential argument against the Whorfian hypothesis and show that its anti-Whorfian conclusion is in part an artifact of conflating two distinct questions: *Do we think in language?* and *Does language shape thought?* Next, I will discuss crosslinguistic differences in spatial metaphors for time and describe experiments that demonstrate corresponding differences in nonlinguistic mental representations. Finally, I will sketch a simple learning mechanism by which some linguistic relativity effects appear to arise. Although people may not think in language, speakers of different languages develop distinctive conceptual repertoires as a consequence of ordinary and presumably universal neural and cognitive processes.

> Are our own concepts of 'time,' 'space,' and 'matter' given in substantially the same form by experience to all men, or are they in part conditioned by the structure of particular languages? (Whorf, 1939/2000, p. 138)

Does language shape thought? Do crosslinguistic differences in the lexicon or grammar have nonlinguistic consequences, such that people who talk differently end up thinking differently in corresponding ways? If so, how does this happen: What features of language affect which cognitive processes and What are the mechanisms? Since Benjamin Whorf directed scholars' attention to this

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Correspondence concerning this article should be addressed to Daniel Casasanto, Stanford University, Jordan Hall, Bldg. 420, Stanford, CA 94305. Internet: casasanto@alum.mit.edu

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set of questions over half a century ago, few topics have incited so much passionate disagreement among linguists, anthropologists, and psychologists alike. In this article, I will not review the sanguinary history of the Whorfian debate (see Gentner & Goldin-Meadow, 2003; Gumperz & Levinson, 1996). Rather, I will start by disentangling two questions about the relationship between language and thought, the conflation of which may contribute to the fervor that the Whorfian hypothesis inspires in its opponents.[1] Next, I will review experimental evidence that crosslinguistic differences in the lexicalization of time correlate with profound differences in the way speakers of different languages mentally represent duration. Finally, I will describe a mechanism by which language causes these differences to arise, which suggests a reframing of Whorf's question about relationships among language, concepts, and experience.

The long-standing majority view on the Whorfian hypothesis is summarized in Steven Pinker's 1994 bestseller *The Language Instinct*. Pinker first posed a question inspired by George Orwell's (1949) dystopian fantasy, the novel *1984*, in which the government seeks to render subversive thoughts unimaginable by making them nameless in the prescribed language, Newspeak:

> *Is* thought dependent on language? Do people literally think in English, Cherokee, Kivunjo, or by [the year] 2050, Newspeak? Or are thoughts couched in some silent medium of the brain—a language of thought or "mentalese"—and merely clothed in words whenever we need to communicate them to a listener? (p. 56)

In response, Pinker wrote:

> [T]he famous Sapir-Whorf hypothesis of linguistic determinism, stating that people's thoughts are determined by the categories made available by their language, and its weaker version, linguistic relativity, that differences among languages cause differences in the thoughts of their speakers [. . .] is wrong, all wrong. (p. 57)

Pinker denounced not only radical linguistic determinism but also linguistic relativity, which is my concern here, and Whorf's concern in the 1939 passage quoted above. To justify his anti-Whorfian position, Pinker asserted:

> The idea that thought is the same as language is an example of what can be called a conventional absurdity[.] (p. 57)

Here, Pinker illustrates a confusion that is rampant in the literature on relationships between language and thought. The idea that "thought is the same as language" (as Orwell suggested) should not be conflated with the idea that "differences among languages cause differences in the thoughts of their speakers" (as Whorf suggested). Orwell and Whorf raised two distinct questions: *Do we think in language?* and *Does language shape thought?* It is possible (and, I will argue, true) that language can shape the way people think even if they do not think in language.

Confusion of the Whorfian question with what I will call the "Orwellian" question pervades Pinker's discussion:

> The idea that *language shapes thinking* seemed plausible when scientists were in the dark about how thinking works, or even how to study it. Now that scientists know how to think about thinking, there is less of a temptation to *equate* [*thinking*] *with language*. (pp. 58–59, italics added)

Not only does Pinker zigzag between Orwell's idea and Whorf's, he also implies a relationship between them that is misleading and, in fact, logically fallacious. The reader is led to believe that the absurdity of the Orwellian proposal should be taken as one of the strongest arguments against the Whorfian hypothesis. To unpack this fallacy, let us turn the Orwellian and Whorfian questions into two statements, O and W [(1a) and (b)]:

(1a) O: We think in language.
(1b) W: Language shapes thought.

There is a clear relationship between these statements. If people think in language, then it must be the case that language shapes thought. In other words, if Orwell was right, then Whorf must necessarily be right, too. This can be expressed in the proposition (2): if O, then W.

(2) $O \rightarrow W$

If we agree to the truth of this proposition, then we must also agree to the truth of its contrapositive (3): If language does not shape thought, then we do not think in language. In other words, proving that Whorf was wrong would entail that Orwell was wrong, as well.

(3) $\sim W \rightarrow \sim O$

However, this is not what Pinker argued. Rather, he suggested that people do not think in language; therefore, language does not shape thought. In other words, because Orwell was wrong, we should believe that Whorf must be wrong. However, this argument assumes that the inverse (4) of our proposition is true, a logical fallacy known as "denying the antecedent."

(4) $\sim O \rightarrow \sim W$

It may sound reasonable at first to say that "if people think in language, then language shapes thought, but because people do not think in language, then language does not shape thought"—provided you do not think about it too carefully. In fact, this is equivalent to saying, "if John has a daughter who plays the violin, then he must be a human, but because John does not have a daughter who plays the violin, then he is not human."

Although the Orwellian question and the Whorfian question are importantly related, they are not related in the way that Pinker suggested (and he is not alone in making this logical error). Evidence in favor of Orwell's idea would also support Whorf's, but evidence against the idea that *people think in language* does not count against the possibility that *language shapes thought.* Clarifying this relationship is important: If people believe that linguistic relativity entails (or implies) the Orwellian notion that people think in language, then no wonder they are afraid of the big bad Whorf!

Orwell and Whorf: Divide and Conquer?

Having distinguished the Orwellian and Whorfian questions, it is possible to evaluate them separately. Pinker's 1994 discussion, which he later dubbed his "obituary" for the Whorfian hypothesis (Pinker, 2007, p. 124), reviews standard arguments against both the idea that we think in language and the idea that language shapes thought. Although arguments against the one idea are often misrepresented as arguments against the other, many of these objections are compelling when properly construed. Pinker takes a shotgun approach to discrediting the Orwellian equation of language with thought, starting with appeals to intuition: We have all had the feeling that we know what we want to say but we do not know how to say it, therefore there must be some difference between what we say and what we want to say. Other arguments stress the inadequacy of language as a medium for thought, pointing to problems such as ambiguity, deixis, and coreference, which seem to require extralinguistic resources to resolve. For example, when we read the ambiguous headline "Hershey Bars Protest" (Pinker, 1994, p. 119), the information we need to decide whether this story discusses an oppressive chocolate manufacturer or some rebellious candy bars does not appear to reside in language, per se. Still other arguments call upon results from psychological experiments, such as Roger Shepard and Lynn Cooper's (1982) studies suggesting that people rotate objects in their mind's eye using imagistic, picturelike representations. Most compellingly, Pinker pointed out that much of what can reasonably be construed as "thinking" happens in the minds of babies, deaf isolates, and aphasics, who lack the full use of language, and even in the minds of animals that lack language altogether. The fact that animals can learn, remember, navigate, communicate, reason about causes, infer goals, build shelters, use tools, cooperate, deceive one another, and construct social hierarchies suggests that quite a lot of thinking can happen without human language.

These anti-Orwellian arguments do not necessarily support Pinker's conclusion that all thinking occurs in a Fodorian "mentalese" (Fodor, 1975). They do not rule out the possibility that *certain kinds* of thinking are mediated by language (see Carruthers, 1996; Spelke & Tsivkin, 2001). They do suggest, however, that even if some thinking takes place in the medium of natural language, *not all* thinking does, and that the Orwellian proposal is problematic, in principle.

Standard arguments against the Whorfian hypothesis, including Pinker's, are of a different sort. Rather than attacking linguistic relativity in principle, they criticize the data and methods that have been used to support Whorfian claims. Do the Eskimos really think about snow more precisely than speakers of a Standard Average European (SAE) language because they can categorize it more precisely in language (Whorf, 1940/2000)? Are Hopi speakers unable to conceptualize time as we do because of their impoverished temporal vocabulary (Whorf, 1939/2000)? There is no good evidence that this is the case. Two things were wrong with some of Whorf's most notorious claims. To start, many of Whorf's linguistic observations did not stand up to scrutiny by later scholars. Arguably, speakers of Eskimo languages do not use any more words for snow than your average snowboarding enthusiast (Pullum, 1991), and the Hopi speakers' way of talking about time may not be as different from the SAE speakers' as Whorf made it seem (Malotki, 1983). If there are not actually any relevant differences between languages, then there is no reason to posit differences in the thoughts of their speakers. Furthermore, the project of inferring cognitive differences solely from linguistic differences is hopelessly circular. Patterns in language can serve as a source of hypotheses about cognitive differences between members of different language communities, but some sort of extralinguistic data are needed to test these hypotheses: Otherwise, the only evidence that people who *talk* differently also *think* differently is that they *talk* differently!

Experimental work since Whorf's time has suffered several additional problems. Pinker noted that some apparent behavioral differences between language groups have turned out to be artifacts of clumsy translation. Famously, Alfred

Bloom (1981) alleged that Chinese speakers are less capable of reasoning counterfactually than English speakers because Chinese lacks subjunctives, which serve as counterfactual markers in English (e.g., If it *were* to rain, then I *would* take an umbrella). In his original experiment, Bloom created English and Chinese versions of a story that required counterfactual reasoning, and he found that Chinese speakers in China failed abysmally to understand the story's counterfactual structure, whereas English speakers in the United States had no trouble at all. Terry Au, a native Chinese-speaking psychologist, examined the stories that Bloom had used and found the Chinese version to be "not very idiomatic" (Au, 1983, p. 161). When Au replicated Bloom's experiment using new stimuli, the crosslinguistic differences in counterfactual reasoning disappeared (Au).

Yet, awkward translations may be the least of the problems exemplified by Bloom's study (and found in many subsequent studies, as well). No matter how carefully stimulus materials are translated, any experimental design that relies on comparing performance across translations confounds differences between items with differences between conditions (and if monolinguals are used, also confounds item differences with group differences), making the results hard to interpret. Furthermore, this study predicted a single difference between language groups: One group should perform better than the other. Even if the predicted difference had been reliable (e.g., if English speakers had shown better counterfactual reasoning than Chinese speakers across studies), it would be hard to know why: the group that is better at counterfactual reasoning could also be better at many other kinds of reasoning that do not correspond to any crosslinguistic differences. Unless predictions are cast in terms of statistical interactions, researchers risk interpreting spurious relationships between patterns in language and patterns in performance on experimental tasks. Finally, the Whorfian hypothesis posits a *causal* relationship between language and thought. Bloom sought to test the hypothesis that language causes differences in counterfactual reasoning using an experimental design that was only capable of demonstrating correlation—a problem that is not intractable, but which still plagues would-be Whorfian research a quarter of a century later (see Casasanto, 2005a; Gordon, 2004).

The Orwellian idea that people think (mostly or entirely) in the medium of natural language, and therefore that language can be equated with thought, is unsupported empirically and is also problematic in principle, given what is known about language and about thought.[2] By contrast, the Whorfian idea that linguistic differences can cause speakers of different languages to think differently faces no such in-principle challenges. When standard arguments are properly interpreted, they do not sound a death knell for the Whorfian hypothesis, but rather a call for more rigorous research.

Time in Language and Thought

Since Pinker's (1994) "obituary," Whorfian research has experienced a renaissance. Experimental evidence has reopened debate about the extent to which language influences nonlinguistic cognition in domains such as space (Levinson, 1996; Li & Gleitman, 2002; Majid, Bowerman, Kita, Haun, & Levinson, 2004), color (Gilbert, Regier, Kay, & Ivry, 2006; Kay & Kempton, 1984; Robertson, Davies, & Davidoff, 2000; Witthoft, et al., 2003), number (Casasanto, 2005a; Gordon, 2004; Gelman & Gallistel, 2004; Miller, Major, Shu, & Zhang, 2000; Pica, Lemer, Izard, & Dehaene, 2004; Spelke & Tsivkin, 2001), and time (Boroditsky, 2001; Casasanto et al., 2004; Chen, 2007; January & Kako, 2007; Núñez & Sweetser, 2006). One obstacle to resolving this controversy has been devising truly nonlinguistic tests to evaluate how speakers of different languages perceive or remember their experiences, particularly in the more abstract conceptual domains such as time.

Across languages, people use the same words to talk about time that they use to talk about space (Alverson, 1994; Clark, 1973; Gruber, 1965; Haspelmath, 1997; Jackendoff, 1983; Lakoff & Johnson, 1980; Traugott, 1978). For example, English speakers might talk about a *long* vacation or a *long* line and moving a meeting *forward* or moving a truck *forward*. Evidence from behavioral experiments suggests that people not only talk about time using spatial language, they also think about time using mental representations of space (Boroditsky, 2000, 2001; Boroditsky & Ramscar, 2002; Casasanto, 2005b, in press; Casasanto & Boroditsky, 2003, 2008; Casasanto et al., 2004; Cohen, 1967; Gentner, 2001; Núñez & Sweetser, 2006; Piaget, 1927/1969; Torralbo, Santiago, & Lupiáñez, 2006; Tversky, Kugelmass, & Winter, 1991). Although using spatial metaphors for time may be universal (Alverson, 1994; cf. Silva Sinha, Sinha, Zinken, & Sampaio, 2008), the particular mappings from space to time vary across languages. For instance, depending on the language, speakers might talk about the future as if it lies *ahead* of us (in English), *behind* us (in Aymara), or *below* us (in Mandarin Chinese). Behavioral studies suggest that speakers of languages that use different spatiotemporal metaphors may indeed think about time differently (Boroditsky, 2001; Núñez & Sweetser, 2006).

There is, however, an important limitation shared by these crosslinguistic studies comparing English speakers' mental representations of time with those of Aymara and Mandarin speakers: Subjects were tested on tasks that required them to produce or understand language. Núñez and Sweetser's participants were producing co-speech gestures, and Boroditsky's were judging sentences containing spatial or temporal language. Perhaps these studies showed relationships between spatial and temporal thinking that were consistent with linguistic metaphors only because participants were required to process space or time *in language* (i.e., because they were "thinking for speaking"; Slobin, 1996). Would the same relationships between mental representations of space and time be found if participants were tested on nonlinguistic tasks?

To address this question, my collaborators and I developed simple psychophysical tasks to investigate whether metaphors in language influence even our basic, perceptuomotor representations of time. Do speakers of languages that use different spatiotemporal metaphors think about time differently—even when they are not using language? First, we analyzed previously unexplored crosslinguistic differences in metaphors for duration in English and Greek. Next, we tested whether these linguistic differences correlate with differences in English and Greek speakers' performance on low-level, nonlinguistic duration estimation tasks. Finally, we conducted a training study to evaluate a causal role for language in shaping time representations (Casasanto, 2005b; Casasanto et al., 2004).

Duration in One or Three Dimensions

Literature on how time can be expressed verbally in terms of space (and, by hypothesis, conceptualized in terms of space) has focused principally on linear spatial metaphors. However, is time necessarily verbalized (and conceptualized) in terms of unidimensional space? Some theorists have suggested so (Clark, 1973; Gentner, 2001), and although this may be true regarding temporal succession, linguistic metaphors suggest an alternative spatialization for duration. English speakers not only describe time as a line, but they also talk about having *oceans of time*, *saving time in a bottle*, and liken the days of their lives to *sands through the hourglass*. Quantities of time are described as amounts of a substance that occupies three-dimensional space (i.e., volume).

Languages differ in the extent to which they describe duration in terms of distance as opposed to amount of substance. In English, it is natural to talk about *a long time* or *a long meeting*, borrowing the structure and vocabulary of a linear spatial expression like *a long rope*. In Greek, the words *makris* and *kontos* are the literal equivalents of the English spatial terms *long* and *short*. They can be used in spatial contexts much the way long and short are used in English (e.g., *ena makry skoini* means "a *long* rope"). In temporal contexts, however, *makris* and *kontos* are dispreferred in many instances where long and short would be used naturally in English. It would be unnatural to translate "a *long* meeting" literally as "mia *makria* synantisi." Rather than using distance terms, Greek speakers typically indicate that an event lasted a long time using *megalos*, which in spatial contexts means physically *large* (e.g., a *big* building), or using *poli*, which in spatial contexts means *much* (e.g., *much* water).

To quantify the relative prevalence of "distance" and "amount" metaphors for duration across languages, the frequencies of the English phrases *long time* and *much time* were compared with the Greek phrases that native speakers reported most naturally expressed the same ideas, *makry kroniko diastima* "long time distance" and *poli ora* "much time." Each expression was entered as a search term in a very large multilingual text corpus (www.google.com). Search results showed that the distance metaphor was dramatically more frequent than the amount metaphor in English, whereas the opposite pattern was found in Greek. Results were corroborated in a questionnaire study showing that English speakers tend to use distance metaphors to describe the duration of events (e.g., long meeting, long party), whereas Greek speakers tend to use amount metaphors to describe the durations of the same events (e.g., synantisi pou diekese *poli* "meeting that lasts *much*," parti pou kratise *poli* "party that lasts *much*"). Although both languages use some distance and some amount metaphors for duration, the relative strengths of these metaphors varies across languages. These preliminary studies by no means captured all of the complexities of how duration is metaphorized in terms of space within or between languages, but findings corroborated native English and Greek speakers' intuitions and provided quantitative linguistic measures on which to base predictions about behavior in nonlinguistic tasks.

Do these differences in metaphor frequency between languages lead English and Greek speakers to think about time differently, even when they are not using language? To find out, we asked English and Greek speakers to estimate the duration of brief events that contained either distracting information about linear distance (distance interference) or distracting information about amount (amount interference). In the distance interference condition, participants viewed a series of lines "growing" across the screen, for various distances and durations. After each line disappeared, they were asked to reproduce its duration by clicking the mouse twice (in the same spot) to indicate the time that elapsed from the instant that the line appeared to the instant that it reached its maximum length. The distance that the line grew was irrelevant to the task and was varied orthogonally to the line's duration. As such, distance served as distractor: a piece of information that was unrelated to the task but could potentially interfere with task performance. In the amount interference condition, subjects viewed a schematic drawing of a container filling gradually with liquid and were asked to reproduce the duration of the "filling" event. Analogously to the distance interference condition, the amount of fill varied orthogonally with the duration of the event and, as such, served as a distractor for the subjects' task of estimating duration.

In previous studies using a similar distance interference task with English speakers (Casasanto & Boroditsky, 2003, 2008), English-speaking participants were unable to ignore the distance that a line grew when estimating its duration, even though distance was irrelevant to the time estimation task. The result was a pattern of cross-dimensional interference: Spatial information interfered with participants' temporal judgments in a particular way. Although, on average, all stimuli lasted the same duration, participants judged lines that traveled a shorter distance to last a shorter time and lines that traveled a longer distance to last a longer time.

Is this conflation of distance and duration universal to humans, or does it depend in part on the conflation of distance and duration in language? If patterns in language are partly responsible for the space-time confusion observed in English speakers, then irrelevant distance and amount information should interfere with English and Greek participants' duration estimates differently. English speakers should show more interference from distance than amount on their time estimates. Greek speakers should show the opposite pattern, being more distracted by amount than by distance interference. Results supported these predictions: The pattern of cross-dimensional interference observed in English and Greek speakers on this pair of nonlinguistic time estimation tasks followed the pattern of spatiotemporal metaphors found in English and Greek. English speakers were strongly affected by the distance that a line traveled but only weakly affected by the fullness of a container, whereas Greek speakers showed the opposite pattern of cross-dimensional interference. The structure of people's low-level, nonlinguistic time representations is not universal: These simple psychophysical tasks indicate that at a basic level, the way we mentally represent time covaries with the way we talk about it in our native languages. However, does experience using different metaphors *cause* speakers of different languages to think differently?

How Language Shapes Time

Previous suggestions for how language could influence representations of time have failed because they have attempted to give an Orwellian answer to a

Whorfian question, equating concepts with words. Paul Bloom and Frank Keil (2001) created the following straw-man, which makes the Whorfian proposal appear hopelessly circular:

> Since the lexicons of languages differ, it would follow that speakers of different languages would come to possess different concepts. How coherent is this proposal? Consider a simple example:
>
> Q: How is it that people can think about time?
>
> A: Because we learn the language of time, words like 'was' and 'tomorrow.'
>
> But this answer immediately raises another question: How do we learn these words? (pp. 361–362)

Bloom and Keil (2001) argued that the ability to learn temporal words presupposes an ability to think about time, thus begging the question of from where this ability comes. However, why should the Whorfian claim that lexical differences create conceptual differences entail that words precede concepts? Language can influence the structure and content of preexisting mental representations via simple learning mechanisms, one of which I will illustrate here.

How do Greek and English speakers come to mentally represent duration differently, relying differentially on mental representations of distance or amount? It is not plausible that using temporal metaphors in language creates the capacity to estimate brief durations, because prelinguistic infants and nonhuman animals share this capacity. Consider, instead, that some mappings from concrete to abstract domains of knowledge (such as mappings from space to time) may be initially established prelinguistically, based on interactions with the physical world (Clark, 1973). As an example, people are likely to track the kinds of correlations in experience that are important for perceiving and acting on their environment; they learn to associate time with linear space by observing that more time passes as moving objects travel farther, and likewise they learn to associate time with amounts of substances accumulating in three-dimensional space by observing that more time passes as substances accumulate more. This proposal presupposes that although mature time representations depend in part on spatial representations, time can also be mentally represented *qua* time, at least initially: In order for cross-dimensional associations to form, some primitive representations must already exist in each dimension. Primitive temporal notions, however, of the sort that we share with infants and nonhuman animals may be too vague or fleeting to support higher order reasoning about time. Grafting primitive temporal representations onto spatial representations may make time more amenable to verbal or imagistic coding and may also import the inferential structure of spatial relations into the domain of time (Pinker, 1997), facilitating the comparison of temporal intervals, transitive inference, serial ordering, and other such mental operations that humans have evolved to perform in the domain of space.

If metaphorical mappings from space to time are based on physical experiences and are established prelinguistically, what role might language play in shaping temporal representations? Because the laws of physics are the same in all language communities, prelinguistic children's conceptual mappings between time and distance and between time and amount should be the same universally. Later, as children acquire language, these mappings are adjusted: Each time we use a linguistic metaphor, we activate the corresponding conceptual mapping. Speakers of "distance languages" like English then activate the time-distance mapping frequently, eventually strengthening it at the expense of the time-amount mapping (and vice versa for speakers of "amount languages" like Greek). At a neural level, long-term strengthening of the more frequent association at the expense of the less frequent association could be mediated by competitive Hebbian learning, and short-term adjustments in the strength of these mappings (due to immediate physical or linguistic experience) could be mediated by more transient neuromodulatory processes.

Did linguistic experience give rise to language-related differences in performance on the "growing line" and "filling container" experiments? Using crosslinguistic data to test for a causal influence of language on thought is problematic, as the experimenter cannot randomly assign participants to have one first language or another: Crosslinguistic studies are necessarily quasi-experimental. A pair of training tasks (i.e., true experimental interventions) was conducted to provide an in-principle demonstration that language can influence even the kinds of low-level mental representations that people construct while performing psychophysical tasks and to test the proposal that language shapes time representations, both in the laboratory and in natural settings, by adjusting the strengths of cross-domain mappings. Native English speakers were randomly assigned to perform either a "distance training" or "amount training" task. Participants completed 192 fill-in-the-blank sentences using the words *longer* or *shorter* for distance training and the words *more* or *less* for the amount training task. Half of the sentences compared the length or capacity of physical objects (e.g., An alley is *longer/shorter* than a clothesline; A teaspoon is *more/less* than an ocean) and the other half compared the duration of events (e.g., A sneeze is *longer/shorter* than a vacation; A sneeze is *more/less* than a vacation). By using distance terms to compare event durations, English speakers in the control condition were reinforcing the already preferred mapping between distance and time. By using amount terms, participants in the critical condition were describing event durations similarly to speakers of an amount-biased language like Greek, activating the nonlinguistic amount-time mapping that is normally dispreferred for English speakers. After this linguistic training phase, all participants performed the nonlinguistic filling container task. If using a linguistic metaphor activates the corresponding conceptual mapping, then repeatedly using amount metaphors during training should transiently strengthen participants' nonlinguistic amount-time mapping. Consistent with this prediction, following about 30 min of training with amount metaphors, native English speakers' performance on the filling container task was statistically indistinguishable from the performance of the native Greek speakers. By encouraging the habitual activation of either distance-time or amount-time conceptual mappings, our experience with natural language may influence our everyday thinking about time in much the same way as this laboratory training task.

In summary, people who talk differently about time also think about it differently, in ways that correspond to the preferred metaphors in their native languages. Language not only reflects the structure of our temporal representations, but it can also shape those representations. Beyond influencing how people think when they are required to speak or understand language, language can also shape our basic, nonlinguistic perceptuomotor representations of time. It may be universal that people conceptualize time according to spatial metaphors, but because these metaphors vary across languages, members of different language communities develop distinctive conceptual repertoires.

However, there is no need to be afraid of this Whorfian effect. The fact that language influences thought does not mean that people think in language, nor does it imply that language interfaces with nonlinguistic mental representations via privileged channels or special mechanisms: In this case, associative learning will do. Whorf asked whether our concepts are given in the same form by experience to everyone *or whether they are conditioned by language*. The results summarized here suggest that conceptual mappings from space to time may be given in essentially the same form via correlations in physical experience to everyone and then *also* conditioned by the languages we speak. If language plays a privileged role in shaping thought, it is perhaps only by virtue of being a ubiquitous and highly systematic form of experience, which, unlike basic perceptuomotor experiences, varies from culture to culture.

Why Worry About Whorf?

Why should we continue to do Whorfian research? One possible reason is that cataloging crosslinguistic cognitive differences could be a step toward charting the boundaries of human biological and cultural diversity. If this is the goal, then the Whorfian effects most worth finding should be extreme instances in which differences between languages produce radically different experiences of reality in their speakers. Alternatively, crosslinguistic cognitive differences could be tools for investigating how thinking works and, in particular, for investigating the role of experience in the acquisition and representation of knowledge: If people who talk differently form correspondingly different mental representations as a consequence, then mental representations must depend, in part, on these aspects of linguistic experience. If discovering the origin and structure of our mental representations is the goal, then crosslinguistic cognitive differences can be informative even if they are subtle and even if their effects are largely unconscious. Whether or not they correspond to radical differences in speakers' conscious experiences of the world, Whorfian effects can have profound implications for the study of mental representation.

Notes

1 I will use the term "Whorfian hypothesis" to mean the *linguistic relativity hypothesis*, that differences among languages cause differences in the thoughts of their speakers, as suggested by the question of Whorf's quoted at the beginning of the article. Arguments supporting linguistic relativity should not be interpreted as supporting *linguistic determinism*, the idea that language rigidly determines the thoughts that speakers are capable of entertaining, which has also been associated with Whorf.

2 The "Orwellian" claim that people think in language therefore language can be equated with thought, is sometimes labeled strong linguistic determinism and attributed to Whorf. I assert that nothing Whorf wrote supports this attribution, although defending this assertion would require a full exegesis of his more radical statements, which I will not undertake here. More importantly, linguistic determinism, the idea that "people's thoughts are determined by the categories made available by their language" (Pinker, 1994, p. 57), does not entail that "the medium of thought consists of the actual words and sentences the person speaks" (Pinker, 2007, p. 133). Language could still dictate "the categories and types that we isolate from the world of phenomena" (Whorf, 1940/2000, p. 213) even if thinking is not carried out in the medium of natural language. There is no empirical evidence for strong linguistic determinism, but none of the arguments that I have reviewed against the Orwellian idea rules out linguistic determinism, in principle.

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Nominal Tense. Time for Further Whorfian Adventures? Commentary on Casasanto

Pieter Muysken
Radboud University Nijmegen

In his insightful and stimulating article, Casasanto (this issue) argues that "people who talk differently about time also think about it differently, in ways that correspond to the preferred metaphors in their native languages. Language not only reflects the structure of our temporal representations, but it can also shape those representations. Beyond influencing how people think when they are required to speak or understand language, language can also shape our basic, nonlinguistic perceptuomotor representations of time." Casasanto introduces material from spatiotemporal metaphors in Greek to argue this point. This brief commentary sketches a further potential source for exploratory work in this area, having to do with Nominal Tense Aspect Mood (TAM).

Elaborating on the Crosslinguistic Observations in Nordlinger and Sadler

Nordlinger and Sadler (2004), in an exploratory crosslinguistic article, called attention to two groups of languages in which temporal distinctions are marked on the noun phrase. In the first group, with Independent Nominal TAM, exemplified in (1) and (2) with the Amerindian language Guaraní, one of the national languages of Paraguay, it is the temporal reference of the nouns themselves that is specified by two suffixes, *–kue* "past" and *–rã* "future":

(1) Guaraní (Nordlinger & Sadler, p. 781)
O-va-ta che-róga-kue-pe.
3-move-FU 1s-house-PST-ADJ.
"He will move into my former house."

Correspondence concerning this article should be addressed to Pieter Muysken, Linguistics Department, Radboud University Nijmegen, Postbox 9103, 6500 HD Nijmegen, The Netherlands. Internet: p.muysken@let.ru.nl

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(2) A-va-va'ekue hóga-rã-pe
1s-move-PST 3.house-FU-ADJ.
"I have moved into his future house."

In the other type of languages, with Propositional Nominal TAM, exemplified in (3) and (4) with the Australian aboriginal language Kayardild, the tense is marked on the noun but has sentential scope. Here, *–wu* is a proprietive case marker with a modal function (M.PROP) and *–y* is a locative case with modal function (M.LOC), which contribute to the tense interpretation of the entire clause:

(3) Kayardild (Evans, 1995, p. 404)
Ngada kurri-nangku mala-wu (balmbi-wu).
1.s(NOM) see-NEG.POT sea-M.PROP morrow-M.PROP
"I won't be able to see the sea (tomorrow)."

(4) Ngada kurri-nangku mala-y (barruntha-y).
1.s(NOM) see-NEG.POT sea-M.LOC yesterday-M.LOC
"I could not see the sea (yesterday)."

Both cases modify the whole clause and interact with marking on the verb. In languages with Propositional Nominal TAM, there is ordinarily a second indicator of TAM, often on the predicate.

Although Nordlinger and Sadler (2004) suggested that the two classes of languages are disjoint, there is at least one language, which I will refer to as Extended, the Bolivian isolate Movima (Haude, 2006), where the same marker is sometimes interpreted with respect to the noun phrase, as in (5), and sometimes with respect to the clause, as in (6).

(5) Aj<a>lo:maj loy os no:no di' pa:ko.
narrate<DR> ITN art.n.PST pet REL dog
"I'll tell you about my (former, deceased) dog."

(6) jayna n-os imay-ni jayna tivij-ni
DSC obl-ART.n.PST night-PRC DSC pain-PRC
os chodo :wi
ART.n.PST stomach
"Then at night, my stomach hurt (past)."

In (5) the neuter past article *os* indicates that the speaker's dog does not live any more, whereas in (6) the marker indicates that the hurting of the speaker's stomach took place in the past. This suggests that the two types of Nominal

TAMs are not entirely unrelated. It should be noted that Haude herself uses the term "nominal tense" in her 2004 presentation (Haude, 2004) but adopted a more complex analysis in her thesis (Haude, 2006), where it is assumed that the element glossed PST in (5) and (6) in fact marks the nonexistence of the entity denoted.

The data in Movima may be interpreted in such a way that Propositional Nominal TAM is a discursive extension of Independent Nominal TAM in that language, through some kind of conventionalized implicature. In other words, the logical impossibility of the nonexistence of my stomach in (6) at the moment of speaking is interpreted as indicating that the hurting took place at some moment in the past. This line of thinking is very similar to the analysis presented in Haude (2008).

The Distribution and Historical Development of Nominal TAM

Although admittedly the evidence from one single language, Movima, is perhaps not convincing, Table 1 shows that in three language families both types of Nominal TAM occur (Arawak, Tupí-Guaraní, and Cushitic), and in the case of Tupí-Guaraní, the languages are quite closely related. Thus, Yuki (listed with Independent Nominal TAM) and Sirionó (listed in the group with Propositional Nominal TAM) are very close indeed. If we accept the Movima scenario of extension from the Independent to the Propositional domain, this would suggest that the situation in Sirionó, if reported correctly, is an innovation. Thus, the two types of Nominal TAM must be at least historically related in some instances.

Table 1 is based on the discussion in Nordlinger and Sadler (2004) and Tonhauser (2007), supplemented with some data from the survey in Adelaar with Muysken (2004). I am sure that in coming years this inventory will be further expanded as more data become available and are systematically investigated.

In terms of areal spread, it is clear that Independent Nominal TAM is found in a number of language families in South America, as well as a few in North America and Africa. Propositional Nominal TAM again is found in South America, as well as Africa and Australia. A few regions in the three continents are particularly rich in forms of Nominal TAM. In contrast to claims by Nordlinger and Sadler (2004, p. 790), who suggested that "the phenomenon of independent Nominal TAM cannot be attributed to a quirk of a single language family or particular geographic region," I do think that there is a likely areal effect in the distribution of the Nominal TAM markers, at least

Table 1 Overview of the distribution of different types of Nominal Tense across language families and individual languages

Type of Nominal TAM	Area	Family	Language
Independent	Amazonia	Arawak	Tariana
			Mawayana
		Tupí-Guaraní	Guaraní
			Tupinamba
			Yuki
		Carib	Hixkaryana
			Apalai
			Macushi
			Wai Wai
			Dekwana
			Trio
			Wayana
		Macro-Jê	Iatê
		Nambiquaran	Nambiquara
		Arawá	Jarawara
		Chapacuran	Wari'
		Matacoan	Mataco
	North America	Algonquian	Potowatomi
		Northern Wakashan	Kwakw'ala
		Salish	Halkomelem
		(Pen)Utian	Lake Miwok
	East Africa	Cushitic	Somali
Propositional	Amazonia	Tupí-Guaraní	Sirionó
		Arawak	Chamicuro
	Africa	Niger-Congo	Yag Dii
			Supyire
		Central Khoisan	Gui
		Cusihitic	Iraqw
	Australia	Pama Nyungan	Pitta Pitta
			Gurnu
		Tangkic	Lardil
			Kayardild
Extended Independent ≫ Propositional	Amazonia	Isolate	Movima

in Amazonia. The most likely scenario on the basis of the currently known descriptive facts is that the phenomenon is strongly rooted in the Carib language family and has spread from there to individual members or subbranches of other language families. However, further study of these families, as well as the specific geographical distribution of the features involved, is needed, both in Amazonia and in other parts of the world.

The present state of knowledge of the distribution of these tenses is presented in Table 1.

The Critique in Tonhauser

Tonhauser (2007) critically discussed the status of the Independent Nominal TAM described by Nordlinger and Sadler (2004) for Guaraní, arguing that in fact the word Tense is a misnomer for the phenomenon described in (1) and (2). Tonhauser carefully analyzed the meaning of the Guaraní suffixes *–kue* "past" and *–rã* "future" and concluded that they behave differently from verbal tense markers. Her analysis focused on five relevant features found in different verbal tense systems. Verbal tenses, she argued,

1. do not exhibit semantic restrictions;
2. cannot co-occur;
3. do not encode a state change;
4. are restricted in denotation by verbal modifiers;
5. have a denotation that may be contextually or anaphorically determined.

The marker *–kue* "past" fails on all five of these criteria, and *–rã* "future" fails on criteria 2–5. There are semantic restrictions on the use of *–kue* because it presupposes existence of the noun at the reference time. The two markers can co-occur, as in (7) (Tonhauser, p. 859):

(7) A-hecha pa'i-rã-ngue-pe
1s-see priest-FU-PAST-ADJ
"I am seeing the former future priest."

Sometimes the Nominal TAM markers mark a change of state (e.g., becoming a teacher or a priest). This does not happen with verbal tense markers. Similarly, verbal tense denotation is restricted by a verbal modifier like an adverb; this does not hold for Nominal TAM markers. Finally, temporal reference can be contextually or anaphorically determined (as, e.g., in a narrated temporal sequence). This is not the case for the Nominal TAM markers. For all of these reasons, it may be better to avoid the term "tense" when referring to these markers.

As such, the critique in Tonhauser (2007) is correct and offers a welcome detailed semantic exploration of the Guaraní markers. However, it left me somewhat unsatisfied, for two reasons.

First, it is much clearer now what Nominal TAM is not and how it differs from verbal tense, but not really how it is to be classified typologically. Semantically, noun phrases are quite different from verb phrases and, thus, the differences between the two classes of TAM markers may be what one would expect on independent grounds.

Second, the account of Tonhauser (2007) focuses on Independent Nominal TAM and does not consider the phenomenon of Propositional Nominal TAM, which may be similar if not identical to some system of verbal tense and which was also discussed in Nordlinger and Sadler (2004). This would be not so bad if the phenomena are totally unconnected, but as I have argued above, they may co-occur in the same language or in the same closely related language family, suggesting closer connections than suggested by Tonhauser.

It may be possible to interpret the development from Independent to Propositional Nominal Tense in the Amazonian case in terms of grammaticalization: The temporal distinction is then brought from the lexical nominal to the grammatical clausal domain, where it starts interacting with other functional projections. In fact, Independent Nominal Tense itself may have emerged through the partial grammaticalization of derivational affixes, which occur in several Amerindian languages in South America (e.g., Chayahuita; cf. Hart, 1988), marking that someone like a mother has died. "Future" markers could come from the marriage domain, indicating "husband to be" and so forth. This would suggest a sequence such as the following:

Derivational elements marking relational status of persons ≫
"independent" nominal tense ≫ "propositional" nominal tense

This scenario would obviously not hold for languages such as Kayardild, where the nominal tense markers also function as case markers.

Perspectives

The phenomenon of Nominal TAM, either Independent or Propositional, presented in the previous sections is not unique to a single continent, but probably not very widespread either among the languages of the world. Once present in a language family, it may spread to adjacent families, as the data from at least Amazonia tentatively suggest. (Admittedly, this picture may change as precise geographical contact analyses are made and descriptive data on more languages in the area become available. I will not hazard speculations about possible areal effects, e.g., on the northwest coast of North America in this respect.) This suggests both perceptual saliency and independent cognitive status in the languages where it is present. Otherwise, areal spread would be less likely.

Furthermore, I have suggested that Independent and Propositional Nominal TAM may in some cases be related—the latter developing out of the former. This is not necessarily the scenario in all cases of Propositional Nominal TAM. In some cases, it may simply result from clitic TAM markers being attached elsewhere than on the predicate or TAM features agreeing with various different elements in the sentence. Propositional Nominal TAM would then be an extreme case of Dependent rather than Head marking (Nichols, 1986) (e.g., in Australian languages).

To finally return to Casasanto's article, the separate cognitive status of Independent Nominal TAM could be the subject of interesting crosslinguistic cognitive research, with the aid of experiments. Tonhauser (2007, p. 842) noted that the marker *–kue* "former, past" in Guaraní is semantically limited in the nouns with which it combines. For the marker *–rã* "future" no such restrictions hold. The marker *–kue* does not combine easily with food artifacts (like "cheese"), with natural kinds (like "rain"), and with final-stage properties (like "survivor") and permanent human relations (like "father"). On the other hand, it freely combines with professions (like "priest"), nonfood artifacts (like "house"), and temporary human relations (like "neighbor"). These restrictions derive in part from world knowledge, to be sure. Phrases like the ones in (8) in English are odd as well:

(8) a. ?my former cheese
    b. ?the former rain
    c. ?the former survivor
    d. ?my former father

However, they can be combined with *–rã*, yielding the English equivalents in (9), not all of them felicitous in English.

(9) a. my future cheese
    b. the future rain
    c. the future survivor
    d. my future father

I am not sure what would be the best experimental paradigm, but a study on the status and permanence of nouns that can and cannot be, and are and are not, combined with *–kue* and *–rã* may well be very rewarding.

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Appendix

Abbreviations in Example Glosses

1s etc.	first person etc. singular
ADJ	adjunct marker
ART	article
DSC	discourse marker
FU	future
ITN	intentional
M.LOC	modal locative case
M.PROP	modal proprietive case
NEG	negation
NOM	nominative
POT	potential mood
REL	relative marker
PRC	process verbalization
PST	past
TR	transitivizer

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Temporal Decentering and the Development of Temporal Concepts

Teresa McCormack
Queen's University Belfast

Christoph Hoerl
University of Warwick

This article reviews some recent research on the development of temporal cognition, with reference to Weist's (1989) account of the development of temporal understanding. Weist's distinction between two levels of temporal decentering is discussed, and empirical studies that may be interpreted as measuring temporal decentering are described. We argue that if temporal decentering is defined simply in terms of the coordination of the temporal locations of three events, it may fail to fully capture the properties of mature temporal understanding. Characterizing the development of mature temporal cognition may require, in addition, distinguishing between event-dependent and event-independent thought about time. Experimental evidence relevant to such a distinction is described; these findings suggest that there may be important changes between 3 and 5 years in children's ability to think about points in time independently of the events that occur at those times.

Introduction

In 1989, Richard Weist published a paper entitled "Time concepts in language and thought: Filling the Piagetian void from two to five years," which began with the claim that there had been next to no research conducted that addressed the development of temporal cognition in the early years. As its title makes clear, Weist's work—an elaboration of an account first put forward three years earlier

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Correspondence concerning this article should be addressed to Teresa McCormack, School of Psychology, Queen's University Belfast, David Keir Building, 18–30 Malone Road, Belfast, UK BT9 5BP. Internet: t.mccormack@qub.ac.uk

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(Weist, 1986)—was an attempt to describe and explain how time concepts changed from the end of infancy through to the end of the fifth year. The account is fundamentally a cognitive developmental one, although Weist draws primarily on studies of children's language to support his proposals regarding a set of key developmental stages. It is fair to say that even though it is now around 20 years since the publication of Weist's work, there are very few competing accounts of the development of temporal concepts in the literature. Moreover, although Weist's account is sufficiently well articulated to be a plausible candidate to fill the "Piagetian void" that he identified, it is not widely referred to by developmental psychologists. In fact, as others have noted, it is difficult to find reference to temporal cognition anywhere in standard developmental psychology textbooks, and in this respect, time differs markedly from any other core domain (Nelson, 1996). Although there has been some Piagetian-inspired research on children's ability to reason about duration, speed, and distance (e.g., Acredelo & Schmid, 1981; Levin, 1977, 1982), there is relatively little published research in the cognitive developmental literature on children's temporal concepts (for notable exceptions, see Friedman, 1990, 2003, 2005; Nelson, 1996; see also Moore & Lemmon, 2001).

This gap in the cognitive developmental literature contrasts greatly with the large body of research on time in children's language—in particular, research on the acquisition of tense. Indeed, it has been suggested that "[the] acquisition of tense and aspect has probably been the most prolific topic of research in the field of applied linguistics" (Slabakova, 2002, p. 172). In fact, though, one of the most long-standing and fundamental debates within that literature—namely the debate over whether children's early use of tensed forms marks aspect rather than tense (e.g., Antinucci & Miller, 1976; Rispoli & Bloom, 1985; Weist, Wysocka, Witkowska-Stadnik, Buczowska, & Konieczna, 1984)—can be interpreted as being, at heart, a debate about children's concepts. Put simply, the issue at the core of the debate is whether young children's use of tensed forms marks a genuine deictic relationship (i.e., whether such use is actually underpinned by something like the adult distinction among past, present, and future as different stretches of time in which an event or situation can be located). It is striking that such debates have, by and large, not fed into the mainstream cognitive developmental literature.

The aim of the current article is twofold. First, we wish to briefly summarize Weist's key claims about cognitive development, focusing particularly on the role he accords to temporal decentering. Second, we want to consider relevant research in the cognitive developmental literature that has been conducted since publication of Weist's work and to examine how it relates to the account offered by Weist. In doing so, we distinguish between two features of temporal cognition that may develop in the relevant period: the ability to coordinate at least three locations in time (taken as a hallmark of temporal decentering) and the ability to conceive of temporal locations independently of the events that have occurred at them.

Weist on Temporal Decentering

The earliest research conducted on temporal decentering was described by Cromer (1971). Cromer's study involved telling children a brief story of a sequence of events that was illustrated in a sequence of pictures, with the left/right direction in which the pictures were put in front of the children corresponding to the earlier/later direction in time. One sequence of pictures showed, for instance, a child climbing the ladder of a slide, then the child sliding down the slide, and then finally the child having fallen off the bottom of the slide and with a pained look on her face. Once the complete story had been illustrated, children were asked to point to the picture in which the protagonist might make certain utterances. In Cromer's terminology, a "decentered" response was required when, because of the tense of the utterance, the correct picture to point to was actually different from the picture that showed the event mentioned in the utterance. Thus, for instance, in the story involving the slide, the correct picture to point to in which the depicted child might say "I will go down the slide" is the picture showing her climbing up the ladder. What Cromer found was that it was not until the age of 4 or 5 that children could produce the correct response when a decentered response was required.

Weist seemed to share the general idea behind Cromer's study, according to which temporal decentering involves something akin to the ability to adopt a temporal perspective on an event from a point in time that may not coincide with the time of the event itself or with the present time. Weist's own account of the development of temporal decentering is inspired by Reichenbach's (1947) analysis of tense. One element of this analysis is the basic idea that the use of tense marks the relationship between the time of utterance (Speech Time, ST) and the time of the event that is being referred to (Event Time, ET). For example, in the utterance "I ate the cheese," the tense of the verb marks the fact that the eating of cheese took place at a time before the time of utterance. However, in addition to ST and ET, Reichenbach's analysis also introduces a further, third element that mediates between ST and ET, which is labeled Reference Time (RT). The notion of RT is particularly clear in cases in which it does not coincide with ST or ET (e.g., in the pluperfect/past perfect tense).

Consider a sentence such as "I had eaten the cheese." This sentence introduces a third time that differs from both ST and ET, a time that occurred after the cheese had already been eaten (the ET) but before the current ST. This time is the RT. Similarly, a sentence in the future perfect tense such as "I will have made the bed" introduces an RT that is in the future some time after the bed has already been made. These distinctions among ST, ET, and RT have been widely recognized within the literature (although see, e.g., Klein, 1994, for alternative terminology and analysis).

On Weist's account, even early use of tense marks a deictic relationship, in that it locates the event in question "before now" or "after now" and thus demonstrates some appreciation on the part of the child of the nature of the relationships among past, present, and future. However, children's early use of tense is thought to be underpinned by an understanding of temporal relationships that is severely limited. At this stage (approximately 1 to $2\frac{1}{2}$ years), children can only think of events as occurring before the present or subsequent to it, but they have no way of considering the temporal relationships between events from a different temporal perspective. Thus, crucially, they have no way of grasping, for example, that events that are currently taking place would have been in the future from the perspective of a point of time in the past and will be in the past from the perspective of a point of time in the future. This is the sense in which, on Weist's account, young children are incapable of temporal decentering.

As children get older, Weist argued, temporal decentering emerges in two stages, which are mirrored linguistically in what he calls the Restricted Reference Time system and the Free Reference Time system, respectively. Thus, on his account, children first start to become capable, around 2 to 3 years, of a rudimentary form of decentering in which they can use an RT that can vary between ST and ET. That is to say, there is a sense in which children at this stage can consider past and future events, not just from their own present perspective but also from the perspective of the time when those events happened. However, this kind of decentering is still restricted in that the RT must coincide with one of the temporal locations that children are already capable of considering (ST and ET). At the more advanced stage, children become capable of more flexible decentering that allows them to freely consider temporal relationships between events by using an RT that may not coincide with either ST or ET.

Weist found evidence for the emergence of the Restricted RT system in the initial use of temporal adverbs and adverbial clauses (e.g., "yesterday/tomorrow"; "when ..."). He argued that the early use of such adverbs introduces a specific temporal context with respect to which events happening within that context are then referred to, even though the context cannot yet be easily separated from the events themselves. One way to express this is to say that a child saying "yesterday I made a cake" is not just indicating that the cake-making happened "before now," but is at least attempting to introduce the idea of a particular other time at which it happened, even though the word "yesterday" may not be used with its precise meaning (i.e., as indicating the day immediately preceeding the one on which the utterance is made). Evidence for the more advanced Free RT system is thought to be present when children start making flexible use of temporal prepositions (e.g., "before" and "after") and of certain tensed forms such as the pluperfect ("I had made the cake"). Such linguistic forms seem to clearly introduce an RT that does not coincide with ST or ET.

The Idea of Two Stages in the Development of Temporal Decentering

Although Weist's distinction between two stages of temporal decentering is framed largely in terms of the linguistic correlates of these stages, it is important to consider whether we can further articulate the distinction in terms of stages of cognitive development. Elsewhere, we have argued that one way of thinking about stages of temporal decentering is in terms of a distinction between *perspective switching* and *perspective taking* (McCormack & Hoerl, 1999). The idea is that the very young child may be capable of simply switching between perspectives (e.g., from the present to the past) without having a proper grasp of the nature of the relationship that holds between those perspectives. In contrast, a child capable of true temporal perspective-taking grasps the objective temporal relationships that exist between different temporal perspectives. We can try to make the distinction between perspective switching and perspective taking clearer by drawing a parallel with a distinction made in the literature on pretence.

Pretend play involving object substitution occurs from around 18 months onward and is often discussed as evidence that children's thinking is beginning to become "freed-up" from a preexisting dependence on how things actually are in the world (Harris, 2000; Harris & Kavanaugh, 1993; Woolley, 2002). In pretend play, children seem to be able to switch between different ways of thinking about the same object (e.g., switch from treating a banana as a banana to treating it as a telephone, to use Leslie's [1987, 1988] well-known example). However, early pretence may involve perspective-switching without the child actually being able to conceive of the relationship between the real and the pretend identity of the object—that is, without, for instance, being able to represent "I am pretending of the banana that 'this is a telephone'" (Harris, 1991; Jarrold, Carruthers, Smith, & Boucher, 1994; Smith, 2002). Thus, although pretend play demonstrates that the child can switch between two difference stances regarding the object, the child may not actually grasp the relationship between these difference stances and may realise that they can represent a single object in two ways (Lillard, 1993; Perner, 1991). It may be several years later until children actually understand, for example, the mentalistic nature of pretence (Lillard, 1993, 1994; Rosen, Schwebel, & Singer, 1997). In fact, there is considerable debate within the literature on pretence as to its representational requirements; see Mitchell (2002).

The general point of bringing in an analogy with pretence is not to argue that early in development, children treat past events as in some sense "unreal." Rather, it is to draw out the distinction between more primitive perspective-switching and true perspective-taking. Thus, analogously to the case of early pretence, the earliest form of temporal decentering may merely involve the child mentally switching to a different temporal context without actually fully representing or understanding the temporal relationships that the different context has with other points in time. In contrast, full-blown temporal decentering involves a grasp of the systematic relationships that obtain between different temporal perspectives in virtue of the fact that they are all different perspectives on the same chronology of events. We elaborate on what this may demand in the next sections.

For the moment, it may be worth mentioning a further issue with regard to the two-stage model of temporal decentering: Is there a difference between the two stages not just in the extent to which they involve different degrees of competence in considering temporal relationships but also in the extent to which they are under the child's voluntary control? The idea is that early perspective-switching may be largely either facilitated by adults or triggered relatively automatically by environmental cues, rather than as a result of the child spontaneously starting to think back to the past or deliberate about the future. Certainly, the literature on the development of autobiographical memory has emphasized a developmental shift from talk about the past that relies heavily on adult scaffolding to one that is initiated and structured by the child (Fivush, 1994; Fivush & Hamond, 1990; Nelson, 1993, 1996, 2001; Nelson & Fivush, 2004). Furthermore, Hudson (2002, 2006) has suggested that talk about the future is initially scaffolded by adults in a similar way. Indeed, both in the case of talk about the past and in the case of talk about the future, it has been claimed that individual differences in memory development and in future thinking may be related to the characteristics of parental scaffolding (Fivush, Haden, & Reese, 2006; Hudson, 2002, 2006; Reese, 2002; Reese & Newcombe, 2007).

Measuring Temporal Decentering

Attempts to measure temporal decentering such as Cromer's (1971) rely heavily on linguistic paradigms (see also Harner, 1980). In fact, it is extremely difficult to devise paradigms assessing children's temporal cognition that do not draw heavily on language, which is a possible reason why there are few widely recognized paradigms in the cognitive developmental literature. Are there any other tasks that appear to require temporal decentering as Weist has characterized it? One feature of his characterization is the requirement, as demonstrated by language use involving a separate ST, ET, and RT, that children can coordinate three separate temporal locations. In a recent series of studies (McColgan & McCormack, in press), we have attempted to examine whether 3–5-year-olds can reason flexibly about novel past and future event series in a task that requires considering how at least three locations in time are related to each other (the present, and at least two locations in time in either the past or the future). In that sense, the demands of our task echo Weist's requirements for the Free RT system. One important aim of our studies was to examine whether reasoning about the past and the future emerge in parallel (see Busby & Suddendorf, 2005; Suddendorf & Busby, 2005)—an issue also touched on in the linguistics literature (Harner, 1982).

In both the past and future tasks used in our studies, children were shown a toy zoo with five cages arranged in a semicircle, with a semicircular path that passed each animal. In the central cage, there was a kangaroo. Beside the other cages, but not beside the kangaroo's cage, there were boxes that were described to children as lockers. In the past task, children were introduced to a doll that had a rucksack on her back that contained a Polaroid camera. As she visited each animal in turn, the doll placed the bag in the locker beside the animal's cage. At the kangaroo's cage, there was no locker. At that point, the doll removed the camera from the bag and took a Polaroid photograph of the kangaroo, which remained in view of the child for the rest of the procedure. She then put the camera back in her bag and continued around the zoo visiting the last two animals and putting her bag in the locker beside each in turn. At test, children were shown that the camera was missing from the bag and told that it must have fallen out into one of the lockers. They were then asked to choose one of the lockers to search in; the correct response was to search in one of the two locations visited after the kangaroo (locations 4 and 5).

Answering correctly involved thinking back to when the camera had last been used and then considering the whole temporal sequence of events that had just unfolded in order to identify the possible points in the sequence at which the camera could have been lost.

In the future task, the layout was the same, but the children were introduced to a doll that had a camera but no rucksack. They were told that she wished to take a picture of the kangaroo but needed to leave the camera in a locker so she could pick it up on her way to visit the kangaroo. Children were asked to indicate where she should leave the camera. The correct response was to choose either of the two locations that the doll would visit before the kangaroo (locations 1 and 2). Answering correctly involved thinking about a point in the event sequence at which the camera would be needed and then identifying an occasion prior to that point at which the camera could be picked up.

Three-, four-, and five-year-olds were tested on both types of task. The only age group that performed consistently above chance was the 5-year-old group. Four-year-olds' problems on the future task were robust and remained even when they were cued to think about the temporal order in which the doll would visit the animals and when the task was simplified so that there was only one animal location before and one animal location after the kangaroo. However, simplifying the task did allow 4-year-olds to perform successfully on the past task.

Our results suggest that there are important changes between 3 and 5 years in the ability to reason flexibly about sequences of novel events in the past and future. They also suggest that, at least under some circumstances, 4-year-olds might find it easier to think about the past than about future, hypothetical, event sequences, a finding that is reminiscent of those of Harner (1980) and Cromer (1971). The tasks do have a spatial component, but it is difficult to devise tasks that do not involve translating temporal order into spatial order in an attempt to make it explicit to children. Previous research indicated that preschool children can translate spatial sequences into temporal ones (e.g., Das Gupta & Bryant, 1989; Fivush & Mandler, 1985; Friedman, 1977; Friedman & Kemp, 1998). Furthermore, it seems likely that the fact that temporal order is mirrored in the spatial layout should facilitate rather than hinder performance, particularly because the layout is extremely simple.

Whether these tasks should be considered as tasks measuring temporal decentering in the sense intended by Weist (1989) is another matter. The tasks require children to think about the relationships between events happening at different times (i.e., the camera must have been lost *after* it had been used to take the photograph, and the doll must pick up the camera *before* she reaches the kangaroo). However, the experimenter never uses the terms "before" and "after" during the task, and it would be interesting to examine whether performance on the tasks relates to performance on tasks that actually require children to indicate their comprehension of the terms "before" and "after," such as those of Trosborg (1982). It may also be interesting to examine the relationship between performance on our task and the production and comprehension tasks used by Weist and colleagues that assess young children's capacity to understand referential location in time (see Weist, Lyytinen, Wysocka, & Atanassova, 1997). As we have said though, it is a matter for debate whether our task should be considered to be one that measures temporal decentering in the sense intended by Weist. Unfortunately, the absence of well-established paradigms for measuring this ability makes it difficult to decide this issue empirically. We now turn to consider whether there is a further feature of mature temporal thought that this discussion of McColgan and McCormack's (in press) study has perhaps not brought out sufficiently clearly: the capacity for event-independent thought about times.

Flexible Temporal Location Coordination as the "End Point" of the Development of Temporal Concepts?

In her insightful discussion of the developmental emergence of temporal thought, Nelson (1996) argued strongly that "there is reason to doubt that the developmental course of the expression of ST-ET-RT relations is as constrained by cognitive development as Weist suggests" (p. 281). She based her argument on a consideration of the monologues produced by Emily, a young child whose presleep monologues were recorded by her parents and have since been the focus of considerable interest to researchers interested in the development of language and narrative abilities (see Nelson, 1996). Nelson's argument is that if sections of narrative are considered as a whole rather than dissected into individual sentences, Emily appears to be able to introduce RT and coordinate it with not just one but a number of different ETs before she is even two years old. One possible interpretation of Nelson's (1996) point here is that analysis of individual sentences rather than the connected discourse of a narrative has led to an underestimation of the age at which children start to use a Free RT system. Thus, her argument could be read as an argument about when we should think this advanced system emerges. However, her point needs to be considered in the context of her other suggestions about the role of event knowledge in development. Nelson's (1996) general line of argument is that abstract temporal concepts must emerge from the child's experiences with repeated event sequences. Early in development, temporal concepts may initially only be present implicitly in children's cognitive representations of such sequences. Furthermore, she argued that children may use particular temporal terms in a limited way only within the context of certain familiar event sequences or routines (see, e.g., Emily's formulaic use of "today" and "afternoon," a use that is not, at least initially, underpinned by a genuine comprehension of the terms' meanings).

One interesting interpretation of Nelson's (1996) position is as follows. A basic form of decentering is indeed manifest in Emily's coordination of ST, ET, and RT across a section of narrative, but she can only coordinate temporal relationships within the context of single, usually familiar event sequences. In particular, she has no way of thinking about the temporal relationships among a number of such sequences. Gerhardt (1989) has put the point as follows: "[T]here is no evidence that she can yet interrelate different event frames or freely interpolate events within these frames" (p. 204). We can distinguish two related ideas implicit in this line of thought: First, Emily may have no *unitary* way of representing the temporal relationships between events belonging to all sorts of different event sequences; secondly, she may have *no way to think about time at all*, other than in terms of the events that occupy it and the familiar types of sequences in which they follow each other. It is in this sense that we might say that young children's understanding of time is "event-based" (McCormack & Hoerl, 1999).

We can contrast this with our adult mature concept of time, which allows us to think about a unitary system of temporal locations in a way that is, in an important sense, independent of the events that occur in it. Indeed, our conventional clock and calendar system gives us a very precise way of singling out and referring to any point in time without reference to an event that may have or will occur at that point in time. For example, 11 AM may be the time at which we had coffee today, but the conventional clock system allows us to refer to that time without reference to what happened at that time today or what usually happens at that time. A parallel can be made here with the way we think about space: In our mature way of thinking about space, we can easily distinguish between particular spatial locations and the objects that occupy those locations. Although our way of identifying particular locations may depend, for example, on the ability to refer to objects actually in, or standing in some other spatial relationship to, those locations (cf. e.g., Strawson, 1959), once we have a fix on the location, we can readily conceive of that location independently of those objects; for example, we can think of the place where our car is parked as a space that might also be empty or where someone else's car might be parked.

A crucial difference between the spatial and the temporal case is that it may be more difficult for children to learn to conceive of time as event independent than it is for them to learn to conceive of space as object independent. For example, an adult can refer to an empty spatial location (e.g., by saying "put the chair there") and indicate the specific spatial location they have in mind in a way that makes it visually obvious, whereas it is much harder to make verbal reference to a specific point in time without referring to certain events that have occurred or will occur at that time. Of course, the conventional clock and calendar system allows such event-independent reference, but the developmental period under consideration precedes children's competence with that system (Friedman, 1982, 1989, 1990), and it is tempting to assume that children can only make sense of the system if they already have the necessary way of thinking about time.

We do not wish to dwell here on issues concerning the development of spatial versus temporal concepts (see e.g., Friedman & Brudos, 1988). The general point is that there is an aspect of our mature concept of time that goes beyond the basic notion of temporal decentering as described in terms of the coordination of different points in time. On Nelson's account, development is to a large extent a matter of thought about time becoming "freed up" from thought about familiar sequences of events. Her considerations suggest that linguistic evidence of coordinating a number of points in time (ST, ET, and RT) falls short of demonstrating a mature concept of time precisely because such coordination may still be underpinned by an event-based notion of time (see Campbell, 2006, for a related argument). When children have only an event-based understanding of time, they might indeed be able to coordinate temporal relationships within individual event sequences, but they have no unitary temporal framework that allows them to consider the temporal locations of events independently of those events themselves.

The idea that development involves children's thought about time becoming independent from the events that occur within it is not a new one (and Nelson's [1996] seminal work on children's representations of event sequences provides a rich context for exploring such a notion). Although Piagetian work on time has largely focused on children's grasp of the relationships among time, speed, and distance, his basic claim was that children's early notion of time was closely tied to observable properties of objects or events. Demonstrations that young children conflate temporal duration with, for example, distance traveled (Piaget, 1969; see Wilkening, 1982) or amount of activity (Arlin, 1986) were originally interpreted within the Piagetian framework as evidence that young children cannot abstract time from other event dimensions. The notion of a shift from event-dependent to event-independent thought about time also appears to be a central one within the linguistics literature. The aspect-before-tense debate is largely a debate about whether children's early use of tensed forms marks properties of events (such as, e.g., completion) rather than the deictic relationship of tense. Although it is not clear that the linguistic evidence supports strong versions of this claim, our understanding of the more recent literature is that children do find it easier to understand some types of tensed verbs (i.e., those describing certain sorts of events) than others; as Wagner (2001) put it, there are aspectual influences on tense comprehension. Furthermore, there is some evidence that the earliest uses of past tense forms are more likely to occur in certain event contexts and for certain types of verbs than others (Shirai & Miyata, 2006). In other words, the basic intuition behind the aspect-before-tense hypothesis—that children's understanding of time is closely tied to their representations of events—may be correct, even if a strong version of the hypothesis is not. Indeed, although Weist (1989) argued against the aspect-before-tense hypothesis, one way of interpreting the cognitive underpinning of his distinction between the Restricted and Free RT systems is that at the Restricted stage, children's use of RT is dependent on knowledge about particular events that happened or will happen at that time (inasfar as they can separate RT from ST at all). Furthermore, Weist (1986, 1989) has argued that young children's mastery of the terms "before" and "after" is limited in a sense that suggests a difficulty separating times of events' occurrence from the events themselves. In particular, they have difficulty in understanding these terms when the order of mention of occurrence of events is the reverse of the order of actual occurrence (Trosborg, 1982).

From Event-Based to Event-Independent Understanding of Time

We have suggested that children's grasp of time and of temporal order relationships is initially tied to their knowledge of familiar event sequences. To get a better understanding of the kind of limitation at issue here, it might help to consider some recent empirical research that might also be interpreted as suggesting that there is a developmental shift from an event-based to an event-independent understanding of time.

It is a feature of the adult concepts "before" and "after" that they can be applied to arbitrary pairs of events. For example, we can easily make sense of the question as to whether one past event occurred before or after another one, even if the events in question were entirely unrelated and occurred at widely spaced intervals. If young children's understanding of time is indeed event based in the way we have suggested, they cannot be said to have a full grasp of those concepts. Yet, an empirical challenge to this idea might be thought to come from research carried out by William Friedman, who has examined a wide variety of aspects of children's temporal cognition. In one study with 4-year-olds (Friedman, 1991), children were asked to judge the relative recency of two novel events that had happened in a school-based setting. The two events were "one-off" events that were not related to each other, such as a demonstration of tooth-brushing technique using an oversized toothbrush or a visitor making a video of the class. One of the events took place 7 weeks before the test and the other took place 1 week before the test. What Friedman found was that even 4-year-olds were above chance in answering the question as to which of the two had happened a long time ago and which happened a short time ago.

Along with other studies, including ones involving adults (Friedman & Huttenlocher, 1997), this study provides strong evidence for what Friedman calls "distance-based" processes, which can at least sometimes inform temporal judgments (see Friedman, 1993). The children who passed Friedman's task were at chance when asked about the day of the week or month in which each of the events had happened, suggesting that their responses were not made on the basis of locating the two events in a conventional time pattern (e.g., on the basis of knowledge that one event happened in February and another in April). Instead, they seemed to rely on some sort of direct impression of distance from the present of the events in question.

Friedman's (1991) results may be thought to suggest that, at least by 4 years, children have some basic notion of distance in time that allows them to think about the relative recency (i.e., distance from the present) of any pairs of events, even unrelated ones widely separated in time. It is not obvious, though, that this equates to an understanding of the temporal relationship between those two events in terms of something like the adult concepts of "before" and "after." In particular, it is unclear whether successful performance on Friedman's task requires a grasp of a linear order leading up to the present along which past events are arranged (McCormack & Hoerl, 2001). Consider again a spatial analogy. A child might know, of two separate places that are visited on a regular basis, that one is further away than the other, without this implying that the child has a proper grasp of how these two places are related to one another. Because of the linear structure of time, it is, of course, in principle possible to derive information about the relation between two past events from information about their respective distances from the present, in a way for which there is no analogue in the spatial case. The question here, though, is what a grasp of time as linear comes to, and whether children do in fact have such a grasp. There is also some evidence from other work of Friedman's (2000) that children are prone to confuse the near future with the recent past in their judgments about the distance of events from the present. Thus, using distance-based processes to arrive at judgments about the relative recency of two events may actually be compatible with a very limited understanding of the structure of time.

One important aspect of a mature understanding of before/after relationships is a grasp of the fact that when two events have happened, it can often make a difference to the overall result which of the two events happened before the other. Indeed, it can be argued that this type of understanding is crucial for grasp of time as linear (Martin, 2001; McCormack & Hoerl, 2005). One study that has examined the development of this sort of understanding is reported by Povinelli, Landry, Theall, Clark, and Castille (1999). The study involved children sitting at a table facing an experimenter, who played first one game and then a second game with the child. Located behind the child were two different boxes and a second experimenter, who put a puppet into one of the two boxes during game 1 and then moved the puppet to the other box during game 2. A video camera was set up to capture, from over the shoulder of the first experimenter, the child playing the two games and, behind the child, the second experimenter hiding the puppet. After the two games had finished, the child was invited to watch the video-recording, now seeing for the first time the second experimenter hiding the puppet in the two boxes. The crucial manipulation was that children were shown two separate video clips of the two games they had played, and they were not always shown the two video-clips in the order in which they had played the games. After they had watched the two video-clips, the children were then asked which box they thought the puppet was in now. Three-year olds were at chance in answering this question; 5-year olds could make the appropriate inference, although they needed to be reminded about the order in which the games were played.

In their study, Povinelli et al. (1999) sought to make sure that children did remember which of the two games they had actually played more recently; that is, unlike in Friedman's study, their interest was not in assessing whether children could make relative recency judgments about the two game-playing events. Rather, they were concerned with whether children can put such relative recency information to work in their reasoning about how the world is right now. As they put it, their interest was in whether children understood "that the events from their recent past are part of a causal arrow of time—a flow of events leading up to and causally determining the present" (Povinelli et al., 1999, p. 1433). Arguably, what Povinelli et al.'s task also brings out, though, is that this sort of understanding requires what we have referred to as an event-independent understanding of time, at least in the following sense. To pass the task, children need to grasp that their memory of which of the two games they played more recently gives them information about the relative order of two different points in time that they can also use in determining which of the two puppet-hiding events was the more recent one. In other words, the task involves not just the ability to get right the order in which the two games were played but also a grasp of the fact that when each of the two games was played, it coincided with another event (the puppet-hiding events). Thus, the task seems to require the general idea of points in time at which events of *different* types can coincide with one another.

Of course, in Povinelli et al.'s (1999) task, children must also realize that the information they are being provided with in the videos can be used to find out which puppet-hiding event coincided with which game. Although Povinelli et al. argued that children of the relevant age do not have a general problem with using information provided by a videotape, ideally their findings would be extended to a context in which this representational medium was not employed. That children seem to have difficulties with thinking about times independently of the events that happen at those times is perhaps demonstrated even more clearly in two experiments we have carried out, which were originally inspired by Povinelli et al.'s study. These studies involved events that children could not perceive at the time of their occurrence, but they did not involve showing videotape footage.

In one of the studies (McCormack & Hoerl, 2005), children were initially introduced to two dolls, Sally and Katy, who always performed actions in a certain order: They learned that Sally always went first and then Katy always went next. Children were also shown a novel piece of apparatus—a large yellow box with two differently colored buttons—and learned how it worked. Pressing one of the buttons caused a toy car to drop down one chute and appear on a shelf in a transparent window, whereas pressing the other button caused a marble to drop down another chute and appear on the shelf. The box was mechanically constructed such that whatever toy was already in the window dropped out of sight into a drawer below before a new toy appeared, so that there was only ever one toy left in the window, and which toy that was depended on which button had been pressed last. Children were given the opportunity to learn which button yielded which toy. At test, a screen was then put in front of the box and, out of view of the child, Sally and Katy pressed one button each. Finally, the box was uncovered again. In one version of the task, after the screen was removed, children could see each doll standing next to the button that she had pressed, but the window in the box was left occluded. In this version, which

4-year-olds consistently failed, children had to infer which toy was inside the window.

The other study (McCormack & Hoerl, 2007) also involved two doll characters, John and Peter, and a doll's house with a bathroom that had a door that could be closed, so that children could not look inside it; the experimenter still had access to the bathroom through the back of the doll's house. The children were told that the dolls were going to go into the bathroom to brush their hair, which had got messy when they were playing outside. The hairbrush, which was sitting by the bathroom sink, was pointed out to them, as were two differently colored cupboards. When the two dolls went into the bathroom, the experimenter closed the door and then said "You can't see John right now, but he goes first and gets the hairbrush and now he is brushing his hair. Now he puts the hairbrush in one of the cupboards. Peter goes last. You can't see him now, but he gets the hairbrush out and now he is brushing his hair. Now he puts the hairbrush into the other cupboard." After this, the bathroom door was opened to reveal each of the dolls standing beside one of the cupboards. Participants were then told that each doll was standing beside the cupboard that he had placed the hairbrush in and were asked two control questions to confirm that they could remember the order in which the two dolls had brushed their hair, followed by the test question "So, where do you think the brush is right now?" Four-year-olds performed at chance in this task, although 5-year-olds were successful.

One way of thinking of both of these tasks, which might explain the nature of the difficulty children had with it, is as follows. To answer the question as to which toy is in the window or which cupboard the hairbrush is in, the children have to bring together information about the order in which the dolls had acted with information, supplied at a later time, about the particular action each of the dolls had carried out. Arguably, though, bringing together these two pieces of information requires operating with a notion such as "the time when Katy pressed the button," which they can then subsequently also think of "the time when the blue button was pressed," in order to arrive at the conclusion that the blue button was pressed after the red one. What is required here is the ability to think, not just in terms of event types, which typically happen before or after certain other event types (as in a familiar sequence), but in terms of a sequence of points in time, about which more and more information is revealed as the experiment progresses, so that a point in time at which a particular event of a certain type has happened can later also be identified as the point in time at which a particular event of some different type has happened.

Put this way, one distinctive feature of event-independent thought about times is that it involves a way of thinking about points in time that leaves open, at least to some extent, which events happened at those points in time. Yet, it might be thought that event-independent thought about time in this sense can actually already be found in children's representations of familiar event sequences of the type studied by Nelson, which are often referred to as scripts (Nelson, 1986; Schank & Abelson, 1977). In the literature on children's grasp of scripts, it is typically assumed that scripts can include optional elements. A child's script for going to a fast-food restaurant, for instance, may leave open which drink the child chooses. Thus, there is a sense in which scripts may include placeholders that can be filled in different ways on different occasions when the sequence of activities described by the script is carried out. There are good reasons, though, for thinking that operating with such placeholders within a script falls short of a genuine appreciation of different possibilities and that we can therefore distinguish between this sort of case and one in which what we have called event-independent thinking about time is present.

A perhaps unexpectedly relevant set of results here comes from recent research on children's ability to make counterfactual and hypothetical judgments. There is a considerable body of research that suggests that 3–4-year-olds can give the correct answer to questions about what might have happened if things had unfolded in a different way than they actually did (e.g., German & Nichols, 2003; Harris, German, & Mills, 1996; Perner, Sprung, & Steinkogler, 2004). However, it is not clear that such counterfactual judgments are always underpinned by the adult notion that what has happened is only one outcome from a number of past possibilities or that what will happen is also only one outcome from a number of future possibilities. Beck, Robinson, Carroll, and Apperly (2006) attempted to examine this issue by asking children what they call "open" counterfactual questions. Their experimental apparatus involved a vertical tube that branched in two in the middle. In one study, a ball was dropped down the apparatus and, on any given trial, could emerge from either branch. Once the ball had emerged, children were either asked "What if it had gone the other way, where would it be?" (the authors called this the "standard counterfactual question") or "Could it have gone anywhere else?" (the "open counterfactual question"). A 3–4-year-old group found the standard counterfactual question much easier to answer than the open counterfactual question. Additional experiments allowed children the opportunity to demonstrate their understanding that, on any given trial, an object could travel down either one of two tubes by placing a mat under each tube to catch a falling object. Again, young children's responses demonstrated they had difficulty grasping that there was more than one possible outcome.

In order to explain the particular difficulty children have with the open counterfactual question, Beck et al. (2006, p. 420) suggested that they may actually be able to answer the standard counterfactual question correctly "without necessarily thinking in terms of alternative possibilities." The first half of the question may simply tell them to imagine a certain scenario, and the second half then ask them to provide further information about a feature of that imagined scenario. All this they may be able to do without taking into consideration what actually happened. In contrast, answering the open counterfactual question does seem to require considering thinking back to an earlier time and recognizing that although events unfolded a certain way at that time, there was a possibility that they could have unfolded some other way.

Beck et al. (2006, p. 423), who also presented similar findings from studies involving future hypotheticals, concluded that "we have no evidence to support the proposal that when 3- and 4-year-olds answer counterfactual and future hypothetical questions they are treating them as possibilities." This conclusion is provocative because it suggests that children's thinking about the past and future may be "event based" in a very specific way: They cannot conceive of a point in time as a point at which an event actually happened, but might also not have happened, and at which a different event might have happened instead. In other words, they do not operate with a notion of points in time which would allow them to think backward or forward in time to the point in time at which certain events have happened or will happen and then to think of that point in time as one at which other events might have happened. Inasfar as they can imagine alternative scenarios to the actual world, they do not consider them as ways the world might actually have been at a particular point in time. Thus, Beck et al.'s study provides further confirmation of a developmental change from an event-based to an event-independent thinking about time.

Temporal Cognition and "Mental Time Travel"

Our opening remarks regarding the dearth of work on temporal cognition in recent developmental psychology may have seemed surprising to readers familiar with recent publications on the development of "mental time travel" in children (e.g., Atance & O'Neil, 2005; Suddendorf & Busby, 2005). This topic has become the focus of much attention in developmental psychology, spurred on to some extent by debates in comparative psychology as to whether animals are capable of mental time travel or whether this is a uniquely human achievement (Clayton, Bussey, & Dickinson, 2003; Suddendorf & Corballis, 2007; Tulving, 2005).

On the face of it, a number of issues discussed under the topic of mental time travel might seem very close to issues that we have raised in this article. For instance, mental time travel is often seen as involving an imaginative recreation of past experiences or of possible future experiences, or the ability "to mentally project [oneself] backwards in time to re-live or forwards to pre-live events" (Suddendorf & Corballis, 2007, p. 299). Arguably, what we have described as temporal decentering also involves some form of exercise of the imagination that might be described in quite similar terms.

Yet, throughout much of the current debate about mental time travel and, for instance, its development in children, an ability for temporal cognition is often just taken for granted; that is, researchers often write as though young children can already be credited with a view of time as stretching from the past, through the present, to the future, and populated with a variety of events of which they know the "what, where and when" (Suddendorf & Corballis, 2007). Instead, they focus on what they see as further abilities—such as meta-representational abilities (Perner, 2001), a certain kind of self-consciousness (Tulving, 2001, 2005), or the ability to set aside present desires in planning for the future (Atance & Meltzoff, 2005, 2006)—which might be required to "travel" in imagination forward and backward in time.

Conclusion

In our view, one key insight of Weist's work, and of some of the other researchers we have mentioned in this article, is that the very ability to think about events in time, far from being easily explained in terms of a basic ability to record "what, where, and when" information about events, is a sophisticated developmental achievement. In this article, we have concentrated on two abilities that can be seen to be involved in such development. The first ability, highlighted by Weist, is temporal decentering. However, we have argued that if this is understood just as the ability to coordinate several different locations in time, then the notion of temporal decentering in itself falls short of a description of mature temporal cognition. Specifically, we have discussed whether a richer notion of a developmental shift from an event-dependent to an event-independent concept of time is necessary to capture important changes in the first 5 years of life.

Indeed, Weist's own characterization of the difference between the Restricted and the Free RT system, which involves the idea of children becoming able to consider events using an RT that is separate from both ST and ET, can be seen as implicitly drawing upon this idea.

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Temporal Cognition and Temporal Language the First and Second Times Around. Commentary on McCormack and Hoerl

Nick C. Ellis
University of Michigan

> He had complimented me on how I spoke Italian, and we talked together very easily. One day I had said that Italian seemed such an easy language to me that I could not take a great interest in it; everything was so easy to say. "Ah, yes," the major said. "Why, then, do you not take up the use of grammar?" So we took up the use of grammar, and soon Italian was such a difficult language that I was afraid to talk to him until I had the grammar straight in my mind. (Hemingway, 1927)

McCormack and Hoerl's state of the art review of the development of temporal concepts from the end of infancy to the end of the fifth year shows that young children's conception of time is quite different from that of adults. Adults and 5-year-old children can construe an event from a range of temporal perspectives and can describe it from a variety of reference times (RTs) that may not coincide with the time of the event itself (ET) or with the time of speaking (ST). Younger children are incapable of such temporal decentring. Two-year-olds' use of tense suggests that although they do understand that events can occur before now (as in *I ate*) or after now (*I will eat*), thus coordinating ET and ST, the complexities of ST > ET > RT (*I will have eaten*) or ET > RT > ST (*I had eaten*) demand additional sophistications. The developmental progression is that RT is first freed from the here-and-now of ST to permit an additional perspective from ET (e.g., *I was eating*), and eventually it is loosed from ET too. These milestones mark the slow realization of abstract abilities of *perspective-taking*, rather than *perspective-switching*, and demonstrate the appreciation of

Correspondence concerning this article should be addressed to Nick C. Ellis, English Language Institute, Department of Psychology, University of Michigan, Rm. 1011, 500 East Washington Street, Ann Arbor, MI 48104-2028. Internet: ncellis@umich.edu

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systematic relationships between the different temporal perspectives possible on the same chronological event sequence. First comes the appreciation of the "causal arrow of time," the flow of events leading up to a particular state, and then the development of means of bending descriptions from a variety of perspectives upon it: As Groucho Marx observed, "Time flies like an arrow. Fruit flies like a banana."

McCormack and Hoerl show that the development of temporal cognition extends over several years: It is initially heavily reliant upon adult scaffolding; its first expressions are tied to particular familiar sequences and routines (they are event based); and its subsequent use as event-independent, generalized co-ordinations emerges first from learner's analyses of sequences of past concrete events rather than future hypotheticals.

There are clear parallels with general aspects of child language development. Two examples will suffice. The first relates to the progression from concrete operations to formal reasoning. In language too, abstract constructions emerge from the conspiracy of concrete exemplars of usage, thus constructionist perspectives on first language acquisition describe the progression from formulaic expressions describing familiar routines and meanings, through limited scope patterns, eventually to abstract schematic constructions. The second relates to the social construction of language: Social coordination of attention, scaffolding, and the reading of others' intentions are all paramount. There are many such aspects of learning and development that are domain-free and that apply equally to the understanding of sequences of events and the understanding of sequences of language.

However, the content of these two cognitive domains is very different indeed, and so learning to refer to time in language must build upon the separable sources of temporal cognition and linguistic cognition, as well as on the relations between these as experienced in contextualized spoken usage, all messy, noisy, abbreviated, and referentially indeterminate.

The influence of semantics on language acquisition is universal. The Aspect hypothesis (Andersen & Shirai, 1994) is a clear case in point. Child language learners are initially influenced by the inherent semantic aspect of verbs in the acquisition of tense and aspect morphology affixed to these verbs. Thus, (perfective) past emerges earlier for telic verbs (achievements and accomplishments with a clear end point, like *retire*, *wake*, *disappear*) and progressive for verbs associated with dynamic atelics (e.g., activities such as *play*, *walk*, and *look*). One interpretation of such aspect-before-tense phenomena is that children's understanding of time in language is closely tied to their representations of time and event sequences.

There are two different strategies of testing this hypothesis. One, clearly exemplified by McCormack and Hoerl, is to set up elegant assessments of children's cognition where the task demands are as language-free as possible. The experiments on time by McCormack and Hoerl, like those she reviews within Theory of Mind (TOM) research, are cleverly crafted. Developmentalists are really good at this sort of thing. I am reminded of the classic off-the-cuff designs of Piaget (1928) and Bryant (1974) and the TOM tasks of Meltzoff (Meltzoff & Moore, 1995) and Baron-Cohen (Baron-Cohen, Cosmides, & Tooby 1997) testing complex notions like *I think that you think that . . .* in young children. McCormack's work shows that you can make children's temporal cognition observable thus to empirically assess the likelihood of several competing hypothetical interpretations.

However, there is another strategy for determining the degree to which temporal language development is constrained by temporal understanding or, alternatively, to the relations of time and language in *thinking for speaking* about time (Slobin, 1996)—that is to compare first language acquisition (L1A) with second language acquisition (L2A) in adult learners who have fully developed temporal cognition. In the remainder of my comments I will focus on two phenomena of L2A of tense and aspect, which talk to these issues.

The first is the aspect hypothesis, again, but this time as it applies in L2A. Adults have developed sophisticated understandings of time and they know all about expressing time in their L1. Nevertheless, aspect-before-tense phenomena also prevail in L2A (Andersen & Shirai, 1994; Bardovi-Harlig, 2000; Li & Shirai, 2000). Adult language learners, too, are sensitive to the lexical aspects of verbs, initially using combinations of lexical and grammatical aspect that are maximally compatible, with telicity being a particularly salient feature. Thus, L2 learners from a wide variety of L1/L2 combinations first use perfective past marking on achievements and accomplishments, and only later do they extend this to activities and state. Similarly, in L2s that have the progressive aspect, progressive marking begins with activities and only extends slowly thereafter to accomplishments and achievements. If aspect-before-tense characterizes adult L2A too, then these patterns of language development do not reflect thinking about time but rather thinking for speaking about time.

The second issue concerns L2 tense marking and morphology more generally. Adults are very good at thinking about time and very good at talking about time in their native language. However, this sophistication is severely curtailed in languages learned naturalistically in adulthood. Unlike love, temporal reference does not get lovelier the second time around.

All languages have rich means to express the position of events in a time line, including verbal morphology (e.g., *walked* vs. *walk*), lexical adverbs (e.g., *now, next, yesterday, tomorrow*), prepositional phrases (*in the morning, in the future*), serialization (presenting events in their order of occurrence), and calendric reference (*May 12, Monday*) (Evans, 2003). Any stretch of discourse typically uses a variety of these cues in combination (e.g., *yesterday I walked to the university but next Tuesday I'll ride the bus*). Children acquiring their L1 eventually learn all of these constructions for expressing time. Adults learning an L2 often do not (Bardovi-Harlig, 2000; Noyau, Klein, & Dietrich, 1995; Perdue, 1993; Schumann, 1987). Usage-based L2A is typically limited in its end state, with naturalistic, uninstructed, or communicatively-based L2A stabilizing at levels far short of nativelike ability at a *Basic Variety* of interlanguage, which, although sufficient for everyday communicative purposes, predominantly comprises just nouns, verbs, and adverbs, with closed-class items, in particular grammatical morphemes and prepositions, being rare, if present at all. As Wolfgang Klein has put it, "there is no functional inflection whatsoever: no tense, no aspect, no mood, no agreement, no casemarking, no gender assignment . . ." (Klein, 1998, pp. 544–545). L2 temporal reference is initially made exclusively by the use of devices such as temporal adverbials, prepositional phrases, serialization, and calendric reference, with the grammatical expression of tense and aspect emerging only slowly thereafter, if at all.

Why do adult L2 learners have difficulty attending to and producing verbal inflections? It cannot be their lack of temporal understanding. More likely are alternative cognitive explanations (Ellis, 2006a, 2006b) in terms of form-function contingency, attention, learning, and transfer, particularly the domain general associative learning phenomena of (a) cue salience, (b) cue redundancy, and (c) the attentional blocking of later experienced cues by earlier learned ones:

(a) *Cue salience*: Lexical cues to time are quite pronounced in the speech stream; verbal inflections are not (consider ***yesterday** I walk**ed***). The low salience of grammatical cues tends to make them less learnable (Goldschneider & DeKeyser, 2001; Slobin, 1992).
(b) *Cue redundancy*: On hearing *yesterday I walked*, the morphological tense marker is redundant; successful interpretation of the message does not require its processing, and the lack of processing entails a lack of acquisition (Terrell, 1991; Van Patten, 1996).
(c) *Blocking*: Learning that a particular stimulus (A) is associated with a particular outcome (X) makes it harder to learn that another cue (B), subsequently paired with that same outcome, is also a good predictor of

it (Kruschke, 2006). Our research has shown its short-term and long-term effects in adult language learning (Ellis, 2007).

Phenomena (a) and (b) apply equally to L1A and L2A. It is phenomenon (c) then, blocking, that may be particularly important in L2A. As McCormack and Hoerl show, when children are acquiring their native language, they are at the same time learning about the world and about various discourse strategies. Young children do not yet know about the custom of recounting events in their usual script order of occurrence, nor do they clearly understand the meaning of temporal adverbs or calendric reference. Studies that have directly compared the acquisition of different systems of marking temporality report morphological means of temporal reference preceding the use of temporal adverbials in children's speech (e.g., Pawlak, Oehlrich, & Weist, 2006) with comprehension studies suggesting that 3-year-olds are able to distinguish minimal tense-aspect morphological contrasts but not contrasts between lexical forms such as *when/then, before/after* (Weist, Atanassova, Wysocka, & Pawlak, 1999) and that 2-year-olds can differentiate past and present tense on the basis of the auxiliaries *will* and *did*, copula *be*, and progressive but are not aided by the inclusion of temporal adverbials (Valian, 2006). Older learners, however, as a result of their L1 experience, do know these things. Perhaps these already known cues block the L2A of verbal morphology. Adult speakers know that temporal adverbs are more reliable than the nonsalient and ambiguous verbal inflections, and, like Hemingway's speaker of Italian, they can usually get their message across by lexical means alone—however ungrammatical, the Basic Variety is communicatively effective. Thus, adult language learners, in the words of Simon (1957), "satisfice" rather than "optimize." They can get by, and, in the words of Robert Byrne, "Doing a thing well is often a waste of time."

These phenomena show the necessity for the understanding of time and language of different strands of research. Domain general explanations from associative learning theory, cognitive science, and socio-constructive processes apply. However, cognitive content is crucial too, as are functional analyses. An understanding of temporal cognition informs our understanding of the acquisition of temporality in language. However, it is mutual. Studies of L2A inform and constrain our theories of L1A and temporal cognition too.

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Time, Language, and Autobiographical Memory

Christopher D. B. Burt
University of Canterbury, Christchurch

Life themes, general events, and event-specific episodes, together with autobiographical knowledge, form autobiographical memory. Each of these memory structures is described, and research that has investigated the storage and retrieval of temporal information for life events, such as place in time, duration, and order, is examined. The general conclusion across all autobiographical memory structures is that very little temporal information is stored in memory. Retrieval of temporal information generally involves constructive processes that use landmark events, distance-based information, life scripts, and general event scripts. The link between these constructive processes and the use of language to express temporal information in autobiographical event narratives is discussed.

Time is a construct by which autobiographical experiences can be ordered, understood, and predicted. It is probably true that almost every description we provide about our life, from the broadest feature to the specific occurrence, will contain temporal markers. For example, when narrating a life experience or when engaged in conversation about some past experience, it is often the case that the event's place in time is implied, its relationship with other past events is apparent, there is an order to the event's key features, and a duration is implied. The specific focus of this article is the relationship between time and autobiographical memory, and, in particular, autobiographical memory representations and the processing of temporal order. The use of temporal markers in autobiographical accounts could simply reflect experience-specific temporal information, which is stored in autobiographical memory. Alternatively, temporal markers could result from rather complex cognitive processing

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Correspondence concerning this article should be addressed to Christopher D. B. Burt, Department of Psychology, University of Canterbury, Private Bag 4800, Christchurch, New Zealand. Internet: christopher.burt@canterbury.ac.nz

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of time-relevant autobiographical knowledge. The evidence for each of these possibilities is examined.

The article begins by defining autobiographical memory. In this section the four primary structures that are suggested to form autobiographical memory are outlined: life themes, general events, event-specific episodes, and autobiographical knowledge. Each of these autobiographical memory structures has its own unique temporal characteristics, and these structures provide a framework for the rest of the article. Research on the temporal attributes of each autobiographical memory structure is examined, looking first for evidence that time information is directly encoded as part of the structure and then at how time information might be either directly retrieved or constructed.

The study of autobiographical memory within cognitive psychology began with a number of attempts to distinguish it from other types of memory. One feature that persistently appears in definitions of autobiographical memories is that they are linked to a specific time and place (Rubin, 1986; Tulving, 2002). For example, when and where you first met your partner would be considered an autobiographical memory. Thus, autobiographical memories are described as being temporally definable (they can be dated), and autobiographical events are assumed to occur on a temporal continuum, one after another. Autobiographical memories can be contrasted with other types of memory, such as how an individual remembers a sequence such as AB44428, which is generally not linked to a specific time or place. The simple inclusion of the time tag, the "when it happened" component, in the definition of autobiographical memory makes it easy to describe how autobiographical memories are different from other memories and in part helped legitimize the field of study. Another key feature of autobiographical memories is that they are related to the *self* and have personal significance (Conway, 2005; Conway & Rubin, 1993). Being related to the self, autobiographical memories define who the person is, rather than what they know. However, and as will be discussed below, an individual will also develop autobiographical knowledge, such as knowing that occurrences of a particular type of event often have similar characteristics, and this can play an important part in developing our autobiographical memories.

In the 1980s the tempo of empirical studies on autobiographical memory began to increase, as did the process of developing our theoretical understanding of the organization and retrieval of autobiographical memories. Emerging from this research was a more complex view of autobiographical memory and, in particular, the recognition that it contains at least four definable memory structures. At the broadest level are *life themes*, such as "when I was at college" and "when I was married to Jane." Indexed within and across these life themes are *general events*, such as "skiing in New Zealand" and "when I broke my leg rock climbing." Indexed to general events are fragments of event-specific knowledge (Conway & Pleydell-Pearce, 2000) or the *episodic components* of the event (Burt, Kemp, & Conway, 2003), such as "preparing the gear for the rock climbing trip, driving into the mountains, the hike to the cliff face, the crack as the anchor pin snapped." Finally, life experiences give rise to *autobiographical knowledge*. Autobiographical knowledge can be shared with other members of our culture, such as the *scripts* that Schank and Abelson (1977) defined, or be somewhat more idiosyncratic to the individual.

A common feature of all four autobiographical memory structures is that they have time-related characteristics. Life themes typically have distinct beginning and end points, and these result in definable durations. The overlapping nature of life themes (e.g., you can be in college and in a relationship with Jane at the same time) allows for sublevels of definable duration. Life themes also have an order that defines their place in the life span or developmental sequence. Furthermore, within a specific culture, certain life themes often occur at rather predictable points in the life span. General events typically occur at a more specific point in time (sometimes a specific day, but, more often, over several days; see Burt et al., 2003), have a before and after relationship with other general events, and have an embedded episodic component sequence. For example, the embedded episodic component sequence defines such things as the order of activities at a picnic. Finally, life experiences allow individuals to gain autobiographical knowledge about various aspects of time, such as duration (e.g., people generally spend 3–4 years at college) and order (e.g., the waiter normally brings the menu before you eat your meal).

The development of autobiographical memory is also linked to an understanding of time constructs. Developmental psychologists have noted that the emergence of autobiographical memory coincides with the development of language and an understanding of at least two levels of temporal ordering. The ordering of sequences within an experience is required for coherent autobiographical memories to be formed (Bauer, Wenner, Dropik, & Wewerka, 2000; Nelson, 1986), as is being able to place the event narrative at a time in the past. Friedman (1993) noted that an understanding of sequence, duration, and a personal past begins during the preschool years (ages 3 to 4) and that it is around this time that children begin to develop autobiographical memories.

The four autobiographical memory structures and the use of temporal markers are evident in the following autobiographical memory description, which for ease of reference is referred to below as the *First date with Jane*: "I met Jane while at University. I was in my first year, and Jane was in her second year, but we were both taking PSYC101.. We had spoken at lectures a few times, and one day I asked her out. At the time I was part of a drama club and they were having a fund raising dinner. So I asked Jane if she wanted to go, and she said yes. It was a formal dinner, so I bought a new shirt, hired a suit and borrowed some shoes off my brother. We had a great night. Jane met an old friend there. The meal was really good, but we had to wait ages between courses. There was a fund raising auction and speakers after dinner. After that was over, a few of us ran off and got a taxi to the Surf Club, and finally we ended up at the Green House for breakfast. That was our first date, and your mum and I got married the following year."

This account contains information about several life themes, "while at university," "both taking PSYC101," and "part of a drama club." There is also a general event, the "fund raising dinner," which has major personal significance because it was the first date with the narrator's spouse and, as such, marked the beginning of a life theme. The general event was described as having several associated events: asking Jane if she would go, buying the shirt, hiring the suit, and borrowing the shoes. The dinner component of the event was described as having a number of episodic components, the *dinner, fund raising auction, after dinner speakers, taxi ride*, and so forth. Finally, the comment that "we had to wait ages between courses" reflects the operation of autobiographical knowledge about event duration—in that the between course waiting time was seen as atypical. Reading or listening to the above autobiographical description, one might conclude that the individual has a lot of temporal information stored in memory that was remembered and used to tell the story. However, is this the case?

Autobiographical Memory Research on Time

A general feature of much of the research on autobiographical memory for time has been to examine retrieval accuracy and to attempt to answer the question: Can a specific temporal feature be recalled accurately? Although this type of objective comparison of a memorial report against a known standard makes for easy application of statistics, it may result in an assessment that does not match the types of demands individuals typically have for temporal information; that is, rarely in everyday life or in conversation is absolute accuracy of temporal information critical. Of course, an ability to retrieve accurate temporal information would suggest that the use of temporal markers in autobiographical memories may be based on temporal information, which is actually stored in memory.

Empirical research and theoretical developments on the temporal aspects of autobiographical memory have primarily occurred in four areas, each of which is discussed below. A small amount of research has examined life themes and, in particular, their distribution over the life span. Considerable effort has been expended studying how individuals recall when a specific general event occurred. This research also partly addresses the question of how events might be ordered. Somewhat less research has examined the accuracy with which the temporal order of episodic components within an autobiographical experience are remembered and the associated storage and retrieval mechanisms. Finally, autobiographical event descriptions often contain information about duration, and this can imply aspects of experiential order. Thus, research on retrieving the duration of autobiographical events will be discussed.

Temporal Order of Autobiographical Themes

Life themes are not so much an autobiographical experience as they are a superordinate label that is associated with various general events. Robinson (1992) referred to these as *personal histories*, "primary forms of organization in autobiographical memory . . . (that) organize temporally distributed experience into thematically-related 'streams'" (p. 223). A life theme is the sum of its event components. For example, each time we experience a general event it is likely to have several thematic relationships. In the *First date with Jane* example, the story had at least three thematic linkages: "while at university," "both taking PSYC101," and "part of a drama club." There are perhaps two broad types of life theme: *typical* and *idiosyncratic*. *Typical* life themes are those that many people experience during their life, and they are experienced at about the same developmental point (e.g., attending the university). These are discussed shortly when the research on life scripts is examined. Idiosyncratic life themes are experienced by fewer people and may occur at any point in the life span (e.g., being in a drama club).

Autobiographical memory accounts often begin by noting the relevant *typical* thematic relationships, as in "I met Jane while at University . . . ." This places the event in the past, places it within a specific period in the past, and, in a general sense, orders the event in relation to other major life themes. This is achieved because the person giving the autobiographical account and the person listening to the account often share the same *life script*. Berntsen and Rubin, drawing on research from anthropology and sociology, proposed the idea of the life script, this being a culturally shared set of expectations relating to the order and timing of major life events and the beginning of new life themes (see Berntsen & Rubin, 2002, 2004; Rubin & Berntsen, 2003). They proposed that specific cultures have a more or less prescribed timetable for the ordering (and to some extent the duration) of major (and generally positive) life themes: There is a time to finish school, to enter employment, to get married, to begin having children, and so forth. Life scripts are a type of autobiographical knowledge about typical life themes, but are not so much acquired from an individual's personal experience with events, as they are handed down from older generations, acquired by observing others, and seen in others' life stories (Berntsen & Rubin, 2004).

One of the values of the life script, and the inclusion of a typical thematic marker in an autobiographical event account, is that they allow an individual to imply when an event occurred, without having to give a specific date. As long as the individual's life has progressed in accordance with their culture's life script, other members of their culture will gain reasonably accurate temporal information from a typical thematic marker. *Idiosyncratic* life themes are less useful as cues to temporal position and order. For example, saying "I met Jane while I was lead singer for X10" would only be a useful temporal marker for other individuals who know a lot about X10. However, because life themes tend to overlap, generally idiosyncratic themes will have a typical life theme running in parallel (occurring at the same time). So generally, when it may be important to note the idiosyncratic theme, because the general event being described is primarily indexed to it, the narrative might well start by linking the idiosyncratic theme to a typical theme (e.g., "I was in a band called X10 while at university . . . ."). Thus, individuals generally have little need to encode temporal information about life themes; knowledge of the life script is sufficient.

Finally, as the general events that we experience change, some themes will become inactive. An inactive theme is one that is not currently being added to with new general events and, as such, characterises the individual's past (e.g., a relationship that finished a few years ago, the job you had while at university). In contrast, an active theme is still currently being lived. Inactive themes are reflected in statements like "when I was a hippie," "during my rugby days," and "at the time I was part of a drama club." These statements convey that the theme was in the past (although they are limited as to their specific temporal association) and also convey that the theme is no longer part of the individual's life.

Temporal Order of Autobiographical Events

Two types of autobiographical memory study have investigated the "when" aspect of general events. This research is concerned with answering the question of how events are placed in time and, in particular, whether specific temporal tags are encoded with event memories. A few studies have used dates as retrieval cues to investigate whether the "when" aspect of autobiographical experiences is stored in memory. Researchers such as Linton (1975), Wagenaar (1986), and White (1982) were among the first to attempt this type of work. Data were obtained on what an individual had actually done on a specific day. For example, Wagenaar studied his own memory by recording events in a diary over a 6-year period. He then questioned himself about his general events, using different types of cues to determine if he could retrieve accurate memories. Cues such as the specific location of the event, names of the specific individuals involved, the activity, and the specific date were used. All of the studies concluded that providing individuals with a specific date, a "when" time cue, such as asking the question "What happened in your life on the 21st July 1976?" generally provided no access to any retrievable memories (in contrast to the other cues such as activity, location, and participants, which can successfully cue memory retrieval). Thus, researchers began to conclude that "dates" were not generally encoded with, or used to organize, autobiographical event memories.

Further evidence in support of this conclusion has come from studies that have given people a description of an event from the past (often autobiographical events taken from a diary or some other personal archival record, but sometimes public events taken from media records) and asked them to provide the date that the event occurred (e.g., Barclay & Wellman, 1986; Brown, Rips, & Shevell, 1985; Bruce & Van Pelt, 1989; Burt 1992b; Burt, Kemp, & Conway, 2001; Ferguson & Martin, 1983; Friedman, 1993; Huttenlocher, Hedges, & Bradburn, 1990; Kemp, 1987, 1988, 1999; Kemp & Burt, 1998; Larsen & Thompson, 1995; Rubin & Baddeley, 1989; Thompson, 1982, 1985a, 1985b; Thompson, Skowronski, & Lee, 1988; Thompson, Skowronski, Larsen, & Betz, 1996). The consistent finding is that after about 2 weeks, individuals have difficulty accurately dating their past experiences, suggesting that date of occurrence information is typically not retained in memory.

Although the dates that individuals assign to their past events are rarely accurate, the error patterns do appear to be consistent. Typically, "forward telescoping," meaning that assigned dates are more recent than the actual dates of occurrence, is found. Thus, although individuals find it difficult to give precise dates for their autobiographical events, their dating errors do sometimes preserve the approximate order of the events. This is evident in the rather high correlations between actual and assigned dates which have been found across a range of studies (e.g., Brown et al.:.88; Bruce and Van Pelt:.77; Burt:.92; Ferguson and Martin:.66)

Burt, Kemp, Grady, and Conway (2000) examined individuals' ability to order their autobiographical events (as opposed to dating the events). In

Experiment 1, events that the participants had recorded in a diary were transcribed onto cards. After an average of 123 days, participants were given six cards at a time and asked to place them in the correct temporal order. Contrary to what might have been expected based on dating error patterns, the participants were not very good at ordering their events (accuracy was measured by absolute position correct), with an across-participant average of 36.5% of the cards ordered correctly. Furthermore, the overall correlation between true temporal order and assigned temporal order was only .54. A similar result was found in Experiment 2 when participants were asked to order photographs they had taken of events (on average 20 days after the photographs had been taken): an across-participants average of 53.2% of the photographs were ordered correctly (see Friedman, 2007, for event ordering data showing similar ability levels). Although individuals in these experiments showed very limited ability to order their autobiographical events, it is worth noting that the time span from which events were sampled was relatively small. In Experiment 1, the participants kept a diary for an average of 79 days, and in Experiment 2, participants photographed their life events over approximately 2 weeks. Thus, whereas these data strongly suggest that individuals are not very good at ordering their experiences, different results may be obtained if they were asked to order experiences that occurred over a much larger time span.

Individuals' relatively poor ability to date and order their autobiographical events is at odds with the frequent use of order and relational words, such as "after, then, following that" in autobiographical accounts. Some light can be cast on how such statements can be made by examining the processes by which events are dated. Although it appears that temporal (date) information is not directly encoded in memory for most events, there are exceptions, and these events may help in maintaining the relative ordering of events. These events are referred to as *landmark* events (see Shum, 1998). Landmark events often have considerable life importance, often mark the beginning or end of a life theme, and as such are likely to be celebrated as an anniversary and have their specific place in time maintained in memory because of this. Although autobiographical landmark events are a very small percentage of an individuals total event experience, they do appear to play an important role in allowing the temporal relations of other events to be determined, which will be discussed shortly. Landmark events are not only personally idiosyncratic but can also be public events. Research on "flashbulb memories" (see Conway, 1995, for a review) has noted how public events such as assassinations, disasters, and terrorist attacks can form distinct, yet shared, temporal markers for autobiographical memory.

Considerable evidence suggests that individuals engage in a series of reconstructive steps when asked to determine the date of a past event (see Friedman, 1993, 2001, for useful reviews). As noted, general events are associated with one or more life themes, and the approximate temporal position of a life theme can be inferred using knowledge of life scripts. Thus, the first part of "date" reconstruction generally involves using the event-to-life-theme association to identify a broad temporal band (life time period or age) around which the event is likely to have occurred. Following this, landmark events may come into play. It is possible that the date of the beginning and/or end of the relevant life theme is stored in memory as a landmark event, and, as such, a specific temporal tag is available. If the event in question has a particular logical position in a life theme (e.g., first sexual experience is likely to happen nearer the beginning than the end of a relationship), the individual can infer that the target event was likely to be closer to the beginning landmark for the life theme than the end landmark. Other types of information about a target event can also play a part when reconstructing its temporal position, in that some events have seasonal or calendar associations (e.g., skiing is a winter sport, swimming is a summer sport).

These constructive processes, if performed for two events, should allow their relative order to be determined with some degree of accuracy. Furthermore, the greater the actual separation between the events, the easier it is to determine their order, primarily because as the separation interval increases, the event's thematic relationships are likely to vary, as are their associated landmark events. A large actual separation between events might also allow another mechanism to operate. Whereas reconstruction is the primary mechanism by which individuals seem to retrieve the time of events, there is some evidence that distance-based processes can also play a part (Brown et al., 1985; Friedman, 1993, 1996, 2001; Kemp & Burt, 1998). Distance-based processes might rely, for example, on the assumption that memory traces decay with the passage of time, and thus how vividly one remembers an event or how many details can be remembered is a clue to how long ago it happened. However, such processes provide little in the way of temporal resolution, giving perhaps only a sense of approximate distance in the past (Friedman, 2004). Furthermore, distance-based processes are not likely to be useful for determining the temporal order of two events that occurred close together but are likely to be useful when the events being ordered are at very different distances in the past (Bastin, Van der Linden, Michel, & Friedman, 2004; Curran & Friedman, 2003).

Temporal Order Within an Autobiographical Event

Individuals not only express the ordering of events in their autobiographical accounts, but they also express the order of the episodic components within events. A general autobiographical event is often described by its set of episodic components. In the *First date with Jane* example, the narrative describes a sequence of episodes in a forward temporal order. Forward temporal order appears to be frequently used when recounting autobiographical events (e.g., Anderson & Conway, 1993). There are many benefits to forward order recounting, including that those listening may find it easier to understand the story and that components of the event that cannot be remembered can be replaced with constructed material that logically fits the sequence. Furthermore, forward temporal order provides a framework for recall that can be used repeatedly. A number of studies have attempted to determine how the temporal order of autobiographical event components is stored and retrieved (see Burt, Watt, Mitchell, & Conway, 1998; Burt et al., 2000, Experiment 2; Burt, Kemp, & Conway, 2008). This body of work has often used photographs as the experimental stimuli. Typically, study participants are either given rolls of film, or given a digital camera, and simply asked to photograph the events of their life over a specified period of time. Each participant's photograph archive is examined for sequences of photographs that show a single event (e.g., a sequence of photographs taken at a picnic). This technique allows the actual order of event components to be known, and participants are typically shown their event component photograph sequence (in a random order) and are asked to sort the photographs into their correct temporal order. This research has found that event component order memory decays very rapidly. Burt et al. (2008) found that some ability to order event components had been lost within 4 hr of an experience, with only 52.4% of photographs being correctly ordered. Burt et al. (1998) found that after an average of 4 days, ordering accuracy averaged 63.2% correct across participants, and after an average of 175 days, it averaged 34.4% correct across participants. In each of these studies, event component ordering errors were clustered around the components true position, and the serial position curves had an inverted bow (U) shape, indicating that the beginning and end components of events were ordered more accurately than the middle components.

Burt et al. (2008) investigated whether Competitive Queuing (CQ) models developed in list learning serial order research (see Glasspool, 2005) might explain autobiographical event component ordering. CQ models postulate that the process of retrieving a sequence involves an activating mechanism that generates a gradient of activations over the sequence of components, with the first item to be retrieved (the first item in a sequence) being the most active, and the item to be retrieved last being the least active: "the set of activated responses forms the 'competitive queue,' as the responses compete for output on the basis of their activation level" (Glasspool, p. 252). However, to extend the CQ approach to autobiographical memory, it would seem necessary to show that an event's temporally first component would have the strongest activation, with temporally subsequent components having progressively less activation. Burt et al. (2008) tested this proposition using reaction time measures. Participants were presented with their photographs (along with foils) and asked to press a key when they remembered the event episode shown in the photograph. Reaction times were not related to true event position, nor were they related to event component ordering accuracy.

Given that no evidence was found to support the possibility that event component ordering was related to component activation strength, Burt et al. (1998, 2008) developed an "associative model" to explain their autobiographical event component ordering data. The associative model suggests that autobiographical event component order is derived from the association between each component and its general event memory. The first assumption that the model makes is that general event memories are developed using autobiographical knowledge, specifically scripts. Schank and Abelson (1977) introduced the idea of event scripts, defining these as learnt sequenced sets of event components linked to a central general event. The classic example is the restaurant script, which is knowledge of the typical sequence of the experience of eating at a restaurant. For example, ordering normally involves four temporally organized episodes: receiving the menu, reading the menu, deciding what to order, and giving the order to the waiter.

When an individual experiences an event, scripts allow them to understand what is happening, how they should behave, and what to expect next. Our associative model suggests that when an event is experienced, each event-specific component is associated with its scripted point in the general event memory. For example, if a guest spills a glass of wine at the time the waiter is taking orders, the "wine-spill event component" is associated with the scripted, "the waiter takes orders," part of the experience, which gives it a temporal location. Essentially, this process changes a general event script by encoding the unique aspects of an experience and, in doing so, forms a unique general event memory. The associative model suggests that as long as the associations between the scripted components and the experienced event component are maintained, the individual will have some idea of the true temporal position (order) of the event components.

Of course, it is well established that individuals can rapidly forget event components and that we do not describe them well in free-recall attempts. Over time, as the details of an event decay from memory, an individual's description of an event is likely to sound more and more like a script (Bartlett, 1932). The associative model argues that an individual's failure to free recall an event component signals it is no longer associated with its general event memory, and the individual's ability to accurately order it is likely to be dramatically diminished. If an event component's association to its general event memory is the mechanism by which temporal order is determined, there should be a progressive loss of ordering ability as the ability to free-recall event components decreases (as retention interval increases), a result evident in the data collected by Burt et al. (1998; 2001; 2008). Furthermore, an association between an event component and its general event memory should determine how vividly an individual remembers the event component, and Burt et al. (2008) found that vividness ratings were negatively correlated with ordering error (event components that received larger vividness ratings were ordered more accurately).

As noted above, one of the consistent findings in the event component ordering data is that the end points of a sequence are often ordered more accurately than the middle components. This finding can be explained by the associative model if it is assumed that the event end points represent definitional boundaries for general event memories (e.g., going to a new restaurant) and, as such, are maintained in memory. Beginning and end components can define the unique features of a particular event and are thus perhaps more likely to remain associated with the general event memory. The middle components of the event may be less distinct, and it may be the case that the things that happen within an event are forgotten first. The end of an event may also put a definitional perspective on the general event memory. For example, a dinner may be the first date with a prospective partner, and what happens at the end of the dinner—a romantic kiss—may well define how the event is remembered.

Event-specific components do not appear to have any form of temporal information associated with them. Rather, general event scripts are suggested to provide useful temporal frameworks for the encoding of event components. The learned central script features provide a temporally organized structure to which unique event-specific components can be associated. Furthermore, the scripted structure, along with its associated components provides for the development of temporally organized event narratives. Unfortunately, many of the specific details of an event are lost from free recall very rapidly, and as this occurs, the ability to accurately order these components decreases. Statements such as "well I don't remember what happened next, but later we . . . ." reflect an acknowledgment that event components are missing from a narrative.

The Duration of Autobiographical Events

Finally, a discussion of the ordering of events and event components in autobiographical accounts must include a consideration of duration. Many features of autobiographical experiences lead to a definable duration, and duration markers are often found in autobiographical accounts. In the event description *First date with Jane,* each of the life themes can be defined in terms of a duration. The general event of attending the fund raising dinner has two levels of definable duration. The sequence of episodes from asking Jane to the dinner until the after-dinner breakfast defines a period of time, and a definable time can be given for each of the episodes indexed within these components (e.g., the duration of the dinner, the duration of the auction, the duration of the taxi ride, etc.). As will be discussed below, the *First date with Jane* narrative contains two types of duration markers.

Including duration markers in an autobiographical narrative is important because the number of episodic components that make up an event (experience) is typically at least partly a function of the total duration of the experience. Individuals also have expectations about the temporal order of event components that are based on an understanding of duration. That is, certain event components are expected to take a certain amount of time, and because of this, they allow other things to happen. Embedding duration information in an autobiographical narrative allows either for these expectations to be confirmed or for anomalies to be noted.

Both cognitive psychology and perceptual psychology contain a vast literature on the estimation of duration, but the majority of this research has been conducted in the laboratory using rather meaningless stimuli like bursts of tone (see Eisler, 1976, for a review). Burt (1992a) was perhaps the first to conduct a large-scale empirical study examining the retrieval of duration information for autobiographical events. The study examined 36 years of diary records supplied by 14 participants for suitable events, such as holidays, taking a course, relationships, being invited to and having attended something, and so forth. Participants were read the event descriptions taken from their diaries and asked how long the event had lasted. The overall median actual duration of the 187 events obtained from the diary records (referred to as test 1) was 9 days and the overall median estimated duration was 10 days. The overall average retention interval in this study was 1,359 days (3.72 years). Some 10 years later, Burt, et al. (2001) located 11 of the original participants from the Burt (1992a) study and again asked them to estimate the duration for their original sample of events, referred to as test 2 (because of the loss of 3 participants, the total number of events was now 147). The mean actual duration for these 147 events was 29.8 days, the mean estimated duration for these events at test 1 (in 1992) was 27.2 days, and the mean estimated duration at test 2 (in 2001) was 29.8 days!

Although the accuracy of the duration estimates obtained by Burt (1992a) and Burt et al. (2001) seems remarkable, these results were not interpreted as evidence that autobiographical memory encodes and retains duration information for specific events. Rather, the accuracy, and almost complete lack of variation over 13 years in the duration estimates, was suggested to reflect the application of reconstructive processes that result in duration estimates that are reasonably accurate and that vary little with time. It was suggested that individuals develop autobiographical knowledge of the typical duration of experiences, store this in memory, and use this information as a basis from which the duration of a past event can be decided. For example, over time, individuals gain experience with events, such as the fund raising dinner described in *First date with Jane*. The typical duration of such an event is stored in memory, and if asked to recall the actual duration of such an event, the individual gives the typical value, which will generally be reasonably accurate.

However, whereas the basis of autobiographical knowledge about event duration may be a set of numerical values representing typical event durations, individuals seem to rarely use these numerical values when giving duration information in an event narrative (just as they seem to rarely give precise dates when placing an event in time). Rather, individuals seem to use a range of language options to express duration. For example, autobiographical event narratives can easily imply duration via noun selection, as in "we stopped for a snack" implies a shorter event than does "we stopped for a meal." The narrator in this case assumes that the listener will know that a snack typically takes less time than a meal. As another example from the *First date with Jane* narrative, if the narrator wants to indicate that the event's duration was not typical, the narrator might say something like "The meal was really good, but we had to wait ages between courses," which clearly indicates an atypically long aspect of the event.

The expression of an event's duration can also be easily implied with variation in activity verb selection (e.g., "After that was over, a few of us ran off and got a taxi to the Surf Club"). For this to occur, the narrator assumes that the listener will make the inference that duration is related to speed. In its simplest form, this relationship is expressed by the idea that if an object has to move from position A to position B, the faster the object moves, the shorter the time taken. Burt (1999) and Burt and Popple (1996) investigated how activity verb use might be related to event duration. In a series of studies they showed that estimated event duration is related to verb use in event descriptions: The faster the implied action speed of the verbs used to describe an event, the shorter the estimated event duration (e.g., Burt & Popple, 1996), and the more activity verbs used to describe an event, the shorter the estimated event duration. These studies also indicated that individuals can easily scale verbs on an implied speed continuum (e.g., activity verbs such as 'sprinted, bolted, raced, fled, dashed' are given very large implied speed ratings, whereas verbs such as 'crept, strolled, walked' are given very small implied speed ratings). Furthermore, for many activity verbs, the standard deviations of the implied speed ratings were relatively small, indicating that individuals have a common understanding of implied action speed of a large range of activity verbs.

In the *First date with Jane* example, the statement "After that was over, a few of us ran off and got a taxi to the Surf Club" uses the verb ran to imply the duration of part of the event. Using the verb "ran" shortens the duration of this part of the event and also implies that there is nothing else in this particular part of the event that should be noted. In other words, because the verb selection indicates a short time interval, the listener is unlikely to wonder if something else happened in this interval about which they were not told.

In summary, individuals appear to store knowledge about typical event duration in memory, rather than duration information for specific past events. The construction of event duration uses this autobiographical event knowledge. However, individuals seem to express event duration by noun and verb selection, rather than numerical values. Expressing an event's duration can function to confirm that the order of an experience is reflected in the order of a narrative describing it.

Conclusion

Experiments across the range of autobiographical memory structures seem to justify the conclusion that time is not routinely encoded as part of autobiographical memory. Nor is time used to organize autobiographical memory, yet it is still the case that narrative descriptions of an episode, event, or theme often show very definite temporal characteristics. The processes thought to be involved in the reconstruction of temporal information for each of the autobiographical memory structures have been discussed. Many of the studies on temporal memory that were discussed found rather poor performance, and it is tempting to conclude that reconstructive processes are not very good at generating the temporal features of autobiographical experiences. However, the research standards used to judge memory reports are not those that are typically applied in everyday life. Thus, one of the keys to understanding how temporal markers are so widespread in autobiographical accounts, yet so obviously absent from memory, is an implicit acknowledgment that "about right" or "approximately right"' is generally acceptable.

Including "about right" temporal markers in autobiographical narratives is probably far less cognitively demanding than attempting to be accurate and precise. One of the markers of cognitive demand is that it takes processing time. Arguably, a conversation or story that is punctuated by pauses during which the individual is refining the temporal markers would be seen as rather odd. In such a case, the effort of refining the accuracy of the temporal markers would probably lead to a negative outcome. Thus, over time, individuals may learn that being approximate in their use of temporal markers is not only acceptable but expected.

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How Semantic and Episodic Memory Contribute to Autobiographical Memory. Commentary on Burt

Indira Tendolkar

Radboud University Nijmegen Medical Centre, Donders Institute for Brain, Cognition and Behavior

In his article, Chris Burt focuses on the relationship between time and autobiographical memory. The question Burt puts forward is whether temporal markers in reports on autobiographic memories reflect specific temporal information or result from rather complex cognitive processing of time-relevant knowledge. The aspect of time is inherent to the concept of memory, which is about retrieving information from the past. The past can reflect a given time point and memory retrieval can relate to this specific context. Alternatively, the past can be defined in terms of duration, and memory retrieval will then be less likely based on the retrieval of a specific episodic context. Here, I want to discuss the aspect of time in autobiographical memory with respect to the kinds of long-term memory involved.

The kind of memory that is involved in retrieving information from the past depends on the time span (i.e., the temporal distance between the initial encounter of some information and the retrieval of this encounter). Typically, autobiographical memory involves declarative memory processes. Declarative memory can be divided into episodic and semantic memory (Tulving, 1983). Semantic memory does not refer to a memory system that is tied especially to language or meaning, but to the acquisition and retention of factual information in the broadest sense, which can be retrieved with a mere feeling of familiarity. Episodic memory, by contrast, enables individuals to recollect events embedded in a certain spatiotemporal context (Tulving). Some have argued that autobiographical memory is a specific sort of episodic memory allowing one to recall events in a self-referent way (e.g., Gardiner, 2001). Wheeler, Stuss, and

Correspondence concerning this article should be addressed to Indira Tendolkar, Department of Psychiatry, University Medical Center St Radboud, Postbox 9101, 6500 HB Nijmegen. Internet: i.tendolkar@psy.umcn.nl

Time to Speak: Cognitive and Neural Prerequisites for Time in Language
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Tulving (1997) have put forward the idea that episodic memory is primarily characterized by the type of awareness that accompanies retrieval, whereas autobiographical memory is defined by the content of the retrieved material in that it is always self-referent. According to Wheeler and colleagues, episodic memory involves remembering by reexperiencing, whereas autobiographical memory need not entail the same degree of subjective awareness. Conway and Pleydell-Pearce (2000) suggested that episodic reexperiencing and autobiographical memories are characterized by different time spans. The time frame of episodic memories can be measured in seconds, minutes, and hours, whereas autobiographical memories encompass much longer periods. This view is in line with Brewer (1986), who suggested that aspects of autobiographical memory might last for days to weeks. Hence, it is very likely that the organization of temporal characteristics within autobiographical memory is based on more than one kind of memory retrieval process.

Burt's argumentation is not primarily built upon the dissociation between episodic and semantic aspects of declarative memory forming the basis of autobiographical memory. He suggested that there are at least four different sorts of memory processes, each of which has different time-related characteristics: life themes, general events, episodic memories of a specific event, and autobiographical knowledge. At the broadest level are life themes, which have a distinct beginning and end (e.g., "when I was at school"). Life themes can be overlapping and thus allow for sublevels of definable durations. Within life themes, general events occur at more specific time points. As these general events typically only cover a couple of days, they often have an embedded episodic component that one can reexperience. Finally, the experience of these different kinds of events allows one to acquire an autobiographical knowledge about the typical duration and order of certain autobiographical events. Burt has shown in his own experiments (Burt, 1992; Burt, Kemp, & Conway, 2001) that the typical durations of experiences are stored as part of autobiographical knowledge and this information can be used to infer the duration of past events.

Thus, in keeping with the episodic and semantic aspects of declarative memory in general (Tulving, 1983), retrieval of autobiographic memories can occur without necessarily having to recollect every temporal context. Autobiographical information can be retrieved on the basis of a knowledge that something has happened without necessarily being able to recollect specific contextual aspects. Whereas episodic memory demands a personal reexperiencing that is difficult to share with others, retrieving self-referent information on the basis of familiarity allows people to share autobiographical knowledge about life scripts (i.e., a culturally shared set of expectations relating to the order and timing of major life events or the beginning of new life themes (Berntsen & Rubin, 2002, 2004).

Burt shows that the error patterns in people's assignments of dates of occurrence appear to be consistent in that assigned dates are often found to be more recent than the actual dates of occurrence. Given that retrieval of autobiographical events will mostly depend on semantic memory rather than episodic retrieval, it is not surprising that, in general, specific time cues seem not to be encoded with the events or used to organize them. Certainly, if we cannot rely much on absolute time cues in our autobiographical memory, relative ordering of autobiographical events becomes an important aspect. The smaller the temporal spans are, the more difficult the ordering becomes. In principle, ordering can be based on memory strength, where events that are close in time are more likely to have the same memory strength and are thus less likely to be distinguished on the basis of this. Indeed, Burt (1999) found that ordering for autobiographical events was more accurate for the beginning and end components of events, similar to primacy and recency effects in item list learning. Yet, he did not find any evidence that autobiographical component ordering is related to component activation strength (Burt, 1999). This suggests that the recollection of specific contextual details is required as part of a series of reconstructive steps that Burt considers to be underlying the temporal ordering of events. Contextual details are more likely to differ between events that did not occur close in time.

Sharing autobiographical memories with others will also depend on how the narrator can illustrate the temporal order of events by means of language. Certain types of words or phrases set temporal markers. Whereas some time markers have a clear definition (e.g., hours, days, etc.), others involve less precise information about time (e.g., "when I began school"). Understanding these temporal markers will depend on the semantic knowledge that the narrator and the audience share with respect to the meaning of certain phrases. This knowledge is culture-specific: "When I began school," for example, often means that you were around 5 years old, but it may mean that you were older, if you happen to be German. The accuracy of temporal markers will depend on the decision of a narrator to report temporal details precisely or to give only a rough sketch on the background of a certain memory. Different kinds of narratives may involve different kinds of memory retrieval, which, in turn, will differ with respect to the required processing speed and effort for recollecting specific contextual details.

Another important aspect of the autobiographical narrative is the effect the retrieval of autobiographical memories as such has on processing temporal aspects of these memories. Certainly, from a memory perspective, one could argue that at the time of autobiographical retrieval encoding of a new version of a certain autobiographical memory will be initiated. This may then lead to a different relative temporal perspective of the autobiographical memory during the next retrieval. The impact of such a potential reencoding may again differ depending on whether semantic or episodic aspects of autobiographical memories are retrieved. One could assume that semantic aspects of autobiographical memories have been consolidated in such a way that they have been stored in a distributed network that should not be affected by such a reencoding (see Fernandez & Tendolkar, in press, for a review on consolidation theory and the underlying neuroscience). On the other hand, episodic recollection of an autobiographical memory will yield a vivid reexperiencing, which may eventually change the autobiographical memory because it was reexperienced in a different way.

To summarize, in his article Chris Burt provides ample evidence that very little temporal information is stored in autobiographical memory. In my comments I have emphasized the need to distinguish between episodic reexperiencing and semantic retrieval based on familiarity. This distinction may be of particular importance considering the relative susceptibility of these two aspects of autobiographical memory to reencoding following retrieval.

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The Perception of Time: Basic Research and Some Potential Links to the Study of Language

J. H. Wearden
Keele University

The article first discusses some recent work in time perception—in particular the distinction among prospective timing, retrospective timing, and passage of time judgments. The history and application of an "internal clock" model as an explanation of prospective timing performance is reviewed and contrasted with the different mechanisms needed for the other two types of time judgments. The article then discusses two areas suggesting relations between time perception research and language. The first is the idea that disturbances in the perception of duration, usually of very brief auditory stimuli, are associated with some language disorders. Another is the common use of metaphors for time, and the article relates these to the issue of whether a genuine "time sense" exists.

Language is certainly not necessary for organisms to show sensitivity to the temporal structure of their environment or even to adjust their behavior to quite arbitrary temporal periodicities or constraints imposed by experimenters. For example, in the Pavlovian "inhibition of delay" procedure, animals receive long presentations of a neutral stimulus (such as a bell or a tone), and when the stimulus terminates, food is delivered. Pavlov (1927) noted that the prototypical conditioned response of salivation eventually comes to be localized in the later parts of the stimulus; that is, the animal learns something about how long the bell or tone lasts. In later experiments by others, animals were rewarded with food for responses, like key-pecks and lever-presses, only at a certain time after

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Correspondence concerning this article should be addressed to J. H. Wearden, School of Psychology, Dorothy Hodgkin Building, Keele University, Keele, Staffordshire, ST5 5 BG, UK. Internet: j.h.wearden@psy.keele.ac.uk

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previous food delivery. With training, their responses come to be concentrated in the time period just before food becomes available, with little responding early in the interval, an adjustment shown not only by "higher" animals like apes and cats but also by lowlier ones including fish (Lejeune & Wearden, 1991).

Not only can animals adjust their behavior to temporal properties of their environment, but, by ingenious training techniques, they also can be persuaded to perform tasks that would be described as showing "time perception" if humans performed them. For example, when presented with two consecutive stimuli, pigeons can make different responses based on the relative duration of the stimuli (Fetterman, Dreyfus, & Stubbs, 1989).

These examples, drawn from a vast literature on animal timing (some of which is discussed in recent reviews by Lejeune & Wearden, 2006, and Lejeune, Richelle, & Wearden, 2006), show clearly that sensitivity to at least two aspects of time, namely elapsed time since some event and the duration of a stimulus, are not the sole provenance of language-capable humans.

In attempting to discuss potential relations between time and language, an experimental psychologist who works on time perception faces the difficulty that the vast majority of the work on the subject makes little contact with language at all, even though verbally competent adults are usually used as experimental participants. Furthermore, since the earliest days of the study of time perception, which date back to the 1860s (e.g., Vierordt, 1868), the aspect of time psychology that has attracted most interest has been the study of *duration perception* (i.e., the study of how people judge how long stimuli and events last). In contrast to an emphasis on duration, the sorts of time judgments that may be most interesting from the linguistic point of view are those involving judgments of *succession*—for example, whether something is located in the past, present, or future, embodied very visibly in the tense structure of languages, or perhaps the use of metaphorical language to describe time ("time flies," "the sands of time," etc.). These topics have not been totally neglected in time perception research, although they represent only a tiny fraction of the work that has been carried out and have not been regarded as part of the mainstream of the area.

In the present article, I will attempt to do two things, spending more space on the former than the latter. The first is to provide the reader with some basic information about the main trends in recent time perception research. This material is expounded in three sections, the first two describing what seem to be distinctly different types of timing. A third section discusses possible relations between attention and memory and time perception. This part of the article concentrates almost exclusively on the issue of how people judge how long events last (i.e., duration perception), and I will try to sketch out the main empirical and theoretical advances in this area in the last 20 or 30 years.

In two later sections, I will briefly review areas in which time and language seem to come together in critical ways. The first of these discusses ways in which disturbances in the perception of speech might arise because of problems in discriminating short time intervals or, more generally, how the ability to perform time discriminations might be a critical process in the regulation of language and conversation. Another section discusses linguistic metaphors for time, which are sometimes so commonly used that we do not even recognize their metaphorical nature, as, for example, when we talk about a "length of time." A brief conclusion then terminates the article.

How Time Flies 1: Prospective Timing and the Idea of Internal Clocks

Prospective timing is the situation in which the participant is aware that time judgments are a focus of the study. The vast majority of experiments on time perception are of this type, and some common examples of methods are (a) interval production ("hold down this button for one second"), (b) verbal estimation ("listen to this tone and judge how long it lasts in seconds"), (c) various sorts of discrimination techniques ("listen to these two tones and tell me which one lasts longer"), and (d) temporal generalization (Wearden, 1992; "does this tone have the same duration as the standard that you heard earlier?").

When people perform prospective timing tasks, their time representations conform to two principles (usually called the *scalar properties* of time) in the overwhelming majority of cases (Wearden & Lejeune, 2008). One of these is *mean accuracy*: People behave as if their internal representation of some clock time, t, is on average equal to t. For example, if people are asked to produce time intervals that match varying "target" intervals without counting and receive feedback after each production, the average time they produce is almost exactly equal to the "target" time (Wearden & McShane, 1988). The second property is the *scalar property of variance*, a form of Weber's Law. Although time representations may be accurate on average, they usually exhibit what is called *scalar variance*, such that the standard deviation of the representation is a constant fraction of the mean. For example, when people produced time intervals in Wearden and McShane's study, the standard deviation of their productions was a constant proportion of the mean (about 13%) as the time produced varied. Wearden and Lejeune discussed evidence for the mean accuracy and scalar variance properties in data from a large number of studies with humans. In general, both properties hold, although some exceptions can be noted.

Although internal representations of time are supposed to be on average accurate, this does not mean that average time judgments obtained in experiments are always accurate. When people reproduce time intervals, for example, a common deviation from average accuracy in behavior is conformity to Vierordt's Law, in which short intervals are reproduced as longer than they really are and long intervals as shorter (Wearden, 2003). However, this and other instances when people's behavior does not directly exhibit mean accuracy can usually be (plausibly) reconciled with underlying accuracy of time representations by using additional processes. How this is done is too complex for discussion here, but Wearden (2003, 2004) provides examples.

The guiding theoretical framework for understanding prospective timing has, for many years, been the idea that humans possess some sort of clocklike device that they can use to measure the duration of intervals. Although the physical nature of this putative clock is currently unknown, the idea has been translated into mathematical models that fit data well (e.g., Gibbon, Church, & Meck, 1984; Treisman, 1963). A popular idea has been a clock of a pacemaker-accumulator type, where a rapidly "ticking" pacemaker is gated to an accumulator, which stores its output, via a switch. So, for example, when a stimulus is presented, the onset of the stimulus causes the switch to close and pulses to flow from the pacemaker to the accumulator. This continues until stimulus offset, when the switch opens again, cutting the pacemaker-accumulator connection. Thus, at the end of the stimulus, the accumulator contains a number of "ticks" of the pacemaker, and this number can be used as the basis for subsequent judgments of how long the stimulus lasted.

A useful metaphor, which captures almost all the properties of the pacemaker-accumulator clock, is that of timing with a tap and a jug. To start timing an interval, the tap is opened and water flows into the jug, and the tap is closed when the interval finishes. The quantity of water in the jug represents accumulator contents at the end of the interval. A moment's reflection suggests that timing with this sort of mechanism should have some obvious properties: First, longer times should, on average, give rise to more accumulation; second, a faster flowing tap (i.e., a faster pacemaker) will result in *more* accumulation in a given time period. However, some properties are less obvious, and Figure 1 shows two of these, illustrated by two conditions where the rate of flow of the tap is varied between 10 and 12 cm^3 s. One property is that differences in tap flow (pacemaker speed) produce greater effects at longer times than shorter ones. Another is that if the time taken to open and close the tap is negligible,

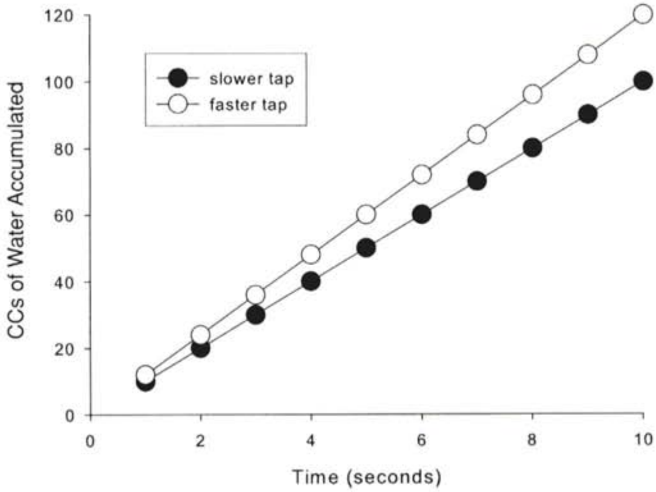


Figure 1 A result from the "tap and jug" model of the pacemaker-accumulator clock discussed in the text. The quantity of water accumulated in different time periods is shown for taps flowing at two different rates.

the "tap and jug" model produces a perfect linear and accurate relation between clock time and the quantity of water accumulated: If the time judged doubles, then the quantity of water accumulated also doubles, and so on, as any multiple of clock time is reflected in the same multiple of accumulated water. It is thus easy to see how a pacemaker-accumulator model will generally produce internal time representations that show mean accuracy.

What evidence is there that people possess a clock of the pacemaker-accumulator type? There are basically two sorts of evidence. The first comes from attempts to change the rate at which the pacemaker runs, usually referred to as "speeding up the clock" studies. Wearden and Penton-Voak (1995) reviewed attempts going back to the 1920s to influence pacemaker rate by changes in body temperature and showed that, in general, there is evidence that increases in body temperature make people behave as if their pacemaker was running faster. In 1990, Treisman, Faulkner, Naish, and Brogan claimed that pacemaker speed could be influenced by the less dramatic methods of accompanying stimuli by trains of repetitive stimulation, usually in the form of clicks or flashes.

Penton-Voak, Edwards, Percival, and Wearden (1996) followed up Treisman et al.'s (1990) work and showed that preceding stimuli by trains of clicks made people judge their duration as longer. This effect was found whether the stimuli were visual or auditory and it was more marked at longer stimulus durations, exactly the effect expected if pacemaker speed had been increased (e.g., see Figure 1). For some other studies of this type, see Wearden, Edwards, Fakhri, and Percival (1998), Wearden, Philpott, and Win (1999), and Wearden, Norton, Martin, and Montford-Bebb (2007). The same effect of repetitive stimulation, this time in the form of visual flicker, on time judgments was found in children as young as 3 years old by Droit-Volet and Wearden (2002). In a recent article, I have also explored methods that appear to "slow down" the pacemaker of the clock (Wearden, 2008).

The second line of evidence for a pacemaker-accumulator clock comes from attempts to uncover whether the underlying time scale possessed by humans is in fact linear and accurate, as the "tap and jug" model suggests it should be. This issue is a difficult one, and some of its complexities are discussed in Wearden and Jones (2007), who also provide what seems to be a convincing demonstration that people do in fact possess a linear and near-accurate underlying time scale. People were presented with a "standard" time interval that actually lasted 10 s, although they were not told this. The interval started and ended with brief clicks, and counting was prevented by requiring the participants to perform a secondary task. After a few repetitions of the standard, people were presented with a range of other intervals, running from 1 to 10 s, and were required to judge what proportion each of these comparison intervals was of the standard. Although, intuitively, the task seems very difficult, in fact average judgments were completely linear and close to accurate, and individual differences between participants were very small. So, people were behaving as if they could use some internal "accumulation" process, in which the accumulated quantity bore a very close relation to real time.

Although it is easy to see how a pacemaker-accumulator model could produce mean accuracy, it is less clear how the scalar property of variance emerges. There are various solutions to this problem. One is to suppose that the pacemaker itself generates scalar variance. For example, if the average rate of clock "ticks" varies according to a Gaussian process from one interval to another, the accumulator contents themselves will have scalar properties when averaged over trials. Another solution is to propose that the scalar property arises not from the initial timing of events but from the way that durations are remembered. This issue is beyond the scope of the present article, but Wearden and Bray (2001) and Jones and Wearden (2004) provide (rather technical) discussions.

In the, rather similar, theoretical models of timing advanced by Treisman (1963) and Gibbon et al. (1984), the operation of the internal clock is just the first stage of the process that leads to time judgments, and the clock is embodied in a more complex cognitive mechanism involving both memories of duration (e.g., the memory of some sort of temporal "standard" needed for a particular task) and decision processes, which vary depending on task requirements. Wearden (1999, 2003) discussed the general principles of such models. In addition, the models proposed theoretical frameworks in which more general cognitive processes can be located, as will be discussed in more detail later.

How Time Flies 2: Retrospective Timing and Passage of Time Judgements

Retrospective time judgments are those made when people are not initially informed that time is the focus of interest of the study or, more generally, when unexpected questions about time are posed (e.g., "How much time has passed since you started reading the page on which this line is written?"). Prospective and retrospective time judgments may seem clearly different, but in fact the distinction between them dates only from Hicks, Miller, and Kinsbourne (1976) and before that the two were not clearly separated. Ivry and Hazeltine (1992) provided a helpful slogan to characterize them: prospective timing is "timing with a timer," whereas retrospective timing is "timing without a timer." That is to say, in retrospective timing, people can make a time judgment but have probably not engaged any specific timing mechanism (having no reason to do so), so they make the time judgment on the basis of something that is intrinsically nontemporal.

Ornstein (1969) proposed a "*storage size*" account of duration judgments that has since been adopted in various forms to understand retrospective timing. The basic idea is that the quantity of "something" stored during the time period is examined retrospectively, and larger quantities lead to longer time judgments. The problem, of course, is to decide just what this critical "something" is. Among the different propositions have been (a) the amount of "memory storage," (b) the quantity of information-processing undertaken during the time period, and (c) the amount of "contextual change" that has occurred—that is, some measure of the different types of processing occurring, such as changes from verbal to arithmetic problems, rather than just the amount of one type. Whatever specific notion is adopted, an obvious problem is providing a precise definition of just how much of "something" has actually occurred, and difficulties in specifying this precisely make accounts of retrospective time judgments vague and difficult to test.

Further difficulties with studying retrospective timing are methodological. In principle, the retrospective timing question can only be posed once; after that the participant knows that time is a focus of interest, so subsequent judgements are likely to be prospective. This leads to wasteful experimental designs, where participants make only one time judgment in the experiment, in contrast to prospective timing, where many time judgments can be efficiently obtained from individuals. Some studies (e.g., Boltz, 1994; Grondin & Plourde, 2007) presented participants with multiple distinguishable events, such as a series of nameable sounds (e.g., footsteps) and then posed questions about duration only after all the sequence has been presented (e.g., "how long did the footsteps last?" "how long did the baby crying last?" etc.). Allied to the methodological problem of obtaining more than just a few data points from individuals is the fact that retrospective time judgments can in some cases be highly variable between participants, so reaching conventional statistical significance levels for between-group comparisons (e.g., of groups differing in the amount of contextual change in a time period) can necessitate large subject populations.

These theoretical and methodological difficulties conspire together to make the study of retrospective timing difficult and it is very underresearched compared with prospective timing, with studies representing only a few percent of published work on time perception. In addition, many experiments use just one or a few time intervals and measures of variance are often not taken, so the "psychophysical function" relating retrospective time judgments to clock time and questions of conformity to the scalar property of variance are hard to evaluate. Grondin and Plourde (2007) is an exception, and here it was found that shorter durations were, on average, overestimated and longer ones underestimated (Vierordt's Law, mentioned earlier) and that the standard deviation of estimates was a declining fraction of the mean as this increased. However, it is unclear whether these features are properties of retrospective timing in general or are related to the specific methods used.

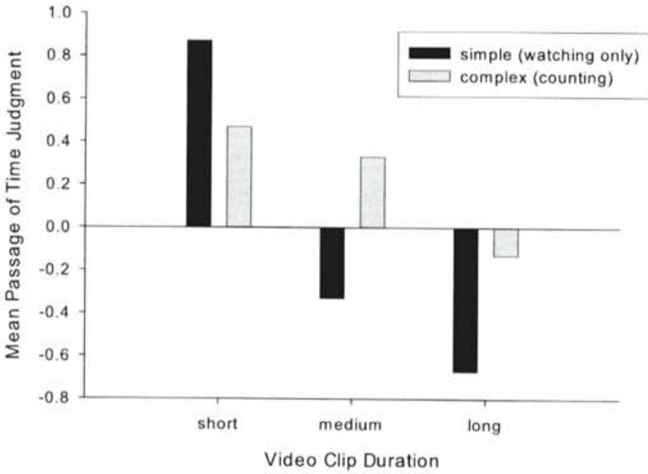
In an article in 2005 I proposed adding a third type of timing to the two discussed earlier, a type that I named "passage of time judgements" (Wearden, 2005). Here, a person is not asked how long a time period lasted, but how quickly time seemed to pass during it—that is, whether time went more quickly than normal, normally, or more slowly than normal. These passage of time judgments seem to capture some aspects of time experience in real life: For example, when waiting in a queue, the usual impression is that time is passing slowly, and when at a lively party or watching an exciting film, one has the impression that time passes quickly.

What are the relations between passage of time judgments and retrospective timing? One possible intuition, which not everyone shares, is that if time seems to pass quickly during some event, the event might be expected to be judged as short, but is this really true? Wearden (2005) contrasted watching an action film with a simulated waiting room. As might be expected, people judged the passage of time during the film as quicker than normal and judged that in the waiting room as slower. However, in retrospective time judgments, the film was judged as *longer* than the period spent in the waiting room. This may appear paradoxical, as "fast" passage of time seems to imply that the event is shorter, but some unpublished work from my laboratory suggested that the two might not be reliably related at all. Figure 2 shows an example.

In this experiment, two different groups watched the film *Shrek*, for three different time periods: short, medium, and long. One group was just told to watch the film; the other was required to note down every time the character Shrek spoke after another character had spoken, which required continuous monitoring of the film and (presumably) more information processing. No time judgments were required until all three clips had been viewed, then people were asked for passage of time judgments and for retrospective time judgments. For both groups, longer presentations of the film led to progressively slower passage of time judgments, but the group monitoring Shrek's speech had relatively blunted judgments (slower when the other group was fast, relatively faster when the other group was slow); see the upper panel of Figure 2. In contrast, retrospective time estimates for the two groups did not differ, with the shortest time period being overestimated relative to the longer ones in both groups (lower panel of Figure 2). This experiment shows that the monitoring manipulation affected one sort of judgment (passage of time) while having little or no effect on the other (retrospective timing). In general, studies in my laboratory have found that passage of time judgments can be affected by a number of variables; for example, ratings of how exciting a film clip was and how fast time was passing have positive correlations of up to around .8. In contrast, retrospective time judgments appear to be unsystematically related to passage of time judgments and also difficult to manipulate by changing the events experienced, or the type of processing used, during the time period judged.

Attention and Memory in Timing

Although research in time perception has often proceeded independently of other sorts of perception or cognition, recent authors have developed some



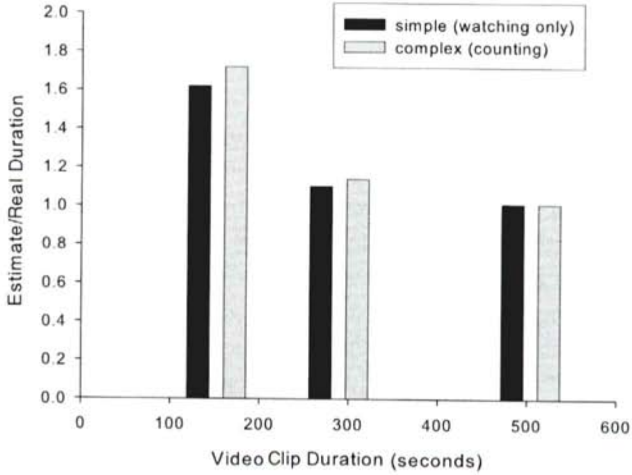


Figure 2 Passage of time judgments (upper panel) and retrospective time judgments (lower panel) from the "Shrek" experiment discussed in the text. Upper panel: Positive values indicate that time is judged as passing faster than normal, negative values that it is passing more slowly. Data are shown separately for the three different video-clip durations and for the two different groups (watching and counting). Lower panel: Retrospective timing estimates divided by real duration (so a value of 1.0 indicates accuracy) for the different groups and experimental conditions.

links between time perception and more general cognitive processes such as attention and memory.

In prospective timing tasks, studies using a variety of methods have almost always found that reducing "attention to time" during an event makes the event seem shorter. A common method is a dual-task procedure, in which a brief nontiming task is presented while a stimulus is being timed. Brown (1997) provided some demonstrations, and a good review, of performance on such tasks; for work using a different method, see Macar, Grondin, and Casini (1994). Increasing attention to time produces less clear effects (although some are claimed; see Mattes & Ulrich, 1998) possibly because in short laboratory tasks the participant's attention is at ceiling and cannot be increased. The explanation for shortening of time judgments with attentional diversion that is usually proposed is that of "loss of ticks" from the pacemaker of the internal clock: When performing the nontiming task, the switch connecting the pacemaker to the accumulator opens, thus cutting the connection between the two, so some ticks are lost while the nontiming task is being performed, resulting overall in a shorter time judgment.

Attention also seems likely to play an important role in determining retrospective time judgments, or passage of time judgments, although this area is very underresearched. For example, it may be that "time passes quickly when you're enjoying yourself" (presumably a statement about a passage of time judgment) because attention is directed toward the enjoyable activities rather than the passage of time itself. Zakay (1992) proposed some principles governing attention to time: Attention may be heightened when (a) time is very relevant and (b) the time intervals are uncertain. A real-life example would be taking someone by car to an airport or railway station where they have a flight or train at a particular time, so there is high time relevance. Encountering a holdup that increases time uncertainty during the car journey may give rise to the impression that every minute spent in the traffic jam "lasts forever." However, an additional factor here may be an increase in arousal occasioned by the stress of the time uncertainty, which makes the internal clock "tick" faster and thus makes external events seem to last longer.

Memory processes have been linked to time perception in different ways, which may not be very closely related to one another, and studies of temporal memory have given rise to a complex and rather technical literature. For example, some research on short-term or working memory for duration suggests that the longer the duration of a stimulus is held in memory, the shorter the duration becomes—the phenomenon of *subjective shortening*. A crude analogy is holding water in a sieve: The longer the water is held for, the less of it there is. Wearden and Ferrara (1993), Wearden, Parry, and Stamp (2002), and Wearden, Goodson, and Foran (2007) provide data and reviews of this phenomenon.

Another area involving memory processes is that of *reference memory* for time; for example, how do people retain temporal "standards" that they use to control their performance? On a temporal generalization task, for example, several comparison stimuli, presented one after the other, must be compared with a previously presented standard, which is presumably retrieved from memory. Jones and Wearden (2003, 2004) discussed the history of the idea of reference memory for time, which comes originally from animal experiments, as when animals learn that food is available at some critical time, and they also presented experimental data and discussed theoretical models of reference memory for time.

A more radical linkage between memory and timing comes from Staddon and Higa's (1999) suggestion that decay of memory can remove the need for any kind of internal clock at all. For example, suppose that an animal can obtain food for a response that occurs more than *t* seconds after the previous food delivery. A clock-based analysis of performance would propose that the food delivery resets the clock, which is then used to time the interval, with responding emerging when the animal is "close enough" to the next food delivery (see Church, Meck, & Gibbon, 1994, for an example). Staddon and Higa proposed that the clock was unnecessary and that the decaying memory of the previous food delivery could itself serve to control behavior: If the memory was strong, responses were never followed by food, but when it weakened (as a result of passage of time in the interval), a response could be rewarded, so animals could learn to "time" using discriminative cues derived from memory decay.

Staddon and Higa (1999) were exclusively concerned with animal timing, but humans may also be able to use memory-based cues to time events, possibly using the strength of the memory trace since the event occurred. Figure 3 shows data from an experiment in my laboratory that used a new technique ("post-event timing"). People watched the film *Toy Story*, and from time to time the film was stopped. When the film stopped, the participants had to estimate how much time had elapsed since some distinctive event in the film (e.g., "how long was it since Woody fell off the bed?"). The distinctive event referred to was not necessarily the last one to have occurred in the video clip. This task has features in common with both prospective and retrospective timing: It resembles prospective timing in that people know that questions about time are going to be asked, but it resembles retrospective timing in that they do not know *which* of the many events is going to be the critical one. Obviously, performance on this sort of task was reasonably good, as data in Figure 3 show, with estimates increasing linearly and fairly accurately as real time since the critical event elapsed. I am currently exploring the processes underlying this

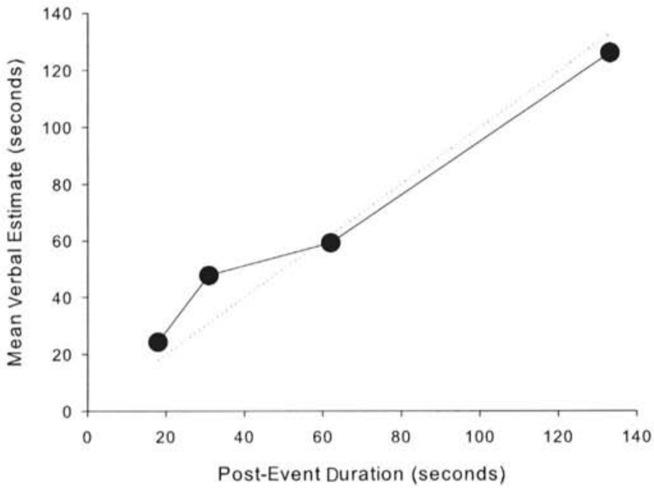


Figure 3 Mean verbal estimates assessed by the "post-event timing" method; see text for experimental details.

sort of time judgment in my laboratory, but the most likely possibility is that people retrospectively examine their memory and then use the strength of the memory trace of the event to make their time judgment.

Memory and retrospective timing would also appear, intuitively, to be intimately linked but as usual in this area there is little conclusive research. For example, when a retrospective timing judgment is called for, a person may search their memory of the "events" during the time period and base their estimate on the number of these events retrieved. This suggests that people who can remember more events may judge the duration as longer than those who can remember fewer. Additionally, memory processes may offer a clue as to why older people sometimes experience the sensation that time is passing more and more quickly as they age. If the retrospective judgment of the duration of some time period is based on the number of events recalled, then a decline in memory performance with age may result in shorter estimates in older people. If the event measured is noted by external markers (e.g., the time of interest is a week or a year), then older people may compare their apparently shorter retrospective estimate (shortened by memory difficulties) with the "marked" time and conclude that "the week flew past." Surprisingly, there appears to be no published study directly linking retrospective time judgments and memory performance in the elderly.

Timing and the Control of Speech

Perhaps the clearest potential linkages between the study of time perception and language come from suggestions that the ability to discriminate time intervals is intimately connected with the perception and control of speech and that "pathologies" of language may be traced, at least in part, to difficulties in rapid temporal processing. The work of Tallal (see Tallal, 2004, for a review) is perhaps the best known, and her basic thesis is that problems in speech perception and production, and associated difficulties in reading, come from problems in "rapid auditory processing," or "temporospectral acoustic analysis" (i.e., difficulties in discriminating the durations of the sounds making up speech). Spectrographic analysis of speech indicates that different syllables are distinguished by subtle differences in acoustic energy distribution over very short periods of time, so a failure to exhibit sensitivity to such distributions can give rise to profound difficulties in understanding spoken utterances, with consequent effects on ability to read. Tallal reviewed the complex literature on relations between timing of short intervals and speech disorders, not all of it completely consistent with her general position. On the positive side, the ability of very young children to discriminate brief time intervals can be highly predictive of "language outcomes at 2 years of age" (Tallal, p. 723). In addition, a training program to aid discrimination between rapidly changing acoustic stimuli can improve scores on tests of language and reading (Tallal, Figure 4, p. 726). On the negative side, some people with difficulties in reading and language comprehension do not differ significantly from controls on tests of rapid temporal processing, although this may only indicate that there are many different types of speech pathologies that do not share a common etiology.

Other work shows that speech disorders like aphasia are associated with difficulties in processing the temporal structure of stimuli that are not themselves linguistic. For example, Stefanos, Braitman, and Madigan (2006) tested aphasic patients and controls on a task involving the detection of gaps in auditory stimuli. A brief gap (ranging from 10 to 80 ms in duration) was either present or absent in an auditory stimulus that either maintained constant frequency throughout or changed frequency. Aphasic patients were impaired in gap detection for both sorts of stimuli but particularly in the changing-frequency case, when their accuracy was sometimes only half that of controls. As in the work of Tallal, the obvious suggestion here is that the difficulties in language processing and difficulties in the discrimination of rapidly changing auditory stimuli are critically linked.

Turning now from speech pathology to normal performance, some authors have attempted to forge links between ideas related to time perception and the way that speech is controlled. Shergill, Tracy, Seal, Rubia, and McGuire (2006), for example, used functional magnetic resonance imaging to identify the brain structures involved in covert language articulation. The task used was that of articulating a word every 2 s, with the word being either self-timed or produced in response to an external cue. The authors were particularly interested in potential overlaps between activation in the brain areas involved in the self-timed condition and those previously implicated in a range of time perception tasks (see Ivry & Spencer, 2004) and, indeed, some overlap was found, although the degree of overlap was far from perfect.

Another linkage between timing and the control of speech comes in Wilson and Wilson (2005), who attempted to model conversational turn-taking using the idea of entrained temporal oscillators. So "during conversation, endogenous oscillators in the brains of the speaker and listeners become mutually entrained" (p. 957), thus allowing the conversation to be coordinated, and smooth transitions from the role of speaker to listener, and vice versa, to be achieved. The idea that oscillators might be the basis for time perception more generally has been a popular one in the last 20 years; see Church and Broadbent (1990) for an early example and Matell and Meck (2004) for a more recent one, although quantitative modeling of time perception using oscillators is not without its difficulties (see Wearden & Doherty, 1995, for example).

Overall, therefore, these few fairly recent examples, selected from many more, show how time perception, particular of very short time intervals, may be implicated in the control of speech. However, from the point of view of a researcher in time perception, the most striking feature of this work is its more or less complete dissociation from the time perception field itself. For example, hardly any of the most cited articles in mainstream time perception feature in the reference lists of the speech-related articles discussed in this section, and the names of researchers who have made major contributions to time perception research in recent years are completely absent, or make only the odd appearance, in reference lists. Given that many issues seem common to the speech-related research and mainstream time perception itself (e.g., the perception of very short durations, or oscillator-based modeling of timing, to name but two), it seems likely that fruitful contacts between the two fields could be developed in the future.

Talking About Time: Time Metaphors and the Existence of a Time Sense

When talking about time, at least in English, metaphorical expressions seem nearly impossible to avoid, and some are so commonplace as to pass almost unnoticed as when, for example, experimental instructions tell a person to judge the "length" of a tone. Language-based metaphors for time have attracted some interest, particularly among sociologists concerned with time (e.g., Torre, 2007), but also among psychologists. For example, Jackson and Michon (1992) presented many examples of metaphorical time usages. Among these are time as space (e.g., "the following time," "face the future") and time as money ("wasting time," "borrowing time") or, perhaps more generally, time as a quantity of something, a quantity that increases or diminishes as time passes. My main concern here is to try to address the issue of what light research in experimental psychology can shed on the question of whether time, in the form of duration, is judged by a separate mechanism from that used to judge other quantitative properties of events, such as other sorts of magnitude, or numerosity, with which it is so frequently linked metaphorically.

The issue of whether judgments of time were essentially based on judgments of something intrinsically nontemporal is not only relevant to recent studies of retrospective timing but is also a venerable historical question. Nichols (1891) in a fascinating article that attempted to review philosophical and experimental work up to the time of its writing, discussed the controversy about whether a genuine "time sense" ("*Der Zeitsinn,*" in Czermak's original usage in 1857), comparable to a sense of vision or hearing, actually exists, or whether sensitivity to time is necessarily based on sensitivity to something else. This controversy continues in more recent times, as in the famous quote from Gibson (1975) that "events are perceivable but time is not." In spite of its celebrity, this remark may be little more than mischievous at least insofar as it refers to duration judgments. A perceived duration is always the duration of some event and may be a directly-perceivable property of the event, just as its color is, so a rephrasing such as "events are perceived but color is not" seems equivalent. Of course, Gibson may be alluding to the fact that no established "organ" for the perception of time has been identified, although, as noted earlier, the proposition that an internal clock exists has been useful for time psychologists, and this may be an "organ" for the *Zeitsinn*.

However, metaphorical usages for time may be lay expressions of fundamental psychological truths about relations between time and other quantities—in particular relations between time and space and relations between time and memory. Some of the relations between time and space are discussed in the article by Casasanto (this issue), in a crosslinguistic context. The fact that time and space might be psychologically related has been known for some years. For example, if three lights are illuminated successively in a darkened room, the distance between the lights can influence the perceived durations between the illuminations, with greater distances leading to longer perceived durations (the *kappa* effect). Conversely, greater times between successive illuminations leads to distortions in perceived distance, once again in the direction of longer intervals being associated with greater distance (*tau* effect). For a recent study of this phenomenon, see Sarrazin, Giraudo, Pailhous, and Bootsma (2004), and see Cohen, Hansel, and Sylvester (1953) for an early publication.

Children may experience particular difficulties in distinguishing duration, distance, and speed, as research by Levin (1992) shows. Most of this work uses tasks developed by Piaget, which involve children observing objects that can move on parallel tracks. The objects can start or finish together (or not), can travel for the same or different distances, and can travel at the same or different speeds. Children can be posed questions about the relative distance traveled, the relative speed, or the relative duration of the trips. Obviously, this procedure can give rise to complicated situations (e.g., objects starting and stopping asynchronously having traveled different distances at different speeds), and it is no surprise to learn that the ability to make correct judgments increases with age. A particular problem identified by Levin is that of confusing duration with distance (so an object that has traveled further will tend to be judged as having traveled for a longer time), two quantities that in everyday life tend to be positively related (i.e., usually, longer trips take more time) and confusing duration with speed. In the latter case, the child must wrestle with the problem that, generally, duration and speed are *negatively* related, as objects that go fast will traverse a distance more quickly than slower ones, even if the distance may be greater. Levin discussed the stages in the development of a "true" time concept, differentiated from distance but, as the *tau* and *kappa* effects show, not to mention the phenomena discussed by Casasanto (this issue), a complete dissociation may not be mastered even by adults.

On the other hand, examples of interference between temporal and spatial aspects of stimuli do not mean that the two are indistinguishable. With increasing development, children come to dissociate the dimension of duration from others with which it is confused when they are younger, such as spatial distance (Levin, 1992), number (Droit-Volet, Clément, & Fayol, 2003), and force (Droit-Volet, 1998). When confronted with stimuli that can differ in both spatial (physical length) and temporal (duration of presentation) aspects, verbally competent adults can clearly distinguish the different dimensions, and their judgments exhibit different characteristics depending on the dimension chosen; for example, short-term duration representations show subjective shortening, whereas length judgments do not (Wearden et al., 2002).

The frequent use of quantity metaphors for time, likewise, need not imply that no direct "time sense" exists: The accumulation processes of the putative internal clock are quantitative, with larger numbers of "clock ticks" representing longer times, so it may be that quantity metaphors arise as a result of some lay appreciation of this sort of internal mechanism. Quantitative representations of time (where different durations are represented by different quantities of something) are not the only possibility; some timing models (discussed by Wearden, 2001, but see Matell & Meck, 2004, for a recent example) use "pattern" representations of time, where different times are represented by qualitatively different states of the system, not by greater or less quantities of some common "currency" like clock ticks. So, for example, *n* seconds is represented by pattern X and *m* seconds is represented by pattern Y, where X and Y may be different patterns of neural activity (Matell & Meck), not necessarily different *amounts* of neural activity. Metaphorical usage appears, however, to prefer some sort of quantitative representation of time.

The question of similarities between the representation of time and that of other stimulus dimensions remains a vexed one. One question that frequently arises is that of whether timing of events in different modalities (the timing of the duration of a tone and a visual stimulus is a simple example) is based on a common "clock" or whether different mechanisms operate when the stimulus is, for example, auditory compared with visual. It has been known since the 19th century that auditory stimuli have longer subjective durations than visual ones that last for the same time (for recent examples, see Wearden et al., 1998; Wearden, Todd, & Jones, 2006). On the other hand, the form of time judgment functions is often strikingly similar when stimulus modalities are different; for example, temporal generalization performance is virtually identical in general form with auditory and visual stimuli (Wearden et al., 1998) and verbal estimates of the duration of stimuli of various sorts increase linearly with real duration (Wearden et al., 1998; 2006; Wearden, Norton, et al., 2007). What is not clear is what conclusions can be drawn from the similarities and differences obtained. For example, judgments of the magnitude of stimuli in many different sensory dimensions show sufficiently striking similarities for general "laws" of sensation growth to be proposed (e.g., Stevens, 1957), but no one would suggest that visual and auditory stimuli were indistinguishable or that they were perceived by a common mechanism.

Conclusions

The present article aims, first, to acquaint the reader with some recent trends in time perception research. In the interest of clear exposition, some issues have been simplified slightly, but the references given will enable an interested reader to delve into the full complexities of the subject if they wish to do so. As is clear, although time perception research has made significant progress in the last 20 or 30 years, many problems still remain, and for present purposes, a particular difficulty is that hardly any of the research relates clearly to language. The second aim of the article was to discuss some potential links between time perception research and language. These links already exist in outline, but the "language-based" research makes little contact with the data accumulated and theory developed recently in time perception research. It seems at least possible that a closer rapprochement between the "language-based" and "non-language-based" research on timing would be to the benefit of both fields, as some common foci seem clearly identifiable.

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Time in Agrammatic Aphasia. Commentary on Wearden

Herman Kolk
Radboud University

In his article, Wearden briefly refers to language disorders as an aspect of language that could be related to time. I will further elaborate on this remark, and while doing so, I will make a connection to still another aspect of language related to time: tense.

Language has a temporal structure and this structure unfolds at high speed. As a guideline, one could consider the fact that the average speaker can easily produce some 20 phonemes per second. This means that linguistic information must be retrieved very rapidly, to prevent disfluency, but must also disappear from memory very quickly, to prevent interference with ongoing speech. When learning language, children must not only store all sorts of new linguistic information but must also learn to retrieve this information fast enough. All children between 2 and 6 years of age therefore go through a period of frequent disfluencies, and for some, these disfluencies will remain and they will become habitual stutterers (e.g., Kolk & Postma, 1997).

Language breakdown in aphasia has also been connected to processing rate. Our own work has focused on agrammatic aphasia, characterized by the presence of telegraphic speech in production and difficulties in syntactic comprehension. This phenomenon has given rise to speculations that particular syntactic representations would be lost in aphasia (e.g., Grodzinsky, 2000). However, as argued by the Swiss neurologist Von Monakow (1914) in the beginning of the 20th century, a representation in the brain is actually a process, or, as he called it, a *kinetic melody*: It unfolds over time and cortical space in a way that is specific to the type of linguistic information it represents. In 1991, Haarmann and Kolk proposed a model of grammatical kinetic melodies and their breakdown in agrammatism (Haarmann & Kolk, 1991). The model, SYNCHRON, retrieves information as it goes from left to right through the

Correspondence concerning this article should be addressed to Herman Kolk, NICI-RU, P.O. Box 9104, 6500 HE Nijmegen, The Netherlands. Internet: H.Kolk@NICI.RU.NL

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sentence. It needs a specific number of time steps to retrieve a particular type of information, called *retrieval time*, and this information remains in memory for another number of time steps, called *memory time*. A process of tree-building starts up, as soon as the first word is recognized and category nodes are retrieved as soon as all words or nodes dominated by this category node are retrieved. The bottlenecks of this process are the retrieval rate and the memory decay rate. The longer it takes to retrieve a particular node, the higher the chance that other nodes, dominated by this node, will have decayed. On the other hand, if memory time is relatively short, it will be hard to build up a complete tree, even with a normal retrieval rate. Furthermore, the greater the complexity of the syntactic tree, the harder it is to obtain synchrony between the highest and the lowest nodes. With this model, Haarmann and Kolk were able to simulate the empirical data from two different studies on agrammatic comprehension, assuming that these patients, rather than having lost part of their competence, suffered either from a slowdown in retrieval or from an increase in decay rate. Both temporal deficits gave exactly the same results. A number of years later, Gary Dell and his colleagues employed a spreading activation model, developed for normal speech errors, to explain patterns of aphasic errors in fluent aphasia. They distinguished two different error patterns, one resulting from slow activation (reduced connection strength was their terminology), another from fast decay (Dell, Schwartz, Martin, Saffran, & Gagnon, 1997).

The effects of such temporal deficits can be demonstrated experimentally. Hartsuiker and Kolk (1998) asked patients to repeat sentences of a particular structure and immediately after gave them a picture to describe. If the sentence that they had to repeat was a passive, they tended to use a passive sentence form to describe the picture, despite of the fact that they almost never produced passives spontaneously. This result fits the timing hypothesis quite well. If the computation of constituent structure is delayed, priming by means of repetition speeds up this computation, because the structural units have already reached a certain level of activation and it will generally take less time to bring these units to threshold.

According to the timing hypothesis, all operations that are necessary for planning a grammatical sentence have to be carried out within a limited amount of time. This means that not only syntactic but also conceptual or message level operations could reduce the chance of computational simultaneity. So a temporal deficit at the syntactic level can have repercussions for higher levels of representation. Hartsuiker, Kolk, and Huinck (1999) carried out two experiments with Dutch agrammatic speakers in which they studied agreement inflection production. They employed a paradigm in which participants were presented with sentence fragments, which had to be repeated and completed (e.g., *the king of the colonies—was powerful*). The participants received the first set of words and had to add the auxiliary and an adjective of their liking.

One manipulation concerned conceptual number of the head noun. This could be singular, like its grammatical number (e.g., *the baby on the blankets*), or it could be plural (e.g., *the label on the bottles*), unlike its grammatical number. In the latter example, although the head noun is grammatically singular, it is in fact referring to a multitude of labels, one on each bottle. Experiments with normal participants have demonstrated effects of conceptual plurality. In particular, they observed that in sentences with a head noun that was grammatically singular but conceptually plural (e.g., *the label on the bottles*), more agreement errors were made than in sentences without such a mismatch (e.g., *the baby on the blankets*). This indicates that normal speakers take conceptual information into account when constructing subject-verb agreement. In two experiments with agrammatic speakers and normal controls, Hartsuiker et al. (1999) replicated this conceptual number effect in Dutch for the normal but not for the agrammatic speakers. In fact, the agrammatics made *fewer* agreement errors than the normal controls! It was concluded that the patients could not take conceptual number into account. Verbs are inflected not only for agreement but also for tense. Following the observation that agrammatic speakers have severe problems with tense, whereas agreement is relatively intact, some have suggested that tense nodes in the syntactic tree are lost in agrammatic aphasia, whereas agreement nodes are spared (Friedmann & Grodzinsky, 1997). The timing approach suggests a different account. Whereas agreement inflection can be decided upon at the syntactic level itself, tense inflection requires computational simultaneity of the syntactic and the conceptual level. Agrammatic speakers should be impaired in this and should therefore make more errors while inflecting for tense than while inflecting for agreement. Kok, Van Doorn, and Kolk (2007) tested this hypothesis by comparing two conditions. In the "inflection-only" condition, the patients received a sentence with an uninflected verb (e.g., *yesterday, my father to-cook dinner*) and they only had to inflect the verb. In "the inflection + word order condition," the words, including the uninflected verb, were presented in scrambled order, and the instruction was to both inflect the verb and read aloud the words in the appropriate order.

Kok et al. (2007) drew upon the language capacity model proposed by Just and Carpenter (1992), which predicts that carrying out two tasks simultaneously leads to slower processing or faster decay. They found that the patients indeed made more errors with tense than with agreement inflection but that both error rates went up in the dual-task as compared to the single-task condition. The increase was the same for both types of inflection, which is understandable if one assumes that the same ordering operation takes place while inflecting for agreement as while inflecting for tense, leading to the same load increase. It should be remembered that this dual-task condition is the natural one. While speaking, ordering and inflecting are part and parcel of language processing. The demands this puts on the processing system were not met by the agrammatic speakers.

Monakow's metaphor of kinetic melodies allows for the independent existence of different levels of linguistic representation, each with their own "melodies." Patel (2003) has drawn attention to the fact that the representation of syntax and music involve very similar areas in the brain, which he sought to explain by referring to the similarity in temporal processing, in the sense described earlier. However, one should not forget that, despite this similarity, syntactic and musical representations must be distinct, as we rarely mistake a sentence for a song. The same holds for different linguistic levels: They must be distinct, not only to make language processing possible but also to account for the fact that they can be selectively affected by brain damage. There are, for example, agrammatic patients with normal articulation. On the other hand, if one assumes that brain damage negatively affects the temporal properties of processing, this damage may implicate several linguistic levels simultaneously and even extend to nonlinguistic tasks. In fact, as a group, agrammatic patients have a higher chance to suffer from articulation difficulties. Wearden (this issue) describes evidence that aphasic patients are impaired in gap detection in auditory stimuli, which were nonlinguistic. So, time connects sequential processing at various different linguistic levels and in various cognitive tasks. Commonalities in brain areas involved and patterns of association and dissociation will help us to discover what kinetic melodies are represented independently in the human brain.

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Neural Bases of Sequence Processing in Action and Language

Francesca Carota and Angela Sirigu
CNRS

Real-time estimation of what we will do next is a crucial prerequisite of purposive behavior. During the planning of goal-oriented actions, for instance, the temporal and causal organization of upcoming subsequent moves needs to be predicted based on our knowledge of events. A forward computation of sequential structure is also essential for planning contiguous discourse segments and syntactic patterns in language. The neural encoding of sequential event knowledge and its domain dependency is a central issue in cognitive neuroscience. Converging evidence shows the involvement of a dedicated neural substrate, including the prefrontal cortex and Broca's area, in the representation and the processing of sequential event structure. After reviewing major representational models of sequential mechanisms in action and language, we discuss relevant neuropsychological and neuroimaging findings on the temporal organization of sequencing and sequence processing in both domains, suggesting that sequential event knowledge may be modularly organized through prefrontal and frontal subregions.

Introduction

The ability to estimate in real-time what will come next when we start acting is a crucial prerequisite for planning sets of coherent behavioral units. For action plans to result in optimally purposive patterns of concatenated individual moves, the specific temporal structure associated to the required sequence of actions needs to be computed prospectively based on adequate representations of event knowledge.

The psychological categorization of the causal-event structure that is inherent to human knowledge has been a *vexata crux* in the field of cognitive psychology, because sequential structures permeate conceptually distinct knowledge domains.

In action, for instance, sequential structures affect movement selection and prediction during the formulation of motor programs and higher order,

Correspondence concerning this article should be addressed to Francesca Carota, Centre de Neuroscience Cognitive, 67 Blv Pinel, 69675 Bron, France. Internet: Francesca.Carota@isc.cnrs.fr

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macrolevel action plans, as well as the analysis of observed series of action clusters. Accordingly, a degraded representation of such high-level structures of sequential knowledge has a direct impact on the physical ability to program motor commands, to control actions, and to achieve its related goals, leading to incomplete or purposeless behaviors (Shallice, 1988; Sirigu, Zalla, Pillon, Grafman, Dubois, et al. 1995; Sirigu et al. 1996, 1998; Zalla, Plassiart, Pillon, & Sirigu, 2001; Zalla, Pradat-Diehl, & Sirigu, 2003).

Sequential information is also a crucial cognitive component in an a priori distinct domain such as language, which exhibits sequential patterns at multiple structural dimensions, such as morphology and syntax. For instance, both local and long-distance syntactic dependencies in natural language (e.g., topicalization, *wh*-movement, etc.), with their embedded semantic relations, may require computational procedures and a working memory system parallel to the ones that are involved in action sequencing. It has been proposed, for instance, that the syntactic component of the language faculty may derive from a set of prelinguistic operations borrowed from the motor planning domain (Steedman, 2002). On the other hand, language may be treated within different temporal spans due to different constraints of memory load and domain-specific governing principles. This would be in line with classical dual-system views of language (Chomsky, 1995, 1998; Pinker, 1994; Pinker & Ullmann, 2002; Ullmann 2001, 2004), which posit that the mental grammar employs an autonomous set of procedural rules capturing regularities intrinsic to language and specifying possible hierarchical and sequential combinations between morphological and lexical material (stored in declarative memory) into richer representations, such as complex words and sentences.

The relevance of sequential information in action and language leads to the question of how these related domain-specific categories of sequential knowledge are internally represented.

Sequential event knowledge is commonly assumed to be stored based on memorized sequence configurations, the so-called structured event complexes (Grafman, 1995, 1999; Wood & Grafman, 2003), also known in terms of schemas (Bartlett, 1932) and scripts (Schank & Abelson, 1975). These internal representations of goal-oriented sets of subsequent cognitive representations of events specify at a high degree of unification the global order of event series, encompassing chronological, linguistic, and motor information (Wood et al., 2004).

In this perspective, it becomes particularly interesting to address the specific question of whether the categorization, activation, and processing of different event knowledge domains rely on a common neural processor or, rather, on a domain-dependent one.

It is widely acknowledged that the prefrontal cortex plays a central role in the storage, the maintenance of sequence representation, and the generation of sequential processes. However, whether and how diverse knowledge categories are reflected and subserved by specialized or overlapping neural codes within the prefrontal regions has been a matter of long-standing scientific debate. Ample work suggests that the specific functional organization of this brain area is largely sensitive to different, domain-specific aspects of event knowledge. A possible explanation of such specialized subregions would be the connectivity with posterior cortical and/or subcortical regions whose functions are related, for example, to higher order sensory processing (parietal cortex, association areas), memory (hippocampus), and motor control (premotor cortex, supplementary motor area, basal ganglia) (Wood & Grafman, 2003). The particular cytoarchitectonic structure (i.e., the arrangement and density of nerve cells in the cerebral cortex; from Greek $\kappa\acute{\upsilon}\tau o\varsigma$ = cell + $\alpha\rho\chi\iota\tau\varepsilon\kappa\tau o\nu\iota\kappa\acute{\eta}$ = architecture) and connectivity of the region (i.e., the connections of its nervous fibres with noncontiguous brain regions) motivates the interaction between the sequential event knowledge system and the neural bases of temporal processing, memory, action, and language.

The present article attempts to characterize the representations of sequential event knowledge structures and the functions of the prefrontal cortex in mediating the computational operations required to generate and process them in action and language.

The remainder of the article is structured as follows. First, some representative models of sequential event structures are sketched from the perspective of cognitive psychology and linguistic theory. This prepares the ground for introducing, as a second concern, the neuroanatomical and functional correlates of sequence processing, focusing on relevant findings from neuropsychological and neuroimaging work for particular dissociations between different categories of event knowledge represented by action and language sequences. We then conclude by profiling the implications of these results for the current models of sequential knowledge processing.

Sequential Event Structures

The representation of sequential event structures is based on a temporal and causal ontology that is rooted in our cognitive ability to perceive and discriminate between two types of events: (a) event types that involve continuous update and change over time, namely processes, and (b) event types that do not temporally change, namely states (Langacker, 1987, p. 258). This ability allows us to establish the relative order between contiguous events in terms of initial events and subsequent ones, which is a prerequisite for planning and processing strategies both in action and language.

In the present article we focus on the particular type of temporal processing of information that is required in sequential structuring and that allows us to establish the relative order of the events in terms of precedence and dominance relations between them.

The ontological dichotomy between states and processes is especially mirrored in verbal *Aktionsart*, a part of the aspectual system, but it is also somehow reflected by the representational models that have been developed within cognitive psychology, some of which include a dynamic principle, whereas others emphasize the static organisation of data structures, as we will argue in the next section.

Frames, Chunks, and Scripts

Multidisciplinary approaches have accounted for the modelling of event sequences in terms of structured templates. We will briefly introduce three major representational models, a meta-scheme independent of the specific domain such as frame, an action-related one, that is, a chunk, and a language-related one, that is, a script.

The attempt to unify the structuring of reasoning, memory, and language under a common abstract denominator inspired Minsky (1975) to propose that minimal knowledge units, or *frames*, interface with the respective "factual and procedural contents" of these domains. Defined as a *remembered framework to be adapted to fit reality by changing details if necessary*, a frame provides a basis for effective adaptative responses to novel situations. However, it consists of a rather static "data structure for representing a stereotypical situation" (Minsky, p. 212), which specifies several types of information, such as instructions about the use of the frame itself, expectations about upcoming events, and steps to undertake when expectations are disconfirmed. For our purpose, one relevant aspect of the frame notion is that it is formally modeled as a treelike network of nodes and relations, which are hierarchically related, with fixed root nodes for true properties of known situations and terminal leaves to be filled by specific instances depending on particular restrictions to be met for satisfying a slot-filler assignment condition. As a result, multiple frames can become interrelated in complex systems, by means of multiple combinations of event structures.

Likewise, event knowledge representation specific to goal-directed action has been modeled in the form of memorized representation units, or *chunks* (Black & Bower, 1979). The process of chunking information, which refers to grouping or clustering together the discrete information units called chunks, is usually assumed to facilitate the understanding and the retrieval of knowledge representations in human short-term memory (Miller, 1956). The psychological reality of chunk-based representations has been specified in terms of episodes containing structures of embedded goals and subgoals (Black & Bower). The particular structure of chunks has an effect on memory. In fact, the chunks contain hierarchically interconnected events, embedded according to different levels of abstraction, including basic, subordinate, and superordinate goal-directed events. The basic events consist of the sensorimotor and physical features involved in the performed actions, whereas the events of higher levels are related to the long-term goal of actions. The basic events, such as motor representations, are processed automatically by perceptual chunking. On the other hand, superordinate events that require intentional control of the related goals are encoded, processed, and recalled on the basis of a goal-oriented chunking principle (Gobet et al., 2001). The hierarchical organization of the goal-oriented events has a direct impact on recall performance, because superordinate events are better recalled when more subordinate events are encompassed within the same episode and inferred from the corresponding superordinate ones.

The interest of the chunk-based model is the conceptual transition from sequential event knowledge representations to goal-oriented action, which also underlies the notion of *script*, a structure that configures an appropriate sequence of events in a particular context, relying on slot fillers, or attribute-value associations, in which each event is interrelated with the subsequent one forming a whole (Schank & Abelson, 1975). Sequences are said to be internally constrained by a causal chaining principle (Abelson, 1973; Schank, 1973), imposing co-occurrence restrictions on sequence units and script sequences according to a "what-if" alternative that allows rejection of incoherent units and reduces order error outputs. Importantly, the script framework extends knowledge representations to event plans. In fact, a parameter of goal-directedness marks the difference between scripts themselves and the set of event sequences (i.e., plans) that are oriented toward a goal, based on a set of intention-driven choices. Accordingly, the internal organisation of scripts and plans is an arborescence built on the causal relationships between event representations, goals and subgoals, respectively.

In the perspective of scriptlike knowledge structure, texts exemplify series of events correlated with goals and plans necessary to achieve them: The stories they report offer stylized representations of scripts, and text structure is designed as a set of paths joined at crucial points, temporally and hierarchically ordered.

The models just sketched share a hierarchical ordering of events, co-occurrence constraints on allowed subsequent events, and goal orientation of plans. These features of sequential event knowledge representation are valid not only for the action domain but also for language, as we will briefly consider while discussing their impact on narrative discourse macrostructures and syntactic microstructures.

Macrostructures: Narrative Discourse

It has been claimed that the representational devices that organize world knowledge for predicting and interpreting new situations, information, and events of experience are "structures of expectations" (Tannen, 1979), which can be applied to language. Language in action, or talk, is indeed shaped through a series of contextually dependent "shifting frames" caused by mismatches in schemas, or expectations about events, objects, and individuals (Tannen & Wallat, 1987). Schank (1973), in his early work on natural language, described how a word in a single sentence triggers expectations about what will follow in the rest of the sentence, and a single sentence about what will follow in the rest of the discourse story, pointing out that the whole of these expectations form world knowledge related to situations.

A *caveat* regarding extending the notion of expectation toward an intentional goal to language comes from theories of discourse that posit a distinction between linguistic and nonlinguistic discourse dimensions. For instance, the linguistic structure of the actual sequence of utterances in discourse is distinct from the intentional structure that is determined by the goals underlying speakers' communicative actions and from the attentional state, or focus of attention recording and keeping track of the referents, the properties, and relations between discourse segments that are salient at each stage of the unfolding discourse (Grosz & Sidner, 1986). Accordingly, although discourse linguistic structure can be segmented, horizontally, into segments and embedded segments by detecting the segment boundaries, it is the intentional dimension that specifies both precedence relations and dominance relations between discourse segments, determining their hierarchical order in terms of planned goals and subgoals. To process discourse thus means to recognize how the utterances of the discourse combine into segments, as well as to understand the underlying intentions and the relationships of precedence and dominance among them. It also means to construct and organize a mental model (i.e., an "attentional state" [or focus of attention] that records, tracks, and dynamically updates behavior).

A question is thus whether, and to what extent, during narrative discourse processing and planning these recognition tasks depend on features that are merely textual (or internal to the linguistic dimension) or also depend on the speakers' knowledge of the discourse domain.

A pertinent point that emerges from psycholinguistic findings is that the planning of the causal structure encompassing orderly causes and consequences is indeed based on fine-grained textual, linguistic features inherent to discourse, such as the contextual accessibility and recency of lexical anchors, or antecedents, of anaphoric expressions; that is, speakers decide what to say next based on (co)text or prior discourse. Interestingly, however, the temporal structure of ongoing narrative also determines the selection procedure leading speakers to choose what they will say next with respect to temporally prior discourse (Simner & Pickering, 2004).

This tells us that, in narrative discourse, the planning of the causal structure of a sequence of consecutive causes and consequences is driven by both linguistic properties and temporal information about the typicality of events and, ultimately, event knowledge.

Although a language-specific component is preserved from the intentional structure underlying communicative actions in language, narrative discourse becomes representative of plans, or goal-directed sequential structures, in both language and action domains. For this reason, it has offered an exclusive test bed for theories and hypotheses about the domain sensitivity of the organization of event knowledge.

It remains now to consider whether a similar temporal treatment also applies to microstructural, local language sequences, such as syntactic structures.

Microstructures: Syntax

Syntax specifies grammatical functions between word constituents to encode hierarchical syntactic relationships, precedence relations in word order, and inflection. Processing and parsing syntactic structure imply the analysis and the decomposition of syntactic constituents by recognizing the relations of immediate dominance and linear precedence between them. For example, in the generative tradition, syntax has been configured as a sequence of structure-building operations such as Merge, or concatenation, a one-step, recursive computational procedure that captures generalized transformations to combine autonomous syntactic trees under a single node (Chomsky, 1993, 1995).

Recent theoretical views attribute great centrality to this type of operations, such as merging or unification, which allow the combination of language material into sequential patterns by discarding unselected competitor candidates, as being a powerful computational mechanism in grammar (Hagoort, 2005; Jackendoff, 2002).

Interestingly, work on combinatory categorical grammar has recently extended a similar view to the action domain. More specifically, a recent hypothesis suggests that composition, a procedure that combines representations and event functions into sequences, constitutes an explicit formal parameter interfacing syntax and simple planned action: In both domains, the causal association between initial, preparatory events and consequent, future outcomes originates in the process of planning, and the related notion of goal-directedness (Steedman, 2002).

It is known that the need to plan and hierarchically combine linguistic units arises because of the mismatch between conceptual messages and word sequences that are linear and spread over time (Levelt, 1989). This process requires the assignment of a relative order between elements, including both motor actions at the base of articulated speech, and syntactic constituents. What it ultimately presupposes is thus the coordination of this assignment mechanism with the planning of the motor unit sequences that serve to package and structure the information flow. In this perspective, the planning and the organization of both motor action and syntactic sequences are closely interrelated in language.

We can now turn to the neuroscientific issue of how sequential event knowledge structures are encoded and processed in the brain. As previously mentioned (see introduction), the question we intend to address is whether specialized neural substrates represent and separately treat sequences of events belonging to specific domains of knowledge, such as action or language. Alternatively, the representation of sequential event structures in both domains could rely on a common neuroanatomical base.

In the next section, we attempt to give an answer by reviewing and discussing the ample literature dealing with the issue of the temporal organization of serially ordered cognitive events across dedicated cerebral networks.

Sequence Processing in the Prefrontal Cortex

Different representational and process-based models have been proposed to explain the role of the prefrontal cortex in action planning and monitoring (Wood & Grafman, 2003). Nevertheless, there is general consensus that this brain region is a preferred location for the abstract representation and expression

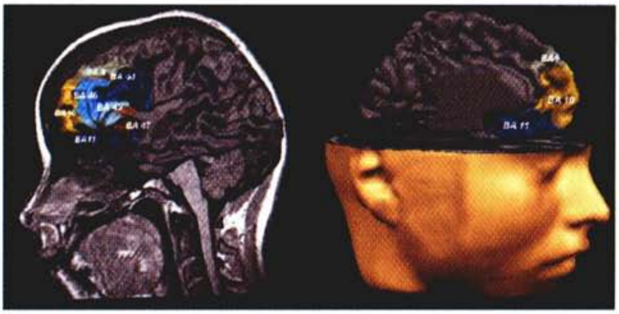

Figure 1 From left to right, lateral and medial views of the prefrontal regions. These include the medial prefrontal cortex (BA 11), the medial (BA 10) and lateral orbitofrontal cortex (BA 47), the dorsolateral prefrontal cortex (BA 9, BA 46), the pars triangularis (BA 45), and the pars opercularis (BA 44) of Broca's area. (All images were made in BrainVoyager; http://www.brainvoyager.com.)

of the temporal structure of complex motor action sequences. It has been widely suggested in the literature that the prefrontal regions play a functional role in the integration of temporally separate events into purposeful action sequences, and in the mediation of domain-specific representations of sequential event knowledge (Fuster, 1989; Goldman-Rakic, 1987; Grafman, 1989).

In fact, several studies provide converging evidence for a preferential involvement of prefrontal subregions in modulating various temporal aspects of sequential event knowledge (Crozier et al., 1999; Knutson, Westdorp, Kaiser, & Hommer, 2000; Zacks Tversky, & Iyer, 2001). For instance, positron-emission tomogarphy results show that the expression of emotional and nonemotional plans recruits the medial prefrontal and the dorsolateral prefrontal cortex, respectively (Partiot, Grafman, Sadato, Wachs, & Hallett, 1995; cf. Figure 1). A particular network—with the inclusion of the right frontal lobe, left superior temporal gyrus, and the middle temporal gyrus bilaterally (Figure 2)—is specifically activated during the temporal ordering of script events, whereas a distinct circuit, more lateralized on the left hemisphere and including the left frontal lobe, left anterior cingulate, and the anterior part of the left superior temporal gyrus (Figure 2), is implicated in assigning an event to a given script or action category (Partiot, Grafman, Sadato, Flitman, & Wild, 1996).

Neuropsychological studies demonstrate that a lesion in the prefrontal cortex is responsible for selective impairment in event sequence processing (Grafman, 1989): prefrontal patients fail to generate the correct temporal order of action sequences, in completing a script and fail to respect script boundaries

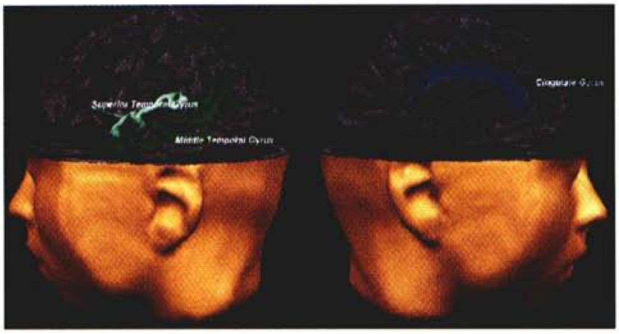

Figure 2 From left to right, the superior temporal gyrus, the middle temporal gyrus, and the cingulate gyrus.

(Sirigu, Zalla, Pillon, Grafman, Agid, et al., 1995; Sirigu, Zalla, Pillon, Grafman, Dubois, et al., 1995).

Comparative studies of prefrontal patients and patients affected by Parkinson's disease (for whom motor output via basal ganglia-thalamocortical pathways is inhibited)[1] reveal that although the prefrontal patients are impaired in the sequential ordering of events, and in respecting sequence boundaries and hierarchies, Parkinson patients fail to establish the contextual importance of each event within the planning activity (Zalla et al., 2000). A possible explanation is that the prefrontal cortex and the basal ganglia have different roles in action planning: During the generation of meaningful event sequences, the basal ganglia may, for example, serve to provide feedback about the value of the constituent action units (Zalla et al.).[2]

The multifunctionality of the prefrontal cortex in the temporal treatment of knowledge structures related to various knowledge domains arises from the particular internal subdivision of this brain area in specialized subparts (see Figure 1), each of which delimits the scope of a particular group of intersected functions (Wood & Grafman, 2003). These functions include, for instance, domain-specific semantic working memory involved in the semantic analysis of initial occurrences of words and pictures, as well as in the selection of semantic alternatives (Gabrieli, Poldrack, & Desmond, 1998).

According to Grafman (1995), knowledge is represented in terms of "structure event complexes" that are stored in distributed prefrontal subregions.

Recent monkey studies also outline the involvement of prefrontal neurons in processing goal-oriented behavioral sequences, reporting category-specific effects in the activity of prefrontal neuron subgroups. More specifically, during the planning of sequences of motor acts, such as paired action sequences (e.g., turn-turn-push-push), alternate action sequences (e.g., pull-turn-pull-turn), and four "repeat" sequences (e.g., turn-turn-turn-turn), cellular activity in the lateral prefrontal cortex appears to be selective for the specific category of the motor sequences to be performed rather than the sequence per se (Shima, Isoda, Mushiake, & Tanji, 2007). As the category of the motor sequences to plan was not signaled by any cue but simply memorized during the training that preceded task execution, a neural representation of the category-related information specific to each type of motor sequence was internally generated within the lateral prefrontal cortex based on macrostructured action knowledge.

Neuropsychological and neuroimaging studies have explored the prefrontal functional organization with the purpose of detecting the domain dependency of the knowledge-related representations and computations. The findings have shed light on the existence of particular dissociations in the prefrontal regions, as will be outlined in the following sections.

Prefrontal Parsing of Hierarchical Action Sequences

Perceiving and understanding patterns of goal-directed action sequences, recognizing and attributing to them their relative and causal hierarchical order and goals within the action flow, presupposes the ability to locate events in time locations, by identifying the breakpoints that mark the transitions from one unit to the contiguous one (i.e., their initial and final boundaries).

Neuroimaging studies report, for example, that transient changes in the activity of a distributed network, including the right frontal cortex, are more sensitive to the segmentation of coarse event units than small ones (Zacks et al., 2001).

Neuropsychological work has examined the ability of brain-damaged patients with left or bilateral prefrontal lesions provoking deficits in action planning to determine the temporal margins of consecutive action sequences illustrated in video scenarios (Zalla et al., 2003). Action chunks located at different hierarchical levels, reflecting fine-grained and coarse-grained events, induce distinct detection strategies: Prefrontal patients exhibit a stronger deficit in segmenting large, higher order event units than small, low-level ones. This selective impairment of top-down chunking mechanisms, mirrored by a defective action monitoring and action planning, suggests that the prefrontal cortex contributes to both parsing and generation of meaningful goal-oriented action sequences. This indicates that the hierarchical organization of meaningful event units and subunits in the prefrontal regions influences the segmentation strategies of continuous, goal-oriented action streams.

A recent hypothesis states that the hierarchical organization of plans, rather than the temporal organization of events, specifically drives the selection of actions in complex, goal-oriented behavior (Koechlin & Jubault, 2006). The hypothesis is supported by neuroimaging data showing a phasic activation in the pars opercularis (BA 44) of the left inferior frontal gyrus when subjects process the boundaries of simple action chunks and in the pars triangularis (BA 45) for boundaries of hierarchically higher chunks of actions. According to this particular segregation of Broca's region (cf. Figure 1), a cascade model of brain activity associated to the nested levels of action hierarchies is proposed in which superordinate action chunks are processed by BA45, intermediate or simple action chunks are processed by BA44, and basic motor responses are processed by the premotor cortex.

The fact that these findings suggest the involvement of a brain region traditionally associated with language functions, such as Broca's area (BA 44, 45; Figure 1) (Broca, 1861), in the domain of action sequence, brings us back to reformulating the central question concerning the domain dependency of the sequential event knowledge representation and processing in the brain: Are there multiple cognitive mechanisms involved in sequential event structure processing related to different domains of knowledge? Are they controlled by distinct brain regions?

Prefrontal Dissociations for Language Versus Action Sequences

Whether the prefrontal cortex hosts independent mechanisms for different domains of temporally organized knowledge is a question explicitly addressed by lesion work comparing impairments in action planning and sequential structuring in syntax (Sirigu et al., 1998). In this study, sequence processing abilities were tested in 10 patients who exhibited selective lesions that included either part of the left inferior frontal gyrus (BA 44), and part of the left ventral premotor cortex (BA 6) (see Figure 3, left panel), or the left dorsolateral prefrontal cortex (BA 45, and part of BA 46) (see Figure 3, middle panel), or both (compounded lesion) (Figure 3, right panel).

The first group of patients showed impairments in tasks of planning and managing everyday activities. The second group of patients displayed agrammatic speech, with reduced syntactic abilities, impaired use of function words and grammatical endings, and generally poor, yet informative, verbal output. In the last group, both executive functions and language syntax were impaired. Two conditions were examined. In a *syntax production condition*, emphasizing morphosyntactic analysis, grammatically correct sentences had to be generated using 30 sets of cards. Each set contained the individual segments of one to four

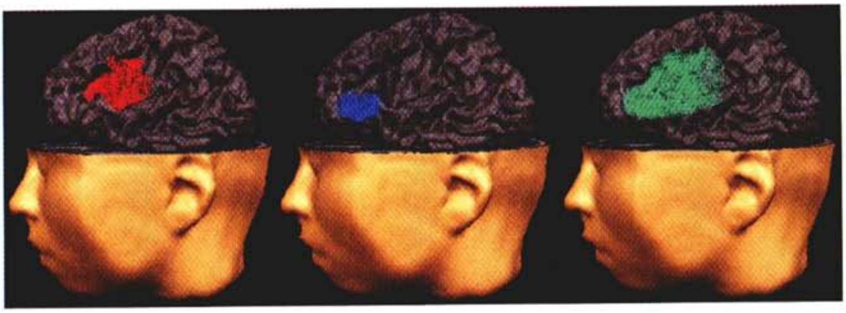

Figure 3 Location of the lesion areas common to each patient group. Left panel: Broca's lesion (BA 44); middle panel: prefrontal lesion (BA 45 and part of BA 46); right panel: compound lesion. (Adapted from Sirigu et al., 1998).

words, which served to form a complete sentence. In half of the sentences, the subject and the object were semantically reversible; that is, they could both play the semantic role of agent and patient, like "lady" and "man"' in the example: "a lady was / pushed by / a man / while she / crossed the street" (from Sirigu et al., 1998, p. 773). This semantic reversibility was not present in the remaining half of sentences like in the example: "the butcher / sharpens his / knife / and cuts a / thick steak" (from Sirigu et al., 1998, p. 773). The reversibility condition was used in order to assess the patients' ability to process word order on the basis of purely syntactic rules, without semantic/contextual information. For instance, semantically reversible sentences prevented patients from adopting task-related strategies that can be available to some agrammatics, such as associating the animate items with the agent role and the subject position. Each sentence could be constructed in one correct order only based on morphosynctatic knowledge.

In a *script condition*, a correct action sequence had to be generated using a set of 20 cards, on each of which a single action was described using one to four words. Following the temporal sequence of actions depicted on the cards, a coherent short narrative had to be produced, for example: "arrive at the new stand / ask for the paper / take it / pay / leave" or "insert card / pick-up the receiver / dial / waiting for an answer / talk." Four different and semantically unrelated scripts could be composed using the actions depicted on the 20 cards, as there were five single actions for each script. The participants were required to establish the semantic content of the script by sorting out the sequences of cards that described a series of actions related to a same script. They then had to process the temporal structure of the script by attributing the appropriate temporal order to the sequence of actions selected for each script. The title of each possible script was indicated on a separate sheet.

The generation of correct action sequences implied respecting temporal restriction rules constraining the action ordering. The task valorized the pragmatic analysis of the story grammar. The results of this study show that, in prefrontal patients, syntactic ordering was intact, whereas both the assignment of single actions to the correct script and the sequence between consecutive actions were severely altered. Broca's patients, in contrast, were able to accurately organize a coherent narrative but could not generate syntactically correct sentences. For instance, they made systematic inversions in the subject-object syntactic positions for the semantically reversible sentences illustrated so far (e.g., "man" was used instead of "lady"). Patients with compound lesions were disabled in both syntax and script abilities. The authors concluded that the double dissociation in the syntactic and script-related, pragmatic abilities is indicative of the involvement of different knowledge domains and mapped onto different networks within the prefrontal cortex (Sirigu et al., 1998). The results were consistent with previous findings showing that prefrontal patients are able to evoke the adequate action prototype (prototypicality of an action for a semantic category) associated with an action plan but impaired in the temporal ordering of actions (Sirigu, Zalla, Pillon, Grafman, Agid, et al., 1995). The fact that a lesion in Broca's area preserves the ability to temporally order words that refer to actions but not words referring to the sequential structure intrinsic to language indicates that sequence processing may be differently represented in the brain according to specific domains of knowledge.

Another result in this direction comes from a functional magnetic resonance imaging study investigating the perception of syntax compared to story grammar (i.e., the set of combinatory rules that specify the appropriate temporal constraints of an action sequence). The syntax and story grammar tasks required the perceptual detection respectively of either syntactic or action sequence errors in sentences visually projected on a screen. The results indicate that the perception of both syntax and story grammar recruits a partially overlapping network of regions (e.g., premotor areas, middle frontal gyrus, inferior frontal gyrus, anterior and posterior superior temporal sulcus, and supramarginal gyrus), more lateralizsed on the left hemisphere for syntax, more bilateral for the action sequences. The perception of story grammar, on the other hand, specifically activates the dorsolateral prefrontal cortex bilaterally, left supplementary motor area, and the left angular gyrus within the parietal cortex (Crozier et al., 1999). The bilateral prefrontal activation is interpreted as being particularly involved in event-sequence representations, temporal ordering of events, and action planning, within a broader fronto-parietal network specific to script processing.

To summarize, globally, these data suggest a selective involvement of the prefrontal cortex in the perception of sequential relations between actions, and domain-specific organization for the representation of sequential event knowledge. However, a partial discrepancy must be noted between the data on the prefrontal dissociation for syntax and scripts, and the neuroimaging findings just presented, regarding the syntactic dissociation in Broca's area. Although a variable element can be found in the slightly different locations of lesions, and partly different tasks used, namely a generation and a perception task, respectively, it is useful to schematically relate these results to the perspective articulated around recent neurolinguistic insights, which in fact also reflect an at least double view of the role of Broca's area.

What About Language Sequences?

The selective involvement of Broca's pars opercularis (BA 44, cf. Figure 1) as reported by Sirigu et al. (1998), is consistent with the ample literature arguing for a specific role of the pars opercularis for syntax and pars triangularis (BA 45, cf. Figure 1) for semantics (e.g., thematic role processing) (Embick, Marantz, Miyashita, O'Niel, & Sakai, 2000; Friederici, Wang, Herrmann, Maess, & Oertel, 2000; see Moro et al., 2001, for an opposite view).

It is well known, however, that Broca's area, just as the prefrontal regions, exhibits an extremely multifunctional role in both linguistic and nonlinguistic domains. Without trying to disentangle this functional mosaic, we note that recent "extended" views propose a frontal nesting of regions in the left inferior frontal gyrus (with the inclusion of BA 44–45, BA 47, and BA 6), which appears to be functionally defined according to an anterior-ventral to posterior-dorsal gradient. Such embedded subregions get involved interactively in the integration of semantic, syntactic, and phonological information (Hagoort, 2005). For instance, PET results show that the Broca's pars opercularis (BA44) and the left Rolandic operculum, caudally adjacent to Broca's area, is recruited during syntactic encoding during speech production (Indefrey, Brown, et al., 2001), whereas the dorsolateral prefrontal cortex (BA 9), adjacent to Broca's area, is specifically involved in the processing of syntax rather than in the integration of syntactic and semantic information (Indefrey, Hagoort, Herzog, Seitz, & Brown, 2001).

Recalling in part the cascade model proposed for the processing of action chunks (Koechlin & Jubault, 2006), a nested model for the neural substrates of language processing suggests that the left inferior frontal gyrus is differentially involved in the computations aimed at the "unification" of different levels of linguistic material into more complex representations. Neuroimaging work showing an increase of neural activity in the posterior portion of Broca's area during the manipulation of temporal order of discrete units both linguistic (phonological) and nonlinguistic (vocal humming) (Gelfand & Bookheimer, 2003), and Magnetoecephalography studies showing its involvement in the processing of musical syntax (Friederici, Rüschemeyer, Hahne, & Fiebach, 2003) complement the insights, leading to the hypothesis that this area may have a multimodal role in higher order categorization and temporal processing that goes beyond the language domain.

Implications and Future Inquiry

This article has attempted to characterize the involvement of the prefrontal cortex in the mental operations that are required for the storage and retrieval of sequential event knowledge. It has focused on functional neuroimaging and lesion analyses of sequence processing of different types of knowledge domains, such as action and language.

Overall, the emerging picture from the studies reviewed here is that sequence processing may be modularly organized within the prefrontal cortex and in Broca's area, depending on the knowledge domain. In particular, the prefrontal cortex and Broca's areas play important but differential roles in the activation of the computational procedures necessary for the formation of sequential strings for action and language, respectively.

The proposal of multiple representational modes of sequential event structures may imply that the nature of the rules that specify the temporal order of sequential events covaries with the specific knowledge domain. For example, action sequences would be based on natural cause-effect and mean-ends relations. On the contrary, word order in language would follow an independent set of rules specific to language structure. The potential domain sensitivity of the computational operations that produce and process sequential event structures is compatible with dual-system models, which conceive of language as forming an independent and cognitive module, self-governed by combinatory rules unique to natural language. The data discussed so far provide evidence for a prefrontal dissociation between action and language sequences that is supportive of this view.

A clearer understanding of the nature of the computations performed in the prefrontal cortex and Broca's area, of their degree of abstraction and granularity, as well as of their potential pertinence for different knowledge domains will contribute to clarify this issue with respect to the more cognitive view of language, according to which grammar is a form of conceptualization and linguistic phenomena are thought to be stored and retrieved by the same cognitive resources that are required by the processing of knowledge structures belonging to nonlinguistic domains (Croft & Cruse, 2004). Further exploration of the possible interplays between the neural underpinnings of action and language sequences may contribute to tease apart these perspectives, by testing whether the combinatory rules of language (the syntactic component) developmentally (and ontogenetically) depend on prelinguistic operations pertaining to the planning of simple motor action sequences (Steedman, 2002) or whether the rules are an autonomous set of procedural rules capturing regularities intrinsic to language (Pinker & Ullmann, 2002).

From the neuroscientific point of view, the acquisition of novel spatial and temporal information about connectivity and real-time interactions of subareas within the prefrontal cortex with more distributed cerebral networks (e.g., neural projections and time-locked phase synchronizations of the neural activity in specific contiguous and noncontiguous brain subregions) will contribute to elucidate the temporal coding and processing of event sequences and to improve the current models of brain representations and activation of sequential event knowledge.

Further advances of cognitive neuroscience in this direction will open new perspectives for stimulating parallels and confrontation between the domains of language and action.

Notes

1 The subcortical structure of the basal ganglia typically intervenes in adaptative motor control (Mardsen, 1982), because the basal ganglia motor circuit modulates cortical output necessary for optimal movement. It has been pointed out that the basal ganglia are involved in more cognitive and motivational dimensions of behavior (Robbins & Everitt, 1992), as well as in the retrieval, management, and constitution of goal-oriented action sequences (Graybiel, 1995).

2 Such a deficit may be caused by attentional set-shifting difficulties when the parallel manipulation of multiple types of information is demanded, rather than from impaired script event knowledge (Owen et al., 1993; Zalla et al., 1998).

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Sequential Event Processing: Domain Specificity or Task Specificity? Commentary on Carota and Sirigu

Ivan Toni
Radboud University, Nijmegen

The article by Carota and Sirigu (this issue) addresses a fundamental issue, namely the domain specificity of our ability to learn and implement sequential structures of events. The authors review theoretical positions and empirical findings related to this issue, providing a useful summary of representative models of sequential event structures, and a reappraisal of some of their previous neuropsychological and neuroimaging studies. The review suggests that, in theory, the computational principles supporting the formation of sequential strings could apply for the processing of both action-related and linguistic items. However, the empirical evidence reviewed here indicates that the cerebral implementation of these principles is sensitive to the characteristics of the sequential events, suggesting that sequential event knowledge might rely on domain-specific cerebral resources.

The review by Carota and Sirigu can be seen in the context of several recent attempts to bring linguistic phenomena to the fold of the motor system (Aziz-Zadeh, Wilson, Rizzolatti, & Iacoboni, 2006; Rizzolatti & Arbib, 1998). The authors provide a stimulating reminder of the difficulties of this enterprise (see also Toni, De Lange, Noordzij, & Hagoort, 2008). Carota and Sirigu try to find a conceptual common ground between our linguistic and motoric abilities, respecting their complexities rather than shoving the former into the latter (Rizzolatti & Craighero, 2007). In this commentary, I will mainly focus on a couple of issues on which Carota and Sirigu do *not* comment.

Given the goal of the article, it is somehow surprising that the authors choose to neglect an important dimension of both linguistic and motoric phenomena. Carota and Sirigu aim at dealing with "[...] the temporal structure

Correspondence concerning this article should be addressed to Ivan Toni, FC Donders Centre for Cognitive Neuroimaging, Kapittelweg 29, 6525 EN Nijmegen, The Netherlands. Internet: ivan.toni@fcdonders.ru.nl

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of complex motor action sequences." In fact, only the ordinal aspects of "temporal structure" are considered. Sequences are reduced to a concatenation of events, or time-invariant tokens. There is no consideration of the dynamical (i.e., time-varying) aspects of linguistic utterances or action sequences, either on a short timescale (milliseconds/seconds) or over longer periods. The latter temporal dimension is crucial for understanding learning-related phenomena, as when we learn novel sensorimotor mappings (Grol, De Lange, Verstraten, Passingham, & Toni, 2006; Mars et al., 2005) or novel syntactic structures (Forkstam, Hagoort, Fernandez, Ingvar, & Petersson, 2006) that require multiple exposures to the relevant events. The former timescale appears relevant for understanding how motor or linguistic primitives interact to achieve outcomes at hierarchical levels different than those afforded by each individual element. For instance, there is a well-known one-to-many indeterminacy between the intended end result of an action (or an utterance) and contingent details of the movements deployed to achieve such a result (Lashley, 1951). Such indeterminacy could be solved if motor plans are organized hierarchically (Bernstein, 1967). This implies that the brain needs to select and combine subordinate motor elements (grasp a cup, empty its content; or utter "Marlboro," show a banknote) within the spatiotemporal boundaries set by a hierarchically superordinate action outcome (put a cup in the dishwasher; inform the shopkeeper that we would like to buy a pack of cigarettes). Neglecting these temporal dimensions considerably limits the space of possible overlap between the control processes of linguistic and action-related phenomena. By the same token, the issue of domain specificity might become distorted when a complex phenomenon like sequence processing is viewed from too narrow a perspective. For instance, the *implementation* of action and linguistic sequences might well rely on spatially segregated cerebral circuits, as argued by Carota and Sirigu. Yet, this dichotomy might dissolve when the *acquisition* of sequential patterns of events is considered, with both sensorimotor and linguistic processes converging on similar learning mechanisms and cerebral substrates (Forkstam et al., 2006; Grol et al., 2006).

Trying to understand the neurocognitive characteristics of our ability to learn and implement sequential structures of events is a daunting challenge. One major component of this challenge is to find an appropriate level of comparison between neural and cognitive phenomena. In this context, the neuroanatomical framework used by Carota and Sirigu might need to be adjusted to a different level of granularity. For instance, it is stated that "[. . .] The multifunctionality of the prefrontal cortex in the temporal treatment of knowledge structures related to various knowledge domains arises from the particular internal subdivision of this brain area in specialized subparts." It is difficult to think of ways in which this statement would not apply to the relationship between any cognitive function and cerebral structures. In a sense, it is trivially true that the structural properties of a homogeneous cerebral region determine its computational properties (Passingham, Stephan, & Kotter, 2002). The crucial and unresolved issue is to specify how cytoarchitectonic and hodological structure can make a region suitable for processing action sequences as compared to linguistic items. For instance, in contrast to the scenario described in Carota and Sirigu, it is surprising how functionally related Brodmann areas 44 and 45 are, despite their massive anatomical differences. For instance, area 44 is a dysgranular area, with strong afferences from somatosensory- and motor-related regions (SII, rostral inferior parietal lobule, supplementary and cingulate motor areas; Petrides & Pandya, 2002) but only sparse projections from visually related regions of the inferior temporal cortex (Pandya & Yeterian, 1998). Conversely, area 45 is a granular area, with massive afferences from most parts of the prefrontal cortex, from regions of the superior temporal gyrus related to auditory processing and from regions of the posterior superior temporal sulcus related to visual processing. Yet, these anatomical dichotomies appear to vanish into subtle functional gradients when phonological, syntactical, and semantic processes are considered in terms of their respective unification operations (Hagoort, 2005). Accordingly, some authors have started to suggest that function might not necessarily respect anatomical borders (Diamond, 2006), at least when these borders are defined by macroscopic features (like sulci) or coarse structural conglomerates (like most Brodmann's areas). In the context of this commentary, it remains to be seen how the simple perspective of a "syntactic area 44" and a "semantic area 45," advocated by Carota and Sirigu, can fit into the larger scenario of the prefrontal functional anatomy. Namely the dorso-ventral transition from manipulation to selection of information to be held online (Petrides, 2005) appears more compatible with positions that emphasize functional gradients (Hagoort, 2005) than with one-to-one mappings between Brodmann areas (or, even worse, vague entities like Broca's area) and levels of sequential event processing.

The review by Carota and Sirigu offers an interesting outline of the domain modularity of sequential behavior. In this commentary I have suggested that future work could consider a broader space of possible correspondences between linguistic and motor behavior (Dominey & Hoen, 2006). This space should consider the spatiotemporal constraints inherent in the production of real actions/utterances (i.e., dynamical aspects of linguistic utterances or action sequences). In addition, the cognitive control of our actions and utterances is also influenced by the social scenario in which they occur, such that voluntary actions might be driven by predictions of the intentions attributed by others to our (linguistic and nonlinguistic) actions (De Ruiter, Noordzij, Newman-Norlund, Hagoort, & Toni, 2007). It also appears important to define an adequate metric for characterizing correspondences between cognitive and neuronal operations, given that the space of cortical lobes, cytoarchitectonic areas, or anatomical modules, is likely to be an oversimplification arising from projecting high-dimensional sensory-motor spaces into the two-dimensional cortical sheet (Graziano & Aflalo, 2007).

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Cognitive and Neural Prerequisites for Time in Language: Any Answers?

Marianne Gullberg
Max Planck Institute for Psycholinguistics
Radboud University Nijmegen

Peter Indefrey
Max Planck Institute for Psycholinguistics
F.C. Donders Centre for Cognitive Neuroimaging

In the position article to this volume, Klein outlines a set of questions that are relevant for furthering the linguist's understanding of what the cognitive and neural prerequisites for time in language might be. He also declares a certain skepticism regarding the likelihood that new methods from other disciplines will provide answers to those questions. The articles in this issue, a selection of state-of-the-art findings concerning time from different disciplines and theoretical frameworks, all address some aspects of those questions. This overview attempts to assess to what extent the questions asked by Klein in his opening statement have been answered by contributions from other disciplines.

As a preamble, a general observation is that there is an inherent ambiguity in the notion of "time in language." The relationship between time and language is twofold. On the one hand, language production and comprehension occur over time and the processes involved have to be temporally orchestrated. The temporal planning skills required for this complex task may be absent at the beginning of language acquisition (cf. McCormack & Hoerl, this issue) or may become impaired in later acquired language impairments (cf. Wearden, this issue; Kolk, this issue). On the other hand, language refers to time in a variety of ways, as evidenced in the catalogues of linguistic means for expressing temporality and aspect (cf. Klein, this issue; Evans, this issue). These two perspectives can interact, as seen in Kolk's example of how impaired memory

Correspondence concerning this article should be addressed to Marianne Gullberg, Max Planck Institute for Psycholinguistics, P.O. Box 310, 6500 AH Nijmegen, The Netherlands. Internet: Marianne.gullberg@mpi.nl

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duration interferes with the simultaneous activation of information (about time) at the conceptual level and syntactic processing, all of which results in a problem with tense marking. This final overview will mainly focus on time in language in the first sense; that is to say, on what is neurocognitively required in order for the linguistic means of expressing time to be deployed in actual language use.

How Do Our Notions of Time and Our Ways to Express Them Change Over the Life Span?

One reading of Klein's (this issue) first question concerning change in temporal representations is to query the relationship between cognitive maturity and language and, specifically, what the necessary and sufficient cognitive prerequisites for time in language may be. That is to say, what do we need to know or understand about time to be able to speak "correctly"? The article by McCormack and Hoerl (this issue) highlights the complex interplay between temporal cognition and linguistic skills. They focus on the development of so-called temporal decentering. This notion is defined not only by the coordination of temporal locations of three events (past, present, future) but also by what the authors call "event-independent thought about time," meaning the ability to think about events independently from familiar settings and concrete events in time. This research presupposes that coordination and event-independent thought are necessary prerequisites for appropriate (and adultlike) use of time in language. Based on what is known about the use of tense, the requirement concerning coordination of time points seems well founded. However, there may be reasons to doubt the necessity of event-independent thought, (i.e., the detachment of events from abstract positions on the time line). Consider, for instance, the use of past tense, which is primarily used to report on events from memory. Although adults may be capable of conceiving of event-free time positions, the storage of events in memory does not appear to make use of time tags referring to an event-independent time representation. Burt (this issue) reports on studies on autobiographical memory that show that the recall of past events does not rely on an abstract "calendric" system. Rather, recall relies on the temporal anchoring of a target event to other, highly salient events such as the starting points of "life themes" ("before I got married") or culturally shared events ("when Blair became prime minister"). Furthermore, autobiographical memory develops in parallel to linguistic development, such that both memory for and language about time seem to rely on more concrete instantiations of events and more on event-dependent temporal concepts than event-independent ones. In other words, the content of memory does not appear to have an event-independent temporal structure in storage or in retrieval. Event-independent thought about time, supposedly the hallmark of adult, mature temporal cognition, may therefore not be necessary to talk appropriately about time.

Further to this, regardless of what the properties of adult temporal cognition may be, data from adult second language (L2) speakers interestingly indicate that temporal cognitive maturity may be necessary but not sufficient for the linguistic treatment of time, as highlighted by both Ellis (this issue) and Roberts (this issue). Adult L2 learners possess mature temporal cognition and a fully developed system for dealing with time in their first language (L1). Despite their cognitive and linguistic sophistication, they nevertheless display difficulties expressing time in the L2. Importantly, their difficulties are reminiscent of the difficulties connected to temporal decentering in children acquiring an L1 (e.g., expressing aspect before tense).

These observations together suggest a more complex relationship between the necessary and sufficient cognitive prerequisites for the treatment of time in language than is generally assumed, with the details of the relationship among (mature) temporal cognition, memory, and linguistic details still remaining to be defined.

How Culture-Specific Are Our Notions of Time?

Assuming a broad sense of "culture" and "notions of time," the answer to this question can only be "very culture-specific." Notions of time such as its granularity (days, hours, seconds or milliseconds), its cyclicity, or its importance for everyday life obviously differ widely across cultures and are also subject to historical changes. These changes are driven, for instance, by advances in the measurement of time, the availability of precise clock times to everyone, and by the role of time in industrial production processes.

Casasanto (this issue) provides a much less obvious answer to a much narrower question: How language-specific are our nonlinguistic representations or notions of temporal duration? More specifically, are they language-specific at all? The answer is "yes." Casasanto's experiments provide evidence that speakers of languages with a preference for duration-as-length metaphors (e.g., a *long* meeting), such as English, and speakers of languages with a preference for duration-as-quantity metaphors (e.g., *much* time), such as Greek, are differentially affected by length or quantity distracters in a nonverbal duration judgment task. Interestingly, Casasanto also shows that this effect is *not* culture-specific but only language-specific, in that English speakers behave like Greek speakers when trained to use more duration-as-quantity metaphors.

How Are Events Located in Time in Other Domains of Cognition?

Two relevant domains of cognition are memory, where past events are stored, and action planning, which deals with future events. Although some past events that are part of our semantic knowledge are stored with calendric tags (e.g., World War II 1939–1945), this is not how autobiographical events are stored in memory, as suggested by the studies summarized by Burt (this issue). When participants are asked to retrieve autobiographical events from memory, they typically fail to do so when prompted with a date cue ("What happened in your life on the 21st July 1976?"). Similarly, when asked to provide the date of a personal or public event, their results are poor. Events do not only seem to be stored without a calendric tag, but they also do not seem to be stored with information about their relative order. When asked about the order of personal events recorded in a diary about 4 months previously, a high proportion of participants' answers were erroneous (Burt, Kemp, Grady, & Conway, 2000). Based on the general finding that an event's location in time is not stored in memory, Burt concludes that the location in time is reconstructed upon retrieval from memory. He suggests three mechanisms for this reconstruction. The first mechanism exploits the fact that although most autobiographical events do not have calendric tags, some important ones do (so-called "landmark" events, personal or public). Furthermore, events can be linked to "life themes" such as "the time I went to school," which often have at least approximate standard locations in time (and standard durations), which are part of our "autobiographical knowledge." Thus, linking some autobiographical event to a life theme and possibly even a landmark event (e.g., the day of graduation) allows for successful reconstruction of an event's approximate location in time.

The second mechanism makes use of the decay of memory traces (cf. Wearden, this issue; Tendolkar, this issue). Some estimate of the remoteness of an event can be obtained from the quality of the recollection. An interesting side observation in this context is that language generally is much less interested in the duration than in the order of events. Although languages can express (often calendric) duration estimation lexically (*next week, last Friday, for 3 days*), it is rare in the languages of the world for duration estimation to be part of the grammaticized, closed-class devices (cf. Klein, 1994). That said, some languages do make "remoteness" distinctions in (past) tense morphology, marking the temporal distance between time of speech and topic time.

Often the distinction is between "today" and "before today." A few languages make more distinctions, such as Yagua, an Amazonian language that distinguishes five levels ranging from "a few hours before the time of the utterance," over "roughly a week to a month ago," to "distant or legendary past" (Dahl & Velupillai, 2008; Payne & Payne, 1990). To use languages with such remoteness distinctions in the past thus requires some duration or distance representation. However, it seems to require a level of detail that memory is not likely to provide. An interesting question is therefore how reconstruction might work in similar systems and whether the quality of memory traces plays a role here (Did something I did in the past happen 2 weeks ago or 8 weeks ago?). A further question is whether the use of a language marking duration requires the development of a different type of memory system. This proposal can be compared to the notion that the use of absolute spatial frames of reference, involving the use of cardinal directions and other geocentric units to locate entities in space (e.g., "spoon to north of cup"; Levinson, 2003, p. 48), rather than relative ones based on the speaker ("spoon to the right of cup") requires the ability to dead-reckon absolute location and orientation (Levinson). It would be interesting to conduct experiments similar to Burt's (this issue) in Yagua or other languages with remoteness distinctions to assess these issues.

A third mechanism suggested by Burt (this issue) allows for the reconstruction of smaller "episodic components" of an event. Although recall of the relative order of episodic components is generally poor, episodic components that are part of an event with a conventional temporal order of event components, such as a visit to a restaurant, can be stored and retrieved in the correct order due to our knowledge of that conventional order (although it may sometimes be difficult to decide whether a particular event component was recalled or confabulated according to the conventional event structure).

Turning to action planning and future events, Carota and Sirigu (this issue) discuss the relationship between future expressions in language and general notions of action planning at the neural level. They explore whether the processing of sequential goal-oriented actions in discourse and of sequential or future events as instantiated in word order draw on similar neural substrates or not (cf. Toni, this issue). Their findings suggest that although prefrontal cortex is implicated in the processing of sequential strings in both cases, the prefrontal cortex and Broca's area play differential roles in the processing of sequential strings for action and syntax, respectively. That is to say, the ordering of events and the processing of word orders expressing these events may not be directly linked at the neural level.

Casasanto (this issue) discusses the relationship between another key conceptual category, namely space, and time, a relationship that has received a lot of attention (see references in Casasanto). The findings reviewed here suggest not only that the two categories display a close metaphorical relationship but also that (spatial) language reflects and also shapes temporal representations outside of linguistic practices. Overall, these findings suggest a permeable and fluid connection between general cognition and linguistic cognition concerning time.

How Do the Various Devices, in Particular, Markings on the Verb and Temporal Adverbials, Interact?

If this question is understood as referring to how temporal information encoded by tense and temporal adverbials is comprehended and integrated, then both Baggio's (this issue) semantic model and Zwaan's (this issue) simulation model have something to contribute. Baggio suggests that the interactions of the temporal meaning of lexical (adverbials) and grammatical devices (tense markers on the verb) are accounted for in a constraint satisfaction model. The system is incrementally confronted with different types of semantic constraints that need to be satisfied and unified for comprehension to take place. In (1), the constraints set up by the meaning of the adverbial *(last Sunday),* which is encountered first, must be unified with the meaning of the tense markings *(–s/ed)* when these are encountered.

(1) Last Sunday Vincent *paints/painted the window frames of his country house.

If the temporal information specified in the adverbial (past) does not match the interval specified by the tense marking (present), inconsistency follows, unification fails, and the sentence is deemed meaningless. Interestingly, Klein (this issue) exemplifies the complex interaction between devices by a different type of construction, namely sentences containing combinations of tense specification and temporal adverbials (e.g., *He has departed yesterday at four*), which are deemed grammatically ill-formed in many languages on the grounds that a particular tense/aspect should not co-occur with temporal adverbials at all. Baggio's explicit semantic framework would find no fault with these types of sentences because there is no conflict between the temporal markers. The ill-formedness seems to reside outside of semantics. There is thus more linguistic work to do to account for these types of interactions.

Zwaan (this issue) does not directly address the issue of the interaction of temporal adverbials and verb marking (cf. Evans, this issue). Nonetheless, he mentions two important roles for temporal adverbials for constructing event representations during language comprehension. In a mental model, event representations are indexed for the time at which the events occurred. Events that have the same time index (that happened at the same time) are more strongly connected in long-term memory. In stories and texts, temporal adverbials such as "a moment later" or "an hour later" provide information regarding whether two events share a time index. For example, Zwaan (1996) has shown that when participants are probed on a recognition task after reading a text, priming between events described as immediately successive (*a moment later*) is stronger than priming between events described as temporally separated (*an hour later*). Thus, in this role, temporal adverbials can interact with the memory encoding of events that are described by verbs.

In another role, temporal adverbials can interact more directly with aspectual markings on the verb, because both can modify the mental representation of an event. According to Zwaan (this issue), understanding the description of an event involving some action means performing a mental simulation of that action. Part of that simulation is a "motor resonance," essentially an activation of the listener's/reader's motor system that shares properties with the motor action in the described event. Zwaan suggests that aspectual distinctions can be reflected in such motor resonance. Thus, motor resonance may occur continuously throughout an imperfective sentence like *He was painting the wall*, but occur only on the verb in the corresponding perfective sentence *He painted the wall*. Importantly, motor resonance during language comprehension requires that all information that is relevant for the simulation be integrated until a "uniqueness point" is reached, where enough information for a simulation is available (cf. Evans, this issue). For example, in the sentence *He slowly opened the door*, motor activation corresponding to the opening of a door can only start when *the door* is reached (excluding other motor actions such as opening envelops). Note that in this example the modifier *slowly* is also part of the relevant information and will affect the exact form of the motor resonance. This means that in Zwaan's simulation model, all linguistic means that modify the meaning of an action operate in the same way, namely by modifying the corresponding motor resonance. This should also hold for temporal adverbials insofar as they affect the form of an action as in *He held up his hand for a moment, then the waiter saw him* compared to *He held up his hand for ten minutes until the waiter saw him*.

How Are Violations Within the Overall Expression of Time Handled?

Baggio's article (this issue) is a most explicit answer to the question how violations within the expression of time are handled at the neurological level. Both his own electrophysiological (ERP) experiment and the experiment of Steinhauer and Ullman (2002), which he reviews, demonstrate that in response to sentences like (2) and (3), there are three distinct ERP responses: a left anterior negativity (LAN) starting as early as 200 ms after the violating verb, a late positivity (P600) starting 600-700 ms after the violating verb, and a sentence final negativity (SFN) following the last word of the sentence.

(2) Yesterday, I *sail Diane's boat to Boston. (Steinhauer & Ullman, 2002)

(3) *Afgelopen zondag *lakt Vincent de kozijnen van zijn landhuis.* "Last Sunday Vincent *paints the window frames of his country house." (Baggio)

The complex electrophysiological response pattern alone suggests that "handling" violations is not one process but rather a set of processes happening at different time points following the violation. Baggio interprets the fastest response (LAN) as being driven by the detection of a feature mismatch (resulting in a failure of syntactic unification), analogous to known LAN/P600 response patterns to case, number or gender mismatches. This interpretation requires him to develop a theory of what the values of a tense feature may be. Note that the violating verbs were marked for tense so that the violation cannot simply consist in the absence of a tense marking but must be due to the temporal meaning of the tense marker and, hence, arise at a semantic level. Given that the violation response started already around 200 ms after the presentation of the verb, Baggio's conclusion that tense feature checking must be informed by semantic representations already at a syntactic unification stage seems valid. Nonetheless, Baggio's definition of a tense violation as a situation in which "the anomalous verb located the event described by the main clause outside a frame specified by an anchoring temporal expression" may be too constraining. Neither his findings nor the findings of other studies so far have investigated the effect of the absence of a tense marking where one is required (a phenomenon that is not uncommon but may even be typical of some learner varieties (cf. Klein & Perdue, 1997). In addition to the observed "semantic" tense violation, there could be a purely "syntactic" tense violation in sentences like (4):

(4) Yesterday, I *sailing Diane's boat to Boston.

Here, a nonfinite verb form appears instead of a finite, tense-marked verb form. Obviously, in English a nonfinite verb form lacks not only tense but also person and number features. To avoid this confound, such an experiment would have to be conducted in a language in which verb forms carry only tense but not person or number features (e.g., Japanese).

According to Baggio (this issue), the SFN reflects another processing stage where the temporal constraints set up by the verb are "readjusted" such that, for example, a "narrative present" reading of the sentence may result. This option points to a flexibility in Baggio's semantically informed tense features reminiscent of cases where syntactic violations of other semantically interpretable features are accepted or even preferred—for example, natural gender congruency in German (5) or number congruency as in English (6):

(5) *Das Mädchen war stolz auf ihr neues Kleid.*
"The girl$_{\text{neuter}}$ was proud of her$_{\text{feminine}}$ new dress."

(6) The police have arrested. . .

It is conceivable that the readjustment process suggested by Baggio (this issue) might also play a role for other features, such that a more general treatment of semantically interpretable syntactic features might result.

In contrast to a feature mismatch, this type of readjustment is not possible in the case of absence of a necessary tense feature in sentences like (4). This type of "tense" violation clearly has a different quality and might serve as a test case for the interpretation of the SFN. As no readjustment is possible, there should be no SFN if the readjustment is indeed reflected in this ERP effect.

In sum, Baggio's findings give a clear indication of how tense violations may be processed. Furthermore, his interpretation in terms of a theory of semantically informed tense feature checking provides a highly interesting account of tense (and perhaps not only tense) processing in general.

Concluding Remarks

This review on the whole suggests that evidence from other disciplines and theoretical frameworks do provide answers to some of the questions that Klein considers to be vital to the linguist whose daily bread consists of thinking about time and language. Other questions have answers under particular readings but leave other aspects of the questions open. Finally, in those cases in which no clear answers are to be had, the cross-disciplinary perspective and the different theoretical frameworks nevertheless seems to inspire new, interesting, and sometimes more specific questions than previously asked. This in turn suggests that, Klein's skepticism notwithstanding, findings and methods from other disciplines and domains can open fruitful new avenues of research to explore old issues.

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