See also: Deixis and Anaphora: Pragmatic Approaches; Jakobson, Roman (1896–1982); Lacan, Jacques (1901–1981); Metaphor: Psychological Aspects; Metonymy; Rhetoric, Classical.

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Psycholinguistic Research Methods

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Psycholinguistics aims to uncover the mental representations and processes through which people produce and understand language, and it uses a wide range of techniques to do this. The preferred psycholinguistic method is to carry out a controlled experiment. This means that the researcher manipulates an independent linguistic variable to control some aspect of language processing and then measures the effect of the manipulation on a dependent variable of interest. For example, consider an experiment aimed at discovering the influence of the age of acquisition of a word (independent variable) on the time it takes an adult to identify that word (dependent variable). The psycholinguist would construct two lists of words, one containing words learned early in life, the other containing words learned later in life, and then measure the effect of age of acquisition (the independent variable) on the time to identify the word (the dependent variable). To make sure that the independent variable is the real cause of any effect observed in the dependent variable, the experimenter needs to carefully control that variable. For example, in the above experiment it is important to make sure that age of acquisition is not confounded with the length of the word or its citation frequency, because we know that longer words and low frequency words take longer to read.

Once the experiment has been run with a sufficient number of participants and a sufficient range of linguistic materials, the data is analyzed statistically. This usually involves taking the average of the values of the dependent variable (response latencies) for each value of the independent variable (each list of words acquired at different ages) and establishing whether the differences associated with the different values of the independent variable are statistically reliable. It is now standard in psycholinguistics experiments to test that the effects hold true both across the range of participants used in the experiment and across the range of linguistic materials used in the experiment.

Because the psycholinguist is interested in the dynamics of language processing, an important distinction is drawn between **on-line** techniques, which measure variables that tap into language processing as it happens, and **off-line** techniques, which measure variables related to the subsequent outcomes of processing. In practice, on-line and off-line techniques compliment each other, with off-line techniques used to determine the outcome of interpretation and on-line techniques used to determine its time course.

Another major distinction between psycholinguistic techniques relates to the nature of the dependent variables they measure. Some experiments have behavioral dependent variables, such as those associated with a reader's eye movements while reading, others have neurophysiological dependent variables such as those associated with electrical brain activity produced while listening to a sentence. The article first considers behavioral methods and then related neurophysiological methods. It starts with methods for the study of spoken and written language comprehension, and then methods for studying language production and dialogue.

Behavioral Methods

Common Assumptions Underlying Behavioral Methods

Although there is a wide range of behavioral psycholinguistic methods, most depend upon the same basic assumptions. One important assumption concerns how measurements of the time to carry out a task relate to inferences about complexity of processing. Whether the timed response be an eye movement or the time to answer 'yes' or 'no' to a question, it is assumed that the complexity of the mental process is reflected in the response latency. For example, if a reader takes longer to read the fragment "... raced past the barn fell" when it is part of the sentence "the horse raced past the barn fell" than the sentence "the horse that was raced past the barn fell," this is taken to reflect greater complexity in the syntactic analysis of the former than the latter. This assumption is used when interpreting results from most on-line techniques.

A more sophisticated timing methodology investigates the trade-off between speed to respond and accuracy of that response. This is called a **speed accuracy trade-off** (**SAT**) method. With SAT, participants are required to make some response to a linguistic stimulus as soon as they hear a tone, presented at different intervals after the presentation of the stimulus. When the interval is short, participants tend to make many errors, and when sufficiently long, they become completely accurate. So plotting response latency and accuracy across the range of tone intervals gives an unbiased measure of the rate at which the task can be carried out. SAT techniques have been used to assess the rate at which different kinds of lexical, syntactic, and semantic processing occur. Although it is considered a particularly refined technique for establishing processing rates, it has the disadvantage that many thousands of trials have to be run to produce a clear SAT profile, and this will mean that there will have to be many examples of each kind of material used. So there are only a limited number of issues that can easily be investigated with SAT.

Another important assumption underlying many behavioral methods concerns the interpretation of priming effects. **Priming** techniques measure the effect of having previously processed a **prime** item on the subsequent processing of a **target** item. The prime might be a word with a particular form or meaning or it might even be a whole sentence with a particular syntactic structure. The rationale behind priming techniques is that any influence of prime on the subsequent processing of the target must reflect some relationship between the mental representations of prime and target items. Typically, when a prime boosts the interpretation of the target (e.g., by speeding up the recognition of the target item), this is taken as evidence that there is something in common between the representation of target and prime. For example, if a person is quicker to decide that *giraffe* is a word having just read the word *tiger* than having just read the word *timer*, then it is assumed that this is due to the closer semantic relationship between *tiger-giraffe* than between *timer-giraffe*. On the hand, when it hinders the interpretation of the target – this is called **negative priming** as opposed to **positive priming** – this is taken to reflect some conflict between the representations of prime and target. Priming techniques are particularly useful for establishing the relationship between different linguistic representations used during processing and are widely used in conjunction with a number of behavioral or neurophysiological measures.

It is beyond the scope of this article to describe all the behavioral techniques that have been used in psycholinguistics. Instead, the article concentrates on techniques that have had a major impact on the field.

Behavioral Methods for Spoken Language Comprehension

Cross-modal Priming A common priming technique used to tap into spoken language comprehension is what is called **cross-modal priming**. In cross-modal priming the prime item is usually a word embedded in a spoken sentence or text used to prime a target item presented in written form, which is why it is called cross-modal. Consider the problem of working out how listeners resolve ambiguous words. Cross-modal priming can indicate the immediate interpretation of an ambiguous word, such as *bug*, in contexts that promote either one or other meaning of the word (e.g., 'insect' or 'listening device'). As participants listen to *bug* in the different contexts, they are presented with a written word (ANT or SPY) or a nonword (AST) and have to decide as quickly as possible whether the target is a word or not (this is called **lexical decision**). The question of interest is whether lexical decision of the targets ANT and SPY is boosted by hearing the prime *bug* in the different contexts. It turns out that when the visual target is presented immediately after hearing the prime in either context it promotes lexical decision for both targets. So this indicates that both interpretations ('insect' and 'listening device') are immediately activated irrespective of the disambiguating context. However, if the visual target is presented at a slightly later point (about 200 ms after the prime), only the target related to the contextually appropriate interpretation (i.e., ANT for 'insect' or SPY for 'listening device') is primed. Cross-modal priming therefore indicates that all meanings of ambiguous words are accessed immediately on encounter, but then only the contextually appropriate meanings are retained as comprehension proceeds.

Cross-modal priming has been used to investigate many aspects of spoken language comprehension. These include influences of prior discourse context on lexical processing, resolution of anaphoric references (e.g., pronouns), and morphological analysis. The technique has the advantage that it can tap into spoken language comprehension as it occurs and often uncovers aspects of processing of which the subject is completely unaware, such as in the ambiguity experiment described above.

The Gating Technique Another technique for establishing when listeners interpret words in relation to information in the speech stream is **gating**. The gating procedure involves presenting increasingly long fragments of speech and measuring when listeners can interpret the speech appropriately. For example, if you want to know at what point a listener can accurately recognize the word *cathedral*, you can present them with the spoken fragments /ca/, /cath/, /cathe/ , /cathed/ … and record the listener's judgements for each fragment. The shortest fragment that can be correctly identified defines the point at which there is sufficient information in the speech for identification. This technique can be used to estimate the earliest point at which the listener could identify a word and so make it possible to test whether this predicts the recognition time for that spoken word.

The Visual World Paradigm One of the most effective on-line measures is **eyetracking** (recording the precise pattern of eye fixations during comprehension). Because visual attention is strongly controlled by where a person is currently looking, eyetracking can be used to indicate what a person is attending to at any point during comprehension and for how long they attend to it. The technique can either be used for reading research (see below), in which case the focus of attention corresponds to the words being looked at any time or it can be used to measure which part of a scene a participant attends to as they interpret spoken utterances about that scene. The latter technique is usually referred to as the **visual world paradigm**. A classic example of the use of this technique is in determining how listeners deal with syntactic ambiguities that arise during comprehension. For example, participants listen to instructions that are initially consistent with two syntactic analyses while they view a scene containing a small number of objects. They might be asked to *Put the frog on the napkin in the box* when there is either one or two frogs in the scene. Analyses of eye movements demonstrate that viewers look at the frog which is on a napkin more if there is also a frog that is not on a napkin than if there is no other frog present. From this it can be inferred that the visual context drives syntactic disambiguation (i.e., it supports the reading in which *on the napkin* syntactically modifies *frog* rather than being a syntactic argument of *put*) at an early stage in processing.

The visual world paradigm has been used to investigate a wide range of issues in spoken language comprehension. These include lexical access, resolution of anaphoric pronouns, development of strategies for semantic and syntactic processing, language development, and even language processing in dialogue. It offers a precise indication of when listeners integrate information from a linguistic utterance with that in the visual world and tends to show that comprehension is both incremental and immediate in relation to most levels of linguistic analysis.

Behavioral Methods for Written Language Comprehension

There are a variety of techniques that tap into the time course of written language comprehension.

Self-paced Reading One class of techniques is **self-paced reading**. The reader determines the rate at which written material is presented and the experimenter records the rate of presentation. A reader might be required to pace himself or herself sentence by sentence, phrase by phrase, or word by word. For example, in the word-by-word procedure, a word is presented, and as soon as the reader has understood it, he or she presses a key to trigger presentation of the next word. The sequence is then repeated until all the text has been read and the time to read each word is recorded. This kind of technique has been used to study syntactic analysis, discourse comprehension processes and in particular resolution of anaphors. It gives a good indication of when a reader encounters difficulty in comprehension, but is limited according to the size of linguistic unit being presented. Whereas larger units such as whole sentences can be read at a normal rate during self-paced reading, smaller units like words tend to be read much more slowly in self-paced reading tasks. Hence, when the technique has high on-line resolution (e.g., when word by word), it also interferes most with the normal reading process. This is not a problem with the eyetracking technique described below.

Rapid Serial Visual Presentation (RSVP) A slightly different technique for presenting written language uses what is called **rapid serial visual presentation** (**RSVP**). With RSVP, readers see sequences of words in the center of a computer screen presented at a fixed fast rate. The experimenter then has the reader carry out an additional task, such as identifying a word in the sequence or trying to recall the sequence of words, which indicates how comprehension is limited by the rate of presentation. This technique has been used to investigate lexical, semantic, and syntactic processing. Like word-by-word self-paced reading, RSVP may well interfere with normal language processing.

Eyetracking During Reading The least interfering on-line behavioral technique for written language comprehension is eyetracking. During reading, the eye moves in a systematic way. There are brief **fixations** in which gaze stays on the same letter interspersed with fast movements called **saccades** during which the gaze moves to another letter or word of the text. For a skilled reader, 9 out of 10 saccades move the gaze from left to right to sample new material from the text, whereas 1 out of 10 saccades return the point of gaze to previously read material (these are called **regressions**). The duration of fixations and the length and direction of saccades (i.e., forward or backward movement of the gaze) directly reflect the ease or difficulty of the reading process. Furthermore, they indicate the precise word in the text that is causing reading difficulty because attention is only given to the word currently fixated.

The limited span of attention during reading can be demonstrated using the **moving window** technique in which a computer program controls dynamically the window of text presented to the reader as a function of where they are fixating. For example, with an asymmetric 12-letter window, the 4 letters to left and the 8 letters to the right of where the reader is fixating will be displayed as normal, whereas all the remaining text will be converted into random letters. The window of text together with its surround of random letters then changes as the point of fixation changes. One can reduce the size and form of the text window and measure when it begins to affect reading rate. It turns out that normal reading is quite possible when the window only contains the word currently fixated plus the first three letters of the next word on the line. However, there is a proviso that the material around the window must retain the spaces between the words in the original text. When the window arrangement is reversed so that the window contains random letters and the surround contains the normal text, readers encounter difficulty. With a reverse window of only 11 letters in width, reading becomes almost impossible.

Moving window studies indicate that readers only take in information from a limited region of text at any time during reading. This means that any extra time spent fixating the region must reflect processing difficulty associated with that region of text or previously fixated regions of text not completely processed but still held in memory.

Eyetracking has been used to study a wide range of linguistic processes, including lexical access, resolving lexical ambiguities, syntactic analysis, and various discourse processing phenomena, such as anaphora resolution. It is particularly effective in determining precisely when the reader makes a decision about some aspect of the linguistic input during sentence or discourse processing. For example, when presented with the sentence *We like the city that the author wrote unceasingly and with great dedication about* readers spend longer fixating the verb *wrote* as compared with the same verb in the fragment *We like the book that the author wrote unceasingly and with great dedication about*. This shows that readers immediately attempt to integrate each word of the sentence with the prior discourse and hence they detect the temporary anomaly produced by *wrote* in the first but not in the second sentence.

Eyetracking is a particularly effective technique because it does not interfere with the normal process of reading. A similar claim is made for some neurophysiological techniques such as ERP, described later.

Behavioral Methods for Spoken Language Production

Until the last decade, language production was not a central topic in psycholinguistics. This was partly because researchers did not have on-line methods for studying production in properly controlled experiments. This meant that the pioneering research on language production depended on off-line techniques, such as the study of speech errors. However, more recent work in language production has been influenced by on-line techniques. We consider both kinds of technique below.

Analysis of Speech Errors Speech error data has been used to draw many interesting conclusions about the nature of language production. For example, it was observed that substitution errors (e.g., saying *if **I** was done to that* rather than *If that was done to **me***) tend to always involve the same syntactic classes (e.g, the pronouns *me* and *that*). Also, as the example shows, the lexical substitution does not always involve a syntactic substitution. Otherwise, the error would have produced *If **me** was done to that*.

Such findings provide evidence that in production, words are chosen before they are strung together to make up an utterance and that this occurs before the words are marked for syntactic case.

Speech errors have been used to argue for an overall organization of speech production into separate message planning, lexical and grammatical assembly, and phonological processing components. There have also been some attempts to develop techniques to elicit speech errors experimentally by priming the errors in a similar fashion to that used in tongue twisters. Many of the conclusions drawn from the analysis of speech errors have been supported by results from more recent on-line techniques such as picture naming.

Picture Naming A particularly influential on-line technique for studying language production is to measure the time it takes participants to name pictures of objects or events. **Picture naming** is commonly combined with some form of priming task (see next section). It can also be combined with other techniques such as eyetracking to give a more precise indication of how words are accessed during language production. For example, a researcher might want to know whether speakers wait until they have all the words available before they start to articulate the first word in an utterance. To find out, the researcher could have participants name two pictured objects *A* and *B* in a phrase of the form *A and B*. If the time to start articulating the name of *A* is unaffected by the time to access the name for *B* as indicated by the time to articulate *B* in isolation, then the researcher can conclude that the speech articulation process begins before both word forms have been accessed. In fact, the evidence supports this conclusion.

Priming Techniques in Language Production An important issue in language production concerns the extent to which utterances are formulated incrementally one unit at a time according to different levels of representation (semantic, syntactic, and phonological). Priming techniques have been used to address this and other related questions. For example, at the phonological level words could be assembled for articulation either as complete packages or incrementally as sequences of distinct phonological units. A so-called **implicit priming** technique has been developed to test this. The participant has to learn sets of pairs of words, such that when given the first word in the pair he or she names the second word as quickly as possible. Crucially, in one condition the second words always share the same first syllable (e.g., single-loner, place-local, fruit-lotus), whereas in the other condition they do not (e.g., single-loner, signal-beacon, captain-major). The question is whether participants can use the implicit prime of the shared first syllable to speed up articulation. It turns out that they can, and more interestingly, the implicit priming only works for the first syllable in the word. When given a comparable list in which the second syllable of the second word is shared (e.g., single-murder, place-ponder, fruit-boulder), there is no articulatory benefit.

There are also techniques for studying priming at the syntactic level in production which use a variant of the picture naming procedure. A typical study might involve participants describing a sequence of pictured events using a verb indicated at the bottom of each picture. Interleaved between these descriptions, the participant checks descriptions they hear against another series of pictured events. By using ditransitive verbs such as *give*, which take either prepositional objects (*give the picture to Mary)* or double objects (*give Mary the picture*), it is possible to study syntactic priming independent of semantic priming. The question is whether having just heard *The sailor gave the banana to the nun* participants are more likely to describe their next picture as *The clown handed the book to the pirate* than *The clown handed the pirate the book*? It turns out that they are.

Behavioral Methods for the Study of Dialogue

As with language production, it is only quite recently that psycholinguists have begun the experimental investigation of language processing during dialogue. Again there is what has sometimes been called the problem of exuberant responses. Because dialogue is inherently spontaneous, how can the experimenter exert the control required for a sound experiment?

One way around this problem is to set up a task that controls what interlocutors can talk about. One such task is the **referential communication task**. One participant is required to describe a series of arbitrary visual patterns such that their partner who is able to reply can identify each pattern from the set that they have been given. This technique has been used to investigate how feedback from the listener affects the nature of subsequent references made by an interlocutor. More complex dialogue tasks have had conversational partners describe routes on a map or positions in a maze as part of some other cooperative activity. More recently, researchers have started to record interlocutors patterns of eye movements while carrying out some version of the referential communication task. In this way, it is possible to combine aspects of the visual world paradigm with those of the interactive referential communication task.

Neurophysiological Methods – ERP, fMRI, and MEG

Techniques for measuring the neurophysiological correlates of language processing have recently increased the psycholinguist's methodological armory. Three particular measurement techniques have been used. The first measures electrical activity at the scalp using **electro-encephalography** (**EEG**) to produce what are called **event-related brain potentials** (**ERPs**). The second measures changes in brain blood flow associated with neural activity using **functional magnetic resonance imaging** techniques (**fMRI**), and the third measures changes in magnetic fields associated with the electrical activity in the brain using **magneto-encephalography** (**MEG**). Each technique has its own advantages and disadvantages as a psycholinguistic tool.

fMRI signals give precise information about the area in the brain associated with the particular activity, so fMRI has proved useful for neurolinguistic investigation. The disadvantage with the technique for psycholinguistics is that it is not good for establishing the time course of the neural activity. This is because it takes time for the neural activity to produce changes in the blood flow. By contrast, ERPs provide precise information about the time course of the neural activity, but it is difficult to establish the source of the activity. This is because the ERP signal is affected by all sorts of irrelevant factors such as the thickness of the skull or interactions between signals from different areas of the brain. Finally, the most recently developed technique, MEG, offers good localization with similar temporal resolution to ERP. Nevertheless, like ERP signals, MEG signals are only sensitive to activity in neural structures with particular orientations, and neither technique is easy to apply when there is contemporaneous motor activity, such as eye movements or articulation during speech.

The most influential psycholinguistic research to date has tended to use ERP because it is both relatively cheap to run ERP experiments and the technique offers similar temporal resolution to that of behavioral measures such as eye tracking. This article concentrates mainly on the use of ERPs, but it will also say something about the use of MEG.

Event-related Brain Potentials (ERPs)

ERPs are derived from measurements of small changes in voltage at different points across the scalp. They are called **event-related potentials** because they are analyzed in relation to the onset of a triggering event. For instance, to derive an ERP that reflects word identification processes, the experimenter presents a word on a computer screen and measures the changes in scalp voltage from the point at which the word was presented. This process is then repeated over a number of trials. Because the data from each trial will contain irrelevant electrical activity, the experimenter takes the average potential across the set of related trials. In this way, the irrelevant 'noise' information can be filtered out. What remains is an ERP waveform with identifiable peaks and troughs of voltage. These peaks and troughs are taken to reflect the activity of bundles of nerve fibers in particular parts of the brain.

In practice, ERP researchers try to identify the characteristic peaks and troughs and establish how they might relate to concurrent processing. One well-established peak is called the **N400**, which corresponds to a negative component of the wave occurring approximately 400 ms. after presentation of the word that triggers it (it is a peak because ERP researchers conventionally plot negative values upward and positive values downward). The N400 has been associated with processes of conceptual or semantic integration of words into their sentential contexts. For example, when you measure ERPs elicited by the words *eat, drink,* or *cry* in the context "The pizza was too hot to *eat/drink/cry,*" then the N400 is larger for *cry* than *drink* and larger for *drink* than the contextually appropriate *eat*. This pattern is consistent with the idea that the N400 reflects conceptual integration (with *eat* being integrated into the sentence better than *drink*) as well as semantic integration (*drink* is semantically related to *eat* whereas *cry* is not).

Another characteristic trough is called the **P600** (a positive change occurring about 600 ms after the triggering word). Unlike the N400, the P600 has been associated with syntactic integration processes. For example, the word *was* when presented in the ungrammatical sentence *The doctor forced the patient was lying* produces a much larger P600 than *was* in the sentence *The doctor thought the patient was lying*. Because these two wave forms, N400 and P600, seem to reflect different kinds of processing, ERP can be used to establish the precise time course of these different processes. So ERP complements other on-line measures such as eyetracking, which do not differentiate between different kinds of psycholinguistic processes in this way.

ERPs have been used to address a wide range of questions both about early stages of lexical processing and more general syntactic and semantic processes in language comprehension. It is best suited for the study of processes that immediately follow presentation of the triggering stimulus because the ERP signal becomes increasingly noisy over time. This means that it is not such a good technique for studying such things as syntactic re-analysis or integration of a sentence into the discourse context.

Magneto-encephalography (MEG)

MEG has only recently begun to be used in psycholinguistics. MEG has some of the advantages of both fMRI techniques and EEG techniques because it enables precise source localization like fMRI and has fine temporal resolution like ERP. It also complements ERP. Whereas ERP electrical signals can only be picked up from nerve bundles that are in particular orientations with respect to the surface of the brain, MEG magnetic field signals can be picked up from nerve bundles that are orthogonal to those giving ERP signals. For these reasons, many researchers are particularly optimistic about MEG as a psycholinguistic method used together with ERP.

One particularly interesting application has been using MEG to establish the relationship between neural representation and linguistic form. The technique depends upon what has been called **mismatch negativity**. It was observed that as the same items are repeatedly presented to subjects, so the MEG signature associated with their processing is automatically reduced (probably because of neuronal habituation). However, when a new item is presented, the signal returns to normal. This happens irrespective of any behavior on the part of the subject. Mismatch negativity can therefore be used to establish the degree to which different items are processed in the same way. The greater the resumption of the activity (i.e., mismatch negativity), the more different the neurological processing of the new item. In this way, mismatch negativity can be used in a similar fashion to priming techniques to explore the neurological representation of different aspects of a linguistic stimulus.

Summary and Conclusion

Psycholinguistic techniques differ according to the kind of variables measured and the extent to which they tap into language processing as it happens. Behavioral measures, such as eyetracking, and neurophysiological measures, such as ERP, are particularly effective for measuring the time course of language comprehension. For language production studies, picture naming and priming techniques have been especially effective.

See also: Dialogue and Interaction; Evoked Potentials; fMRI Studies of Language; Magnetoencephalography; Psycholinguistics: Overview; Reading Processes in Adults; Speech Errors: Psycholinguistic Approach; Spoken Language Production: Psycholinguistic Approach.

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Psycholinguistics: History

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Our faculty for language has intrigued scholars for centuries. Yet most textbooks assume that psycholinguistics has its origins in the late 1950s and 1960s, and that nothing of note contributed to its evolution before then. In some respects this is true, in that it was only then that psycholinguistics began to proliferate as an identifiable discipline within the psychology literature. This proliferation was marked by the founding in 1962 of the *Journal of Verbal Learning and Verbal Behavior* (which subsequently, in 1985, became the *Journal of Memory and Language*). Why the original journal was so titled, and why its title presents us with a historical paradox, will become clearer as this review unfolds. The review's purpose is to consider how the present-day state of the art evolved. In so doing, it will touch briefly on ancient Greek philosophy, 19th century neuroscience, 20th century psycholinguistics, and beyond. It will consider approaches to the brain as practiced in both ancient Egypt and modern neuroscience. It will be necessarily selective, in order to make some sense of the historical developments that contributed to psycholinguistic science.

From the Ancient Egyptians to the Greek Philosophers

The earliest to write about language and the brain were the ancient Egyptians – the first to write about anything at all. A catalog of the effects of head injury (and injuries lower down the body also) exists in what is now referred to as the Edwin Smith Surgical Papyrus, written about 1700 B.C. The writer (believed to have collected together information spanning perhaps another 1000 years before) referred there to what is presumed to be the first recorded case of aphasia – language breakdown following brain trauma. However, the Egyptians did not accord much significance to the brain, which unlike the other organs of the body, was discarded during mummification (it was scraped out through the nose). They believed instead that the heart was the seat of the soul and the repository for memory, a view largely shared by the Greek philosopher Aristotle (384–322 B.C.) – a somewhat surprising position to take given that he was a student at Plato's Academy and that Plato (427–347 B.C.) believed the brain to be the seat of intelligence.

Plato was possibly the earliest to write at length on language (where others may have spoken, but not written). Certainly, his writings were the most influential with respect to the philosophy of language and the question 'what does a word mean?' Plato, in his *Republic*, considered the meaning of words in his Allegory of the Cave (as well as in *Cratylus*). In this allegory, a group of prisoners have been chained all their lives within a cave. All they see are the shadows of objects cast upon a wall by the flames of a fire. They experience only those shadows (in much the same way that we can only experience the results of our sensory percepts), and their language similarly describes only those shadows. Plato noted that when using a word, the prisoners would take it to refer to the shadows before them, when in fact (according to Plato), they would refer not to objects in the shadow world, but (unbeknown to the prisoners) to objects in the real world. Thus, for Plato (and a host of more contemporary philosophers, from Frege to Puttnam), the true meaning of a word – its reference – is external to the person who, by using the word, is attributing meaning to it. But why should it matter what a word refers to?

The *psycholinguistic* endeavor is to uncover the mental processes that are implicated in the acquisition, production, and comprehension of language. Just as psychology is the study of the control of behavior, so psycholinguistics is the study of the control of linguistic behavior. A part of any psycholinguistic theory of mental process is an account of what constitutes the input to the mental process – that is, what information is operated upon by those processes. While Plato was of course correct that the form of the real-world object dictates the form of the sensory image presented to the allegorical prisoner, the mental processes involved in that prisoner's use of language can operate only on mental derivatives of that sensory image. There may be properties of the real-world object (such as color, texture, and density) that are not represented in their shadow-forms, and thus mental processes that might otherwise (outside the cave) develop sensitivity to those properties need never develop such sensitivities if constrained to living a life inside the cave. But while the shadows would not permit the distinction between, say, a tennis ball and an orange, the *contexts* in which the shadows were experienced, or their names heard, *would* distinguish between the two – mental sensitivities would develop, but they would not necessarily be grounded in the perceptual domain. These distinctions, between the actual world and our *experience* of the world, and between an object or word and the *context* in which that object or word might occur, led other philosophers, most notably Wittgenstein in his *Philosophical Investigations*, to propose that the meaning of a word is knowledge of its use in the language – that is, knowledge of the contexts in which it would be appropriate to utter that word, where such knowledge is shaped by experience. We return to this theme when we consider in more detail the more recent history (and possible future) of psycholinguistics.

The Earliest Empirical Studies

The pre-history of psycholinguistics (up until the 19th century) was dominated by philosophical conjecture. The term *dominated* is used loosely here, as there was no *systematic* and ongoing questioning of the relationship between mind and language, or indeed, brain and language – there was no *community* of researchers asking the questions. But modern-day psycholinguistics is dominated not by philosophy (although it had its moments), but by experimental investigations that measure reaction times, monitor eye movements, record babies' babbles, and so on. Its pre-history lacks such experimentation. This is not to say that no experiments were performed. Certainly, there were isolated cases, generally of a kind that would not be tolerated in the modern age. Indeed, one of the most widely replicated studies (if one is to believe the historians) is a study that was carried out on at least three and possibly four independent occasions between the 7th Century B.C. and the 16th Century A.D. In each case, some number of babies were apparently brought up in isolation (except for carers who were either mute, or instructed not to speak), with the aim of the experiment being to discover what language, if any, the children would grow up speaking. The results varied. The Egyptian Pharaoh Psamtik (7th C.B.C.) was credited by Herodotus with discovering that they spoke Phrygian. The Roman emperor and German king Frederick II (1194–1250 A.D.) carried out a similar study, but all the infants died. King James IV (1473–1513 A.D.) is supposed to have performed a similar experiment on the island of InchKeith, although it is likely that this study never in fact took place (the fact that the children are reported to have emerged from their isolation speaking Hebrew is one reason to doubt the truth of the story). And finally, Akbar the Great (1542–1605), the grandfather of Shah Jahan who built the Taj Mahal, similarly failed to discover man's 'natural language' (although there is some suggestion that in this case, the infants acquired a form of signed language inherited, in part, from the infants' carers).

The 19th Century Emergence of the Cognitive Neuropsychology of Language

The first *systematic* studies of the relationship between language and brain were conducted in the 19th century. This is probably the earliest point in the history of psycholinguistics from when a *progression* of studies can be traced, with one author building a case on the basis of earlier studies coupled with newer data. The protagonists at this time were Gall, Boulliard, Aubertin, Broca, Wernicke, and Lichtheim, to name a few. None of them would be described as 'psycholinguists,' but to the extent that their work (like modern-day *cognitive neuroscientists*) informed accounts of the relationship between brain and language, they are no less a part of the history of psycholinguistics than are the linguists, philosophers, psychologists, and cognitive scientists who have influenced the field through their own, sometimes radically different, perspectives.

Franz Gall is perhaps better known for his work on phrenology, but he believed that language function was localized in the anterior parts of the brain. His student Jean Boulliard collected clinical evidence in support of Gall's theory, and in turn, Boulliard's student Ernest Aubertin did the same. It was at a meeting in April of 1861 that Aubertin made his beliefs plain: If a case of speech loss could be found that was not accompanied by a frontal lesion, he would give up his (and his intellectual forbearers') belief in the localization of language. In the audience was Paul Broca, after whom are named Broca's aphasia and, within the left frontal lobe, Broca's area. Broca was struck by Aubertin's empirical challenge, but at the same time realized that craniology (Gall's lasting influence on his students) could not provide the proof that was required to establish a link between language loss and cerebral localization – only anatomical inspection of the brain could do that. Coincidentally, within a few days he was presented with a patient suffering from speech loss who died a few days after that. Broca's postmortem analysis of this patient's brain (and the damage to what is now referred to as Broca's area), coupled with earlier observations made by Marc Dax (on right hemiplegia and its correlation with speech loss), but published at the same time, established the anatomical validity of the localization hypothesis. About 10 years later (in 1874), Carl Wernicke published his work on 'sensory aphasia' (deficits in the comprehension of language). This work was considerably enhanced by Wernicke's student Ludwig Lichtheim who, in 1885, produced a schematic (cf. a 'model') of how three interlinked centers in the brain are implicated in aphasia: Broca's (the 'center of auditory images'), Wernicke's (the 'center of motor images'), and a diffusely located 'concept center.' Lesions to each of these areas, or to the connections between them, produce different kinds of aphasias. Most interesting of all, his schematic enabled him to predict disorders that had not yet been described. This ability of a conceptual 'model' to make as yet untested predictions is a theme we shall return to.

The Early 20th Century Influence of Behaviorism

By the end of the 19th century, the study of language began to change, as did the study of psychology more generally. Interest in the psychology (as opposed to *philosophy*) of language shifted from being primarily (or even solely) concerned with its breakdown to being concerned also with its normal use. Wilhelm Wundt in *Die Sprache* (published in 1900) stressed the importance of mental states and the relationship between utterances and those internal states. William James similarly (at least early on) saw the advantages of introducing mental states into theories of language use (see his 1890 *Principles of Psychology*, in which several contemporary issues in psycholinguistics are foreshadowed). But the early 20th century was a turbulent time for psycholinguistics (as it was for psychology): J. B. Watson argued that psychology should be concerned with behavior and behavioral observation, rather than with consciousness and introspection (the Wundtian approach). And whereas Wundt had argued that a psychology of language was as much about the mind as it was about language, behaviorists such as J. R. Kantor argued against the idea that language use implicated distinct mental states. For Kantor, the German mentalist tradition started by Wundt was simply wrong. Even William James turned away from Wundtian psychology. Thus, the behaviorist tradition took hold.

The late 19th and early 20th centuries were a time of great change in linguistics, too. The 19th century had seen the emergence of the Neogrammarians, a group that studied language *change*. They were interested in how the sounds of different languages were related, and how within a language, the sounds changed over time. They were less interested in what a language 'looked like' at a particular moment in time. This changed at the beginning of the 20th century when Ferdinand de Saussure brought *structure* into the study of language. He introduced the idea that every element of language could be understood through its relation to the other elements (he introduced *syntactic* distinctions that are still central to contemporary linguistics). In the 1930s, the Bloomfieldian school of linguistics was born, with the publication in 1933 of Leonard Bloomfield's *Language*. Bloomfield reduced the study of language structures to a laborious set of taxonomic procedures, starting with the smallest element of language – the *phoneme*. In doing so, Bloomfield firmly aligned the linguistics of the day with behaviorism. And just as behaviorism eschewed mental states in its study of psychology, so the Bloomfieldian tradition eschewed psychology in its study of language. The study of language was firmly caught between the proverbial rock and a hard place – between behaviorism on the one hand and taxonomy on the other. Mental states were, the argument went, irrelevant – whether with respect to psychological or linguistic inquiry.

The behaviorist tradition culminated (with respect to language) with B. F. Skinner's publication in 1957 of *Verbal Behavior.* Here, Skinner sought to apply behaviorist principles to verbal learning and verbal behavior, attempting to explain them in terms of conditioning theory. Verbal behavior (and *Verbal Behavior*) proved to be the final battleground on which the classical behavorists and the mentalists would clash.

The Mid-20th Century and the Chomskyan Influence

In 1959, Chomsky published a review of Skinner's *Verbal Behavior.* He argued that no amount of conditioned stimulus-response associations could explain the infinite productivity or systematicity of language. With Chomsky, out went Bloomfield, and in came mental structures, ripe for theoretical and empirical investigation. Chomsky reintroduced the mind, and specifically mental representation, into theories of language (although his beliefs did not amount to a theory of psychological process, but to an account of linguistic structure). So whereas Skinner ostensibly eschewed mental representations, Chomsky apparently proved that language was founded on precisely such representation. Some later commentators took the view that the Chomskyan revolution threw out the associationist baby with the behaviorist bathwater. Behaviorism was founded on associationism. Behaviorism was 'out,' and with it, associationism. Symbolic computation was 'in,' but with it, uncertainty over how the symbolic system was acquired. It was not until the mid-1980s that a new kind of revolution took place, in which the associationist baby, now grown up, was brought back into the fold. The intervening 20 years were typical teenage years – full of energy, punctuated by occasional false hopes that nonetheless proved essential to the maturation process.

Two years before his review of *Verbal Behavior*, Chomsky had published *Syntactic Structures*, a monograph devoted to exploring the notion of abstract grammatical rules as the basis for generating sentential structure. According to Blumenthal in his 1970 account of the history of psycholinguistics, Chomsky's departure from the Bloomfieldian school was too radical for an American publisher to want to publish a lengthy volume that Chomsky had written outlining the new approach, and only Mouton, a European publisher (and presumably more sympathetic to the tradition that Chomsky was advocating) would publish a shorter monograph based on an undergraduate lecture series he taught at MIT. In fact, this is not quite accurate (N. Chomsky, personal communication); Chomsky had indeed written a longer volume (subsequently published in 1975), and it is true that initial reactions to the manuscript were negative (but, according to Chomsky, not unreasonable), but *Syntactic Structures* was not a compromise brought about through Chomsky's search for a publisher; he had not, in fact, intended to publish it. Instead, Cornelis van Schooneveld, a Dutch linguist and acquaintance of Chomsky's who was visiting MIT and happened to edit a series for Mouton, suggested that Chomsky write up his class notes and publish them. This he did, and modern linguistics was born. Psycholinguistics became caught up, almost immediately, in its wake.

Chomsky's influence on psycholinguistics cannot be overstated. He drew an important distinction between 'competence,' or the knowledge we have about a language, and 'performance,' the use of that language (a distinction that was reminiscent of Saussure's earlier distinction between *langue* and *parole*). Both, he claimed, arise through the workings of the human mind – a mind, which furthermore is innately enabled to learn the structures of human language (although not everyone agreed with the arguments for a language acquisition device akin to a mental organ – a concise summary of the counterarguments was written by Bates and Goodman (1999)). It is perhaps surprising that against the backdrop of *Syntactic Structures* and Chomsky's *Review of Skinner's Verbal Behavior*, a new and influential journal dedicated to research into the psychology of language should nonetheless, in 1962, give itself a title (the *Journal of Verbal Learning and Verbal Behavior*) that firmly placed it in the behaviorist tradition.

From Linguistic Competence to Psychological Performance

Chomsky's theories of grammar were theories of competence, not performance. And yet, his work on *transformational grammar* initiated a considerable research effort in the early 1960s to validate the psychological status of syntactic processing (the construction of representations encoding the dependencies between the constituents of a sentence). Many of these studies attempted to show that perceptual complexity, as measured using a variety of different tasks, was related to linguistic complexity (the so-called Derivational Theory of Complexity). However, whereas the syntactic structures postulated by transformational grammar did have some psychological reality, the devices postulated for building those structures (e.g., the transformations that formed a part of the grammatical formalism) did not. It soon became apparent that the distinction between competence and performance was far more important than originally realized – the linguists' rules, which formed a theory of competence, did not make a theory of psychological process.

Subsequently, the emphasis shifted toward examination of the psychological, not linguistic, mechanisms by which syntactic dependencies are determined (a process referred to as *parsing*). In a seminal paper published in 1970, Thomas Bever pointed out that in cases of ambiguity, when more than one structure (i.e., dependency relation) might be permissible, there appear to be consistent preferences for one interpretation rather than another. This consistency appeared to hold not only across different examples of the same kind of ambiguity, but across different people, too. Thus, despite the grammaticality of '*the horse raced past the barn fell*' (cf. '*the car driven past the garage crashed*'), the preference to interpret '*raced*' as a main verb (instead of as a past participle equivalent to '*driven*') is so overwhelming that the sentence is perceived as ungrammatical (and the preference is then said to induce a 'garden path' effect). Evidently, grammaticality and processability are distinct mental phenomena.

On the Influence of the Digital Computer

The 1970s saw enormous growth in psycholinguistics. Advances were made across a wide range of phenomena, including the identification of both printed and spoken words, the reading process, sentence comprehension (with much of the emphasis on the resolution of ambiguities of the 'garden path' kind), and the mental representation of texts. Whether there was a 'spurt' in the number of publications is contentious, because although there undeniably was such a spurt, the whole of psychology experienced the same rapid growth. It would be wrong, however, to attribute all this advancement to the influence of Chomsky. The demise of behaviorism played a part (and certainly Chomsky played a part in that demise), but so did the advent in the 1950s of the digital computer. The 'mind-as-computer' metaphor had a subtle but pervasive influence on both psycholinguistics and the study of *cognition* generally. Computer programs worked by breaking down complex behaviors into sequences of simpler, more manageable (and hence more understandable) behaviors. They relied on *symbol manipulation* and the control of *information flow*. They distinguished between different levels of explanatory abstraction (the high-level programming language, the assembly code, and the flow of electrical currents around the hardware). And perhaps most important of all to the empirical psychologist, they enabled novel predictions to be made that might not otherwise have been foreseen had the 'model' not been implemented in full; complex interactions among the components of a program were not easy to foresee.

The influences of the digital computing revolution were felt in different ways. Some were direct, with researchers building computer simulations of mental behavior (in the growing field of *Artificial Intelligence*, several language 'understanding' programs were written, some of which are still relevant 35 years later – e.g., Terry Winograd's SHRDLU program written in 1968–1970). Other influences were indirect, coming to psycholinguistics via philosophy. One such example was Jerry Fodor's Modularity of Mind hypothesis (from 1983). One simplified interpretation of this hypothesis (it was interpreted in different ways by different researchers) was that there are two alternative ways of theorizing about the mind: one is to assume it is incredibly complex and that multiple sources of information interact in multiple ways, and the other is to assume that it can be broken down into a number of modules, each of which performs some particular function and is 'blind' to the workings of the other modules (perhaps taking as input the output of one or more of those other modules). Fodor argued that certain aspects of cognition were modular (the input systems), and certain others were not (central processes). This hypothesis had considerable influence in psycholinguistics, and for a time (the mid-1980s to early 1990s), hypotheses were evaluated according to whether they were modular or not. There seemed little agreement, however, on where one drew the boundaries (for example, was spoken language recognition a part of an input system? If it was, how could 'higher-level' knowledge of the context in which the language was being interpreted influence the modular and encapsulated recognition process? – Some argued it could not, while others argued it could). It was about this time, in seeming opposition to the trend toward *symbolic computation*, that a new computationally motivated approach to cognition emerged in the mid 1980s, apparently eschewing symbolic computation *and* modularity.

The Late 20th Century Emergence of Connectionism: Statistical Approaches to Language

In 1986, David Rumelhart and Jay McClelland published *Parallel Distributed Processing*. This edited volume described a range of *connectionist*, or *neural network*, models of learning and cognition, and marked a 'coming of age' for connectionism. It was, for many researchers in psycholinguistics, their first introduction to a wide range of research in this emerging field. Of particular interest were the facts that 'knowledge' in connectionist networks is encoded as patterns of connectivity distributed across the neural-like units, and 'processing' is manifest as spreading patterns of activation. These networks can learn complex associative relations largely on the basis of simple associative learning principles (based primarily on work published in 1949 by Donald Hebb, a student of Lashley's). Various algorithms exist to set the 'strengths' of the connections between the units automatically, so that a given input pattern of activation across some set of units will spread through the network and yield a desired output pattern across some other set of units. Indeed, multiple input-output pairings can be learned by the same network. Importantly, and in contrast to the ideals of the behaviorist traditions, neural networks can develop internal representations.

Several connectionist models had profound effects on developments in psycholinguistics. TRACE, for example, developed by McClelland and Jeff Elman in the 1980s, was a model of spoken word recognition that formed the focus of empirical research for a good 20 years after its inception. But TRACE did not learn anything – it was hardwired. An extremely influential model that *did* learn by itself was described by Elman (1990), who showed how a particular kind of network could learn the dependencies that constrain the sequential ordering of elements (e.g., phonemes or words) through time. In effect, it learned which kinds of word could follow which other kinds of word (hence, it was a *statistical model*, because it encoded the statistics of the language it was trained upon). Interestingly, it developed internal representations that appeared to resemble grammatical knowledge; words that occurred in similar sentential contexts came to evoke similar internal representations (that is, internal patterns of activity when the word was presented to the network) – and because words of the same grammatical category tend to occur in the same sentential contexts, different 'clusters' of words emerged, with each cluster representing a different category of word.

Not surprisingly, the entire connectionist enterprise came under intense critical scrutiny from the linguistics and philosophy communities, not least because it appeared to reduce language to a system of statistical patterns, was fundamentally associationist, nonmodular, and eschewed the explicit manipulation of symbolic structures (because the internal representations that emerged as a result of the learning process were not symbolic in the traditional sense). Within the context of the symbolic-connectionist debate there developed what became perhaps one of the longest surviving disputes in contemporary psycholinguistics; between those that believe that word formation (e.g., the formation of 'walked' from 'walk,' 'ran' from 'run,' and 'went' from 'go') is driven by knowledge of *rules* and *exceptions* to those rules, and those who believe it is driven by *statistical regularity* (which can apparently capture, in the right model, both the regularly and irregularly formed words). The debate shows little sign of abating, even 20 years later.

Critics notwithstanding, statistical approaches to language (both with respect to its structure and its mental processing) are becoming more prevalent, with application to issues as diverse as the 'discovery' of words through the segmentation of the speech input, the emergence of grammatical categories, and even the emergence of meaning as a consequence of statistical dependencies between a word and its context (cf. Wittgenstein's views on the meaning of words). Empirically also, the statistical approach has led to investigation of issues ranging from infants' abilities to segment speech and to induce grammar-like rules to adult sentence processing. The reason that such approaches have proved so appealing is that statistics are agnostic as to the nature of the real-world objects over which the statistics are calculated – thus, the fundamentally same algorithm can be applied to sequences of phonemes, words, or sentences. Their implementation within a neural network is similarly agnostic – the same network and the same algorithms that enable that network to induce the appropriate statistics can be applied to many different domains. Connectionism opened up experience-based learning to a range of psychological domains, not just the linguistic domains. And experience-based learning was attractive not least because it required fewer assumptions about the existence of innately specified domain-specific faculties (and in a multi-authored volume published in 1996, Jeff Elman teamed up with a variety of developmental psychologists to argue that connectionism was attractive precisely because it enabled a new perspective on how innate constraints on learning and neural structure might be an important component of human language acquisition (Elman, 1996)).

Neural networks can be criticized for being (among other things) too unconstrained – they can, in principle, do more than might be humanly possible – but the opposite criticism, that they are too small and do not necessarily 'scale up' is another criticism that is often heard. Neural networks as currently implemented are just the 'medium' on which are offered up the statistics. To misuse a common adage, the proof will be in the pudding, not in the plate that serves it up. There is little doubt, from the historical perspective, that although the emergence of connectionism has offered a powerful theoretical tool, its emergence has also polarized sections of the psycholinguistic community, between 'connectionists' on the one hand, and 'symbolists' on the other. This polarization is not unique to psycholinguistics, however, but pervades the study of cognition more broadly. And as if to further muddy the theoretical waters, the beginning of the 21st century has seen renewed interest in yet another (no less controversial) paradigm – one that grounds language (and cognition) in action.

The Early 21st Century and the Grounding of Language in Action and the Brain

Traditional theories in cognition suppose that the job of the perceptual system is to deliver to the cognitive system a representation of the external world. The job of the cognitive system is then to reconstruct, mentally, that external world. This reconstruction subsequently forms the basis for 'commands' sent to, for example, the motor system. Cognition thus mediates between perception and action. An alternative approach, termed 'embodied cognition,' is that cognition and action are encoded within the same representational medium. Cognition is thus rooted in the same motoric and sensory representations that support interaction with the external world. Or, put another way, cognition is grounded in the same neural substrates that support sensory-motoric interaction with the external world. One consequence of this view is that language, a component of cognition, should, like the other components of cognition, be studied in the context of (i) the interactions it causes between the hearer and the world, and (ii) the neural substrates that support those interactions. Coincidentally, the 1990s saw a boom in research into the neural substrate of language, in part due to the increased availability of neuroimaging technologies (predominantly *PET* and *fMRI,* with *EEG* and more recently *MEG* also proving influential). It also saw increased research into the relationship between language and action. Taken together, these two streams of research provided increasing evidence for embodied cognition.

With respect to imaging, a variety of studies demonstrated what Lichtheim had alluded to a century earlier – that concepts are not represented in some discrete location within the brain, but are distributed across different regions. For example, words whose meanings implicate tool use (e.g., 'hammer') activate regions of the brain responsible for controlling motoric action (during the use of the tool) and other regions involved in the recognition of object form (during perception of the tool). Color words (e.g., 'yellow') and words referring to nonmanipulable artefacts (e.g., 'house') do not activate motoric areas to the same extent, but they do activate regions close to those implicated in form perception and, for color words, color perception. Importantly, there is no single region that is primarily active; rather, words and concepts activate complex patterns of activity that are distributed and overlapping within different parts of the brain that are known to have (other) motoric and sensory functions. The meanings of (at least some) words do appear, then, to be grounded in those neural substrates that support sensory-motoric interaction.

About the same time that increased attention was focusing on neuroimaging, new techniques for studying language and its effects on *action* were also being developed. One of these involved the monitoring of eye movements as participants listened to commands to manipulate objects in front of them, or as they listened to descriptions of events that might unfold within the scene before them (one can view language-mediated eye movements as central to the relationship between language and action, because eye movements signal overt shifts in attention, and because attention to something necessarily precedes (deliberate) action upon it). It was found that eye movements were closely synchronized with processes implicated in both spoken word recognition and sentence processing, and that much could be gleaned about what kinds of information were recruited at what point during a word or sentence in order to interpret the unfolding language with respect to the scene in front of the participant (it is not without some irony that in L. N. Fowler's famous Phrenology bust, from about 1865, the faculty for language is located just below the left eye). Another technique involved measuring motoric responses to different kinds of linguistic stimuli – for example, words or sentences referring to movements toward or away from the body were found to interfere with responses in a judgment task (e.g., 'does this sentence make sense?') that involved moving a finger toward or away from a response button. A range of studies, some involving TMS (Transcranial Magnetic Stimulation – a method for either temporarily stimulating or suppressing a part of the brain, such as parts of motor cortex) have confirmed this motoric component to language comprehension.

It is noteworthy, with respect to the embodiment approach to cognition, that some of its basic tenets have been around since the earliest days of (contemporary) psycholinguistics. Winograd's SHRDLU program, for example, viewed the meaning of a word such as 'place' or 'lift' as that part of the program that caused placing or lifting – language comprehension within that program was grounded in sensory-motoric representation – and as such, SHRDLU followed in the Wittgenstinian tradition of treating meaning as use. Similarly, it is noteworthy that although most of the neuroimaging of language has been carried out independently of theories of embodied cognition, much of the work converges on the same theme – that aspects of language are represented in the same representational substrates that control our sensory-motoric interactions with the external world.

Epilogue

And that, broadly speaking, is where the field is now. In the space available, it is impossible to document all the trends that have influenced contemporary psycholinguistics, and which have influenced not just what kinds of language behavior we study (e.g., language breakdown, normal language use, ambiguity resolution, and so on), but also how we study those behaviors (through studying aphasis, neuroimaging, language-mediated eye movements, and so on). And we have still to see the full influences of connectionism, statistical learning, embodied cognition, and the neuroscience of language. What we can be sure of is that the boundaries between the study of language and the study of other aspects of cognition are wearing thinner (the eye movement research mentioned above is at the interface of language and vision, for example). No doubt there are already developments in 'neighboring' fields of study (e.g., the computational sciences and non-cognitive neurosciences) that will also have an impact, but have yet to emerge as quantifiable influences on psycholinguistics. For example, researchers are already using computational techniques coupled with detailed neuroanatomical research on the neural structure of the brain to attempt to understand the kinds of 'computation' that distinct parts of the brain may be capable of. Such research promises greater understanding of the brain's ability to learn, represent, and deploy language. And although the history of psycholinguistics is relevant to understanding where the field is today, perhaps of greater interest is where the field will be tomorrow.

Acknowledgments

This article is a substantially expanded version of a short, 1500-word section on the history of psycholinguistics that appeared as part of a broader review of issues in psycholinguistics (Altmann, 2001). The reader is referred to this paper for in-depth review of (some of) the topics that constitute the field of psycholinguistics. The author would like to thank the publishers of this article for donating his fee to the charity Médecins sans Frontières, and Silvia Gennari for advice on topics ranging from Plato to neuroimaging.

See also: Cognitive Science: Overview; fMRI Studies of Language; Human Language Processing: Connectionist Models; Human Language Processing: Symbolic Models; Language, Visual Cognition and Motor Action; Modularity of Mind and Language; Psycholinguistics: Overview; Sentence Processing.

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Psycholinguistics: Overview

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Emergence of Psycholinguistics in the Late 1950s and 1960s from the Chomskyan Revolution

Although the study of language has been part of psychology from its earliest years, including for example in the work of Wilhelm Wundt, the father of psychology, a distinct field of psycholinguistics emerged in the late 1950s largely in response to the impact of Chomsky. In the preceding decades, notably in the United States, psychology had been dominated by the behaviorist approach of researchers such as B. F. Skinner. They treated language as a form of verbal behavior, which, like all other behavior, they believed was governed by simple stimulus–response associations. Chomsky demonstrated the shortcomings of the behaviorist approach in explaining the productivity of language and its complexity, and his work, notably *Syntactic structures* (1957), provided a major impetus for a new kind of psychological investigation of language. This was driven by an interest in the mental representation of language in general and syntactic structures in particular (*see* **Psycholinguistics: History**).

Psychology since the demise of behaviorism has again been concerned with understanding the way that people accomplish various information-processing tasks. In the field of psycholinguistics this means a concern with the cognitive processes by which a string of sounds in an utterance, or marks on a page, are processed to identify individual words and sentences, and how this emerging structure becomes mentally represented as a meaningful concept. The goal of this process is to derive models that account for how people achieve this so rapidly and successfully, given what we know about the general limitations of human cognitive processing. To oversimplify: the psychologist is concerned with **how** the linguistic units are processed and represented; the linguist is concerned with the description of the structures that emerge from any such processes.

Research Topics in the Early Years of Psycholinguistics

In its early years psycholinguistics reflected the concerns of linguistics and the central role of syntax. Psychologists such as Miller and Isard (1963) showed that the syntax influences the way people interpret sentences, and even how many words people can remember from a string of words that make no sense. More words are remembered from a 'sentence' like 'Accidents carry honey between the house' than from strings with no syntactic structure such as 'On trains hive elephants the simplify.' The focus on syntax and its importance in language processing led many psycholinguists to try to test the psychological reality of Chomsky's theory of generative grammar. Experiments were designed to explore the notion that when people process sentences, what they are doing is retrieving the deep syntactic structure as described in Chomsky's transformational grammar. So initially, a number of studies seemed to show that the relative ease or difficulty with which a reader or listener could process a given sentence was directly related to its syntactic complexity. Chomsky's kernel sentences, equivalent to active affirmative declarative sentences, were recalled most easily and processed most quickly, while sentences including one or more transformations such as negative or passive forms were more difficult to process. These kinds of study led to the so-called derivational theory of complexity. This was superseded as it became clear that the results of many of the studies that apparently provided support for this purely syntactic view of how people process sentences could also be accounted for by the influence of semantic factors. Although sentence processing remains one of the most significant topics in psycholinguistics, the range of language phenomena that are studied has broadened considerably since the early 1960s. The assumption that the role of psycholinguistics is to demonstrate the psychological validity of any particular syntactic theory has also been overtaken.

Models of Sentence Comprehension

Many of the models of sentence comprehension that have been developed in psycholinguistics try to elucidate the cognitive processes that are involved when a reader or listener interprets a sentence. There is considerable experimental evidence that sentence comprehension is incremental, that is, that an interpretation is built up on a moment-by-moment basis from the incoming linguistic information. The evidence for this incremental processing is particularly striking in the way listeners recognize spoken words (see below), which are often identified before all the acoustic information has been heard.

Even in written language processing we have clear signs of the incremental nature of linguistic processing. This is illustrated by the difficulties most readers have with sentences like the following: 'The horse raced past the barn fell' (Bever, 1970). This is known as a garden path sentence, because nearly all readers interpret this **while** they are reading, with 'raced' as an active verb and so expect the sentence to end after 'barn.' They do not realize that the sentence could have an equivalent interpretation to 'The horse that raced past the barn, fell.' The incremental way that sentences seem to be interpreted by readers or listeners is a major source of potential ambiguities of interpretation. Many sentences in a language have potentially more than one interpretation as they are processed, yet the reader or listener is usually not aware of any problem in arriving at one clear interpretation of a sentence.

The cognitive architecture that underpins such an achievement has been a source of much debate in psycholinguistics. Some researchers have held that in the frequent cases where more than one analysis of a sentence is possible, the reader or listener computes all possible analyses in parallel. The difficulty of garden path sentences has led others to propose serial models, where it is assumed that a single analysis is computed and corrected later if this is needed. Models have been proposed to account for the empirical evidence on sentence-processing difficulties. These often involve various versions of parallel analyses, where candidate analyses are only active for a brief period of time or are ranked according to frequency in the language or plausibility with the context. One of the most influential of these accounts is the constraint-based model of MacDonald *et al.* (1994). The weightings attached to each candidate analysis are based on the frequency of a syntactic structure in the language, the plausibility of the words in the sentence to their assigned syntactic roles, etc. So this model is an example of an interactive model where many different sorts of information, syntactic, semantic, pragmatic, contextual, and frequency, can all play simultaneous roles by activating alternative interpretations of the incoming linguistic information. In models of this type, semantic factors can override syntactic processing biases. This model is attractive to psychologists for a number of reasons. It is amenable to modeling by connectionist approaches (*see* **Cognitive Science: Overview**) and it avoids the problem of having to base cognitive processes on syntactic rules, which for psychologists appear to change arbitrarily with changes in linguistic theories.

In contrast, one of the other most influential models of sentence processing is the garden path model (Frazier, 1979). This uses only syntactic principles in its initial stage. An analysis is computed based on two syntactic preferences, the most important being the principle of minimal attachment, the other being the principle of late closure. The first principle means that the parsing of the sentence that produces the simplest parse tree, with fewest nodes, takes precedence. So a sentence like 'Mary watched the man with the binoculars' is usually interpreted to mean that Mary (not the man) was using binoculars. According to Frazier's interpretation of phrase structure rules, this interpretation involves one node fewer than the alternative and so demonstrates the principle of minimal attachment in action. This principle takes precedence over the principle of late closure. This is the preference to attach incoming materials to the current phrase or clause. This latter principle is used to explain the preference for interpreting sentences like 'John said he will leave this morning' to mean that the phrase 'this morning' relates to the verb 'leave,' not the verb 'said.'

As part of the ongoing debate about the adequacy of different models of the parsing process there has been an active discussion in the experimental literature over several years about the extent to which semantic factors can override or guide the analysis of syntactic structure. This has been explored in several studies focusing on the ease or difficulty with which sentences containing reduced relative clauses can be processed. Several studies have tested how people interpret sets of sentences like the following:

(1a) The defendant examined by the lawyer turned out to be unreliable.
(1b) The defendant that was examined by the lawyer turned out to be unreliable.

(2a) The evidence examined by the lawyer turned out to be unreliable.
(2b) The evidence that was examined by the lawyer turned out to be unreliable.

Sentences like (1a), which contain a reduced relative clause, are more difficult to process than their equivalent full relative clause (1b). Readers initially treat 'examined' as a main verb whose subject is 'the defendant.' They then have to reanalyze this garden path when they reach the phrase 'by the lawyer.' The argument is the extent to which structurally similar sentences (e.g., [2a]) cause readers to have equivalent processing problems. This is what might be expected from a purely syntactic view of parsing. In contrast, in an interactive constraint-based model, the semantic implausibility of interpreting an inanimate noun such as 'evidence' as the subject of the verb 'examined' should protect the reader from the need to reanalyze an initial incorrect syntactic structure.

Trueswell *et al.* (1994) seemed to show just such a pattern. This was considered powerful evidence in support of interactive constraint-based models of sentence processing. More recently, Clifton *et al.* (2003) have challenged the evidence that semantic factors override syntactic processing in the initial stages of parsing. They used more sophisticated techniques for monitoring and analyzing eye movements to determine the processing difficulties experienced by readers. They found that reduced relative clauses caused disruption to processing, irrespective of the semantic plausibility of the relationship between the apparent subject and main verb. Semantic factors, however, influenced how quickly the readers **recovered** from their wrong analysis of the syntax of the sentence. Clifton *et al.* (2003) stressed that the key thing for psycholinguistic models of sentence processing is not whether the data on processing reduced relative clauses support garden path or constraint-based models. They claim that the important goal is to develop parsing models that deal both with the task of creating structure and evaluating the structure that is created.

Although there have been numerous studies of sentence processing conducted by psycholinguists over the decades, the vast majority of these have focused on how readers interpret written sentences. A few studies have tackled the issue of how listeners use the cues in spoken language during parsing. Minimal attachment strategy can be shown to be overcome by the prosodic cues in real spoken sentences. Similarly, the principle of late closure, which can cause syntactic ambiguities in written sentences, can be less problematical in spoken materials because of clear prosodic cues to the intended interpretation. Even the apparent errors in spoken sentences, such as the disfluency 'uh,' can have an impact during the parsing process. Bailey and Ferreira (2003) presented sets of sentences to listeners such as the following:

(3a) Sandra bumped into the busboy and the uh uh waiter told her to be careful.
(3b) Sandra bumped into the busboy and the waiter uh uh told her to be careful.

These sentences are ambiguous up to the point when the listeners hear 'told.' 'Sandra' could have bumped into 'the busboy' or 'the busboy and the waiter.' Yet the listeners who heard the materials most often interpreted sentences like (3a) to mean that 'the waiter' was the subject of a new clause, i.e., that it was the subject of the verb 'told.' This shows that disfluencies can systematically influence the way listeners parse incoming sentences. The same effect was observed when the interruption was not a disfluency but an environmental sound such as a telephone ringing.

Speech Production and Speech Errors

These studies represent a welcome aspect of the broadening of the psycholinguistic research agenda to include more consideration to the production and comprehension of spoken as well as written language. The study of speech disfluencies is one part of this. Speech disfluencies encompass a range of phenomena, including pauses in speech such as silences, filled pauses, and fillers such as 'uh' and 'um,' as well as speech errors such as slips of the tongue, spoonerisms, and malapropisms. When we speak we aim to produce a grammatically well-formed utterance with no noticeable hesitations. Yet this ideal delivery cannot always be achieved. It is estimated that around 5% of words in speech are disfluent in some way. Yet these disfluencies are not random in their patterns of occurrence. Even the similar-sounding disfluencies 'uh' and 'um' have been shown to have systematic contexts of use. Speakers use 'uh' before a short delay in their speech production but use 'um' before a more significant delay. Speakers seem to become disfluent because they are experiencing some kind of problem in planning and producing their utterance. Speakers have been found to pause more before unpredictable words, suggesting they might be experiencing word-finding difficulties. Speakers also pause more at the start of an intonation unit, which suggests that pausing is related to the speech-planning process (*see* **Pauses and Hesitations: Psycholinguistic Approach**).

Speech errors have also been studied by psycholinguists, who have classified them according to the assumed units of processing and types of mechanism involved in their production. For example, speech errors can relate to the phonemic features of the word, the syllabic structure, or the phrase or sentence being produced. This is illustrated in one of the famous errors reportedly produced by Dr Spooner in the 19th century when rebuking one of his students: 'you have tasted the whole worm' when he presumably intended to say 'you have wasted the whole term.' Here the initial phonemes are swapped but the rest of the morphemic and syntactic structure of the target utterance is preserved. Errors of this type became known as 'spoonerisms' as a result.

The kinds of error that occur can tell us a good deal about how speech is produced. Speech errors are very varied. They can reflect many different linguistic levels. Errors can involve the sounds of the words involved, for example saying 'the lust list' for 'the lush list.' They can relate to the intended words in a phrase, 'the pin of a head' being said in place of 'the head of a pin.' Errors may also focus on the semantic relations of the intended words, so a speaker may produce 'I like berries with my fruit' rather than 'I like berries with my cereal,' among many other forms of errors.

Some types of errors, however, do not occur and these patterns of occurrence and nonoccurrence have been used to help understand the speech production process. Content and function words are not substituted for one another and indeed substitute words are usually the same part of speech as the intended target word. When the wrong sound is produced, however, the substituted phoneme seems to have no grammatical relation with the intended target sound. The spacing between the errors is also informative for models of production. Errors of word substitution usually involve words that are a phrase apart. Yet sound errors seem to relate neighboring words. This sort of evidence has been used by several researchers to develop general models of the speech production process (*see* **Speech Errors: Psycholinguistic Approach** for more details).

Speech Recognition

Psycholinguists have also been concerned with exploring the processes involved in speech perception. Jusczyk and Luce (2002) summarized over 50 years of research on this topic. They described key research issues in the domain as understanding invariance, constancy, and perceptual units. In speech there are no invariant acoustic features that map directly to corresponding phonetic segments. The acoustic properties of sounds vary widely depending on the surrounding linguistic context. To make matters even more complex for the listener, there is also wide variability in the way phonetic segments are produced by different speakers depending on age, sex, and individual speaker characteristics. It is not even easy to determine what are the basic perceptual units that listeners use to recognize speech. Some research studies seem to suggest the phoneme as the basic building block of perception while others show advantages of the syllable over the phoneme. Conversational speech is therefore a very variable signal that does not even provide clear cues to boundaries between words. Yet understanding words in speech is an effortless and successful process for listeners with normal hearing. How is it done?

One of the key research challenges for psycholinguists was therefore to produce models of spoken word recognition. One of the most influential models is the Cohort Model (Marslen-Wilson and Welsh, 1978; Marslen-Wilson, 1989). In this account, when a listener hears an initial sound, all the words known to start with that sound become activated. This cohort of candidate words is gradually whittled down to a single word, as more acoustic information is processed and candidate words are eliminated. An important feature of the model is the uniqueness point. This occurs when the listener has heard enough acoustic information to reduce the cohort to a single candidate, i.e., there are no other words known to the listener with that particular sequence of phonemes. Syntactic and semantic context from the surrounding discourse can also play a role in rejecting potential candidate words. In later versions of the model, this can only occur after the uniqueness point, though in earlier versions, context could also be used to eliminate possible words before the uniqueness point. The recognition point occurs when a single item remains in the cohort. This may be before the end of a word.

One of the strengths of the model is the way it can account for the speed with which spoken word recognition often occurs, often occurring before the word offset. In later versions of the model the activation of candidate words is a graded process. Candidate words are not completely eliminated as acoustic information accumulates, but rather they have their activation level reduced. This can rise again if later acoustic information matches a rejected candidate word. This is important, as one of the problems of conversational speech is that individual words or phonemes are often not articulated clearly and the listener must be able to recover and recognize words whose initial sounds were mispronounced or misheard in a noisy environment.

The main competitors to speech recognition models are various connectionist accounts, notably Trace (McLelland and Elman, 1986). This is a connectionist or parallel distributed processing (PDP) account of spoken language processing. In such models researchers were attempting to produce computational models of language processes which were inspired by what was known about the structure and processes of the human brain (*see* **Cognitive Science: Overview**). In spoken word recognition models, this meant that the feature units were simple units with dense series of interconnections, which processed by sending many messages in parallel. Such structures were developed as analogous to the neural architecture of the brain with its many nerves and interconnections.

The Trace model has three layers of units, corresponding at the lowest level to features, then at the next layer to individual phonemes, then at the top layer to complete words. All have dense arrays of interconnections between them, which like nerve pathways can be excitatory or inhibitory. The connections between levels are excitatory and connections within levels are inhibitory. Connections between levels operate in both directions, so both top-down and bottom-up processing can occur. The connectivity of Trace means that evidence is boosted and plausible hypotheses about the possible words emerge strongly. So a feature such as voicing will energize the voice feature units. These will then transmit activation to all the voiced phonemes at the phoneme level, which will in turn activate all the words that begin with these phonemes. At each level the activated units inhibit competitors at the same level, so reducing possible competitors. A word is recognized when in the end a single active unit remains.

Trace is a very interactive model. It gives context a bigger role in recognition than the cohort model. As a computational model it has the virtues of specificity. Trace models can be built and simulations run and then compared with the experimental data from human listeners. These comparisons have generally shown that Trace can cope with some of the problems of variability in production of features and phonemes, can account for the context effects on spoken word recognition that have been reported in the literature, and can cope with the kind of degraded acoustic input that is so typical of real conversational speech. The main criticisms that have been leveled at Trace concern the large role that context is given, which may be an overstatement of how this operates in human recognition. The other limitation is the less than elegant way that the time course of speech recognition is modeled, with duplication of the levels and nodes over successive time periods.

Other connectionist models have also been developed. Despite the competing architectures of the models, there is general agreement on key aspects of the speech recognition process. This involves activation of multiple candidate words, followed by competition among those known lexical items that share a similar sound profile; these processes have to be able to cope with less than ideal acoustic input and deliver perceptions of words very rapidly (for further details *see* **Speech Recognition: Psychology Approaches**).

Discourse Processing

The gradual broadening of the psycholinguistic research agenda has not been limited to the inclusion of speech alongside written language. Psycholinguists have also shown a growing interest in the processes involved in the interpretation not just of single sentences, but of complete texts. One of the first psychologists to explore the complexities of this process was Bartlett (1932). In his research on the way people remembered and reproduced stories that they had heard, he highlighted key research themes in discourse processing that are still current research topics. Bartlett noted how quickly the surface form of the story is lost and an individual's own interpretation of the text is what is remembered. He introduced the concept of a 'schema,' which was used when readers recalled a narrative. This consisted of an organized set of information based on prior experiences that is used in interpretation and recall. The interpretation of a narrative that is retained consists of a mix of input from the text and from schemata. In some of Bartlett's studies, British students listened to North American folktales. When asked to recall the stories accurately, strange narrative details relating to the activities of ghosts were unconsciously altered and supplemented by details from the participants' world knowledge, so that the recalled version of the stories became more coherent by conventional Western standards.

More recently, a growing body of psycholinguistic research has been addressing the challenges of how readers build up a coherent mental representation to create a sense of the narrative world. One of the key concerns of psycholinguistic studies of text or discourse processing is the problem of inferences. Since Bartlett's seminal studies, it has been known that readers expand on what is in the text by drawing inferences based on their knowledge of the world. But what are the time course and limits of such inferencing? Many studies have been concerned with addressing such questions. Experimental studies have shown that some inferences seem to be made automatically **as** we read a text while some are made **later** to resolve apparent problems or inconsistencies. This was demonstrated in a study by Sanford and Garrod (1981), who presented readers with pairs of sentences such as the following:

(4a) Mary was dressing the baby.
(4b) The clothes were made of wool.

(5a) Mary was putting the clothes on the baby.
(5b) The clothes were made of wool.

The participants read the second sentence just as quickly in both cases. This suggests that verbs such as 'dress' cause readers to automatically draw the inference concerning 'clothes.' In contrast Haviland and Clark (1974) found that some inferences took a small but significant amount of time during reading. In their experiment they used pairs of sentences like the following:

(6a) Harry took the picnic things from the trunk.
(6b) The beer was warm.

(7a) Harry took the beer from the trunk.
(7b) The beer was warm.

They found that sentences like (6b) took longer to read than (7b), because the readers had to make the backward inference that the beer was part of the picnic supplies.

Researchers wished to determine the limits on the kinds of inferences which are made immediately and automatically and which are made later. Clearly, there must be limits on the amount of background knowledge readers activate and one of the research goals is to understand what these limits are and the cognitive processes which support this. Models have been developed that attempt to specify the way inferences are made and the way coherent mental representations are derived from texts. (For a fuller account of inferencing *see* **Coherence: Psycholinguistic Approach**).

Although there are significant differences between the models, there are several agreed features of how discourse processing operates in terms of the way readers update their mental representations of a text, the way some information is held in the foreground of processing while others is background, and the way that certain inferences are drawn automatically to maintain a coherent account of the text. For details of the various models of discourse processing that have been proposed (*see* **Discourse Processing**).

Reading as a Developmental and Educational Process

Before an interpretation of a written text can be made, the words on the page have to be read. Although apparently effortless for the skilled adult reader, the processes of identifying letters, recognizing words, and thus distinguishing the meaning conveyed in even a simple sentence, are complex. One key to unraveling how this is accomplished has been to study readers' eye movements. These have been shown to be very systematic and to consist of three main types: short forward movements of around 6–9 letters called saccades, which last on average 20–50 ms; backward movements called regressions; and the pauses or fixations when the readers' eyes rest on a word for around 250 ms.

Rayner and colleagues have shown there are consistent patterns in these movements (see e.g., Rayner, 1998). When reading more difficult texts, fixations grow longer, saccades grow shorter and regressions become more frequent. Even within a single text, readers will spend more time fixating relatively uncommon words compared to familiar ones. Eye movements are designed to keep the middle of our visual field, where our vision is best, aimed at new areas of interest. However, we are able to distinguish quite a lot of information within a single fixation. A skilled adult reader of English will usually be able to identify 15 letters to the right of the fixation point but only three or four letters to the left.

When children begin to learn to read they fixate words for longer than skilled readers. They also have a shorter perceptual span than adults, which means that in a single fixation they are able to identify fewer letters. Gradually these patterns approach those of adults as reading proficiency increases. The typical English reader's asymmetric perceptual span starts to appear in most young readers within a year of starting to learn to read. This seems to reflect the left-to-right nature of reading English, as readers of Hebrew, which is read right to left, show the opposite pattern in their perceptual spans. Like much of psycholinguistics, the study of skilled reading has largely been the study of skilled English reading but more recently interesting studies have been conducted on other languages, notably on nonalphabetic scripts such as Chinese and Japanese. (*see* **Reading Processes in Adults** for more details).

Visual Word Recognition

One aspect of the reading process has received a great deal of research attention in psycholinguistics: the process of visual word recognition. A whole set of phenomena have been identified in the processes of recognizing written words. These include the process of priming. Words are recognized more quickly if they have been read previously. This is known as repetition priming. Words are also recognized more quickly if a word of similar meaning has just been presented, so 'butter' is recognized more quickly if 'bread' has just been read. This is known as semantic priming. Priming can also occur between words which do not seem to have a direct semantic relationship, such as 'music' and 'kidney,' which are linked by an intermediate word 'organ,' which was not presented to the readers.

Other phenomena which researchers have identified in word recognition include the fact that words which are common in the language, such as 'road,' are recognized more quickly than similar words that are less common, such as 'rend.' This word frequency effect is a strong influence on recognition speeds, with even fairly small differences in word frequency influencing reaction times. It is the most robust effect in studies of word recognition, appearing in many different studies using a wide variety of research methods.

These and other phenomena about how words are recognized have been used to develop a variety of models of word recognition. These can be grouped into families of related accounts. Some of the proposed models are direct access models, where perceptual information goes straight to feature counters or units. Other accounts propose that perceptual information is used to trigger a search through the mental lexicon, that is, the stored representation of all the words known to the reader.

One of the best-known serial search models was proposed by Forster (1976). In this account, the perceptual input is used to build a representation of the word to be recognized which is then checked in two stages by comparisons with a series of access files, which are analogous to the cards in a library index system. Once an input string is matched to an access file it is then linked to the master files, analogous to the books on the shelf, which contain the full lexical entries for each word. The files are organized to speed up the process of word recognition, with groups of files being arranged in bins that contain similar words. Within a bin, files are organized by word frequency. The details of the model are described to account for the observed features of the recognition process. For example, there are cross-references between master files that would support semantic priming. Despite these features it is not clear that this kind of serial search model can convincingly account for the speed with which words are recognized. It has also been criticized as being based on a rather dated analogy with the cognitive system as a digital computer rather than as a neural system.

Very recently, however, Murray and Forster (2004) have published an account of a series of word recognition studies that are claimed to show strong support for the serial search model. They claim that the structure within bins, notably the **rank** ordering of words within a bin in terms of frequency, accounts for the pattern of experimental results on word frequency effects more parsimoniously than alternative direct access models.

More popular models of word recognition involve direct access from the sensory information to the lexical units. One of the most influential of the early accounts of this sort was the Logogen Model (Morton, 1969). In this model, perceptual information, either from visual or auditory analysis, feeds directly into the logogen system. This consists of a series of units, logogens, which represent known words. Logogens act as feature counters and when a logogen has accumulated sufficient evidence to reach a threshold it fires. A word then becomes available to the output buffer, is recognized, and can be articulated. The logogens receive input from the cognitive system as well as the sensory input routes and so the resting threshold of the logogen can be varied by, for example, prior experience of a word, or from the sentence or discourse context. Common words with which an individual has had a lot of prior experience will have a lower threshold and will fire with less sensory input and hence be recognized more quickly. Similarly, words that are highly predictable from context will also have their thresholds raised and so will be recognized rapidly.

The Logogen Model has been used as the basis of computational models of word recognition, notably the interaction activation model (IAM) proposed by McLelland and Rumelhart (1981). This was one of the early connectionist or PDP accounts of language processing. Researchers were trying to produce computational models of language processes which were inspired by what was known about the structure and processes of the human brain (*see* **Cognitive Science: Overview**). In word recognition models, this meant that the feature units were simple units with dense series of interconnections, which processed by sending many messages in parallel. The IAM consisted of three layers of units, corresponding at the lowest level to the visual features of letters, then at the next layer to individual letters, then at the top layer to complete words, all with dense arrays of interconnections between them, which like nerve pathways could be excitatory or inhibitory. The model was able to account for a wide range of experimental observations on word recognition. (For more details *see* **Word Recognition, Written.**)

Models of this type have become very widely used in psycholinguistics to explore a wide variety of language processes. This trend towards testing computational models against the existing experimental literature in a way that can link to new insights about the neural processes involved in language and cognitive processes is a popular approach in current psycholinguistics.

Dialogue and Gesture

In parallel to this concern with understanding the cognitive processes and the possible neurological architecture involved in language processing has been a growing interest in language processing in context. This means not only the growth in studies of how extended texts are processed but also a developing field of psycholinguistic studies of interactive language use. These studies have focused on language in its natural setting, interactive dialogue.

Dialogue represents the most ubiquitous form of language use. As young children, we learn to use language through dialogues with our parents and caregivers. Even educated adults spend a great deal of their time in conversations with family, friends, colleagues. Spoken dialogue is still used to obtain many forms of goods and services. In the many nonliterate cultures in the world dialogue is the main or only form of linguistic interaction.

Yet till recently dialogue received rather little research attention in psycholinguistics. One of the challenges for psycholinguists who wished to study dialogue was to derive methods of exploring the phenomenon which would produce testable and generalizable research questions and findings. One experimental method which has been used to allow the study of comparable dialogues from many pairs of speakers is the referential communication paradigm, developed by Krauss and Weinheimer (1964). In this, pairs of speakers are presented with an array of cards depicting abstract shapes. The speakers have to interact to determine which card a speaker is referring to at a given point in the dialogue. These early studies revealed key aspects of dialogue, including the way that over the course of a dialogue, the lengths of descriptions of even complex and abstract stimuli become much shorter and more concise. The interaction between the speakers was found to be crucial in this process. If this interaction was disrupted the speakers were not able to reduce their descriptions to the same extent.

Later studies on referential dialogues were conducted by Clark and colleagues. In one influential paper, Clark and Wilkes-Gibbs (1986) developed a collaborative model of dialogue. From studying many pairs of speakers engaged in dialogues, they highlighted the way speakers work together through their contributions to dialogue to arrive at a shared and mutual way of referring to things they wish to discuss. This means that the speaker and the listener both take responsibility for assuring that what has been said is mutually understood or 'grounded' before the dialogue proceeds.

In this view of dialogue, speakers follow the principle of collaborative effort and try to minimize their overall effort in arriving at an agreed description. This is done iteratively over a number of turns of speaking, often with each speaker contributing part of the description. This process makes use of the opportunities and limitations of spoken dialogue in a way that highlights its differences from written language. In text, the writer can take as much time as is needed to produce a description that she thinks the reader will understand. In dialogue, however, the speaker is under time pressure, as conversation rarely allows long gaps in which to plan an utterance. The speaker therefore has to produce an immediate description and may not be able to retrieve the most appropriate description or judge what way of describing a referent will be interpretable by the listener. The advantage of dialogue, however, is that the speaker and the listener can work together to refine or clarify the speaker's initial description till they both share a common understanding.

The highly collaborative nature of this process is reinforced in two key studies by Clark and colleagues. Clark and Schaefer (1987) showed how contributing to dialogue is characterized by two phases. Each time a speaker wishes to make a contribution, they produce a stretch of speech that is the content of what they wish to contribute. This is called the presentation phase. They then require an acceptance phase, in which their listener gives evidence of understanding the previous contribution. So the dialogue involves two activities: content specification and grounding, that is attempting to ensure that both speakers understand the content sufficiently for their current conversational purposes.

The importance of the ability to actively contribute to the dialogue interaction was demonstrated in a study Schober and Clark (1989). Using the referential paradigm they had pairs of speakers complete the task. An additional participant was included in each interaction who overheard everything that was said but did not take part in the dialogue. This overhearer had a much harder time trying to identify the intended referents of the descriptions than the conversational participant, despite having the same pictures and having heard everything that was said. The suggested explanation is that the descriptions were not grounded for the overhearers. They had no chance to collaborate and ensure that they understood each description as it emerged during the dialogue.

So there is clear evidence that dialogue is an interactive and collaborative process that involves speakers and listeners attempting to cooperate and achieve mutual understanding. The detailed mechanisms that underpin these general processes of adaptation to the interlocutor are now the focus of a good deal of psycholinguistic study. There is some controversy over the extent to which speakers are able to adjust and adapt their output to their listener's needs. In terms of the forms of referring expressions chosen by speakers there is evidence of adjustment to the listener's general level of knowledge of the domain. When it comes to adjusting the intelligibility of their articulation, speakers seem to be largely egocentric. They reduce the clarity of their word production in terms of what is familiar to them as speakers rather than modeling their listeners' needs. The time course of adaptation is also debated, with some studies showing speakers initially produce utterances from their own perspective but later monitor their listeners and adapt. Other studies show listener adaptations from the start of speaking (for more details *see* **Dialogue and Interaction**).

As language processing is studied in more natural contexts of use, it becomes clear that speakers and listeners do not just communicate using the verbal channel. Visual signals from the mouth, face, hands, and eyes are all important features of communication. Researchers have begun to explore the way the visual channel is used by speakers and listeners and the relationship between verbal and visual signals.

More generally, in a dialogue, what we say, how much we say, and even the clarity of the way the words will be spoken have all been shown to change when speakers do or do not have access to visual signals. So speakers who can see one another need to say less to complete a task, use more gestures, can exchange turns of speaking more smoothly, and articulate their words less than when they cannot see one another.

The important role of visual signals in the perception of speech and how these are integrated with acoustic information is a fascinating research area. This was highlighted in a seminal study by McGurk and MacDonald (1976). They demonstrated that when a listener hears a phoneme such as 'ba' while watching a face mouthing 'ga,' the sound which is heard is a fusion 'da.' This is a powerful illusion that occurs even with knowledgeable listeners/viewers and has been demonstrated with young babies (*see* **Audio-visual Speech Processing**).

The role of visual signals in the production and comprehension of more extended stretches of discourse has also been the subject of considerable study. From studies of conversation and storytelling, the important role of gestures and their relationship to the accompanying speech has been established. For some kinds of gestures there is a close temporal relationship with the accompanying speech. Listeners also seem to fuse information presented visually and verbally. If they are told a story by a speaker who uses speech and gesture and are then asked to retell the story later, information originally presented by gesture, such as the speed of an action or the manner of leaving, is often relayed in speech and vice versa (for more information **Gesture and Communication**).

Future Directions in Psycholinguistics

Several trends seem apparent in psycholinguistics. Some of these seem to be the result of improvements and developments in the research methods available to psycholinguistics. One is an increased interest in detailed investigations of language in richer, more naturalistic, contexts. New research techniques such as improved methods of tracking a speaker or listener's eye movements mean, for example, that studies of dialogue, or the relationship of a speaker's production to the surrounding context, can be studied with the precision that used to be only possible in studies of isolated word recognition or sentence processing.

Improvements in the ease and accessibility of various brain-imaging techniques mean that these are being used not only as contribution to our understanding of the neural substrate of different language processes. Techniques such as ERP (event-related brain potentials) can now be used more and more as means to explore the precise time course of language processing. Newer techniques such as MEG (magneto-encephalography) are beginning to offer psycholinguists not just good information about the temporal patterns of language processing but also detailed information about the location of associated brain activity. (For more information *see* **Psycholinguistic Research Methods**.) The growing interest in the neural substrates which support language processing has received a major boost from the development of these new forms of brain imaging.

The interest in how to build neurologically plausible models was of course one of the drivers behind the expansion over the last 20 years in connectionist models of language. These have made a major contribution to our understanding of how a wide variety of language processes, such as spoken or written word recognition, might operate and be learned. The challenge in the future will be to see whether connectionist models can be implemented for more extensive language processing, such as text comprehension or contribution to dialogues. The way such models can or cannot be scaled up to simulate more complex language processing will be one of the key challenges for the next few years.

In the future psycholinguistics will also need to address its undoubted Anglocentric bias. The vast majority of studies of language processing are in fact studies of English language processing. In a number of areas a few studies are emerging which consider other languages but this effort needs to be greatly increased. Over the last 50 years psycholinguistics has expanded dramatically and made considerable progress in understanding a wide variety of language processes. With new research techniques and a more balanced research portfolio in terms of the languages studied and the research efforts applied to production as well as comprehension, spoken as well as written language, future progress seems assured.

See also: Audio-visual Speech Processing; Cognitive Science: Overview; Coherence: Psycholinguistic Approach; Dialogue and Interaction; Discourse Processing; Gesture and Communication; Pauses and Hesitations: Psycholinguistic Approach; Psycholinguistic Research Methods; Psycholinguistics: History; Reading Processes in Adults; Sentence Processing; Speech Errors: Psycholinguistic Approach; Speech Production; Speech Recognition: Psychology Approaches; Word Recognition, Written.

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Psychosis and Language

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Several psychiatric disorders are included under the broad definition of psychosis. The most common disorders are schizophrenia (which is prototypical of the psychoses), schizophreniform disorder, schizoaffective disorder, and delusional disorder (APA, 1994). These other psychotic disorders share some distinctive features with schizophrenia (e.g., a schizoaffective disorder is a disturbance in which a mood episode and characteristic symptoms of schizophrenia occur together). Furthermore, an array of psychiatric and medical conditions also presents with psychotic attributes and is often characterized by presenting typical symptoms of schizophrenia.

The contemporary consensual definitions of schizophrenia and most common psychotic disorders of the *Diagnostic and statistical manual* have resulted from more than 100 years of conceptual work. The current criteria for schizophrenia derive from the early works of Emil Kraepelin (1899), Eugen Bleuler (1911), and Kurt Schneider (1957).

Background History of the Contemporary Diagnostic Criteria for Schizophrenia, Autism, and Asperger's Syndrome

Emil Kraepelin meticulously described the symptoms of schizophrenia, which he named *dementia praecox*, referring to the disruption of emotional and cognitive features as well as to the deteriorating course of the disorder. He also tentatively proposed a pathophysiological localization, suggesting that abnormalities in the frontal lobe would be the substrate of problems with reasoning and volition, whereas abnormalities in the temporal lobe would be the substrate of delusions and hallucinations (Kraepelin, 1899).

In his conception of schizophrenia, Eugen Bleuler emphasized the importance of a formal thought disorder (disorder of associations or 'splitting'). To overcome the limitations of Bleuler's approach in the observation of the disorder, the concept of thought disorder was transformed into problems of language and communication behavior in the work of Andreasen (1979) and into disorganized speech in the criteria for schizophrenia in the *Diagnostic and statistical manual of mental disorders* (4th edition) (DSM-IV) (APA, 1994).

In the mid-20th century, Kurt Schneider (1957) described the primary disorders of the experience of thought representing the current core features of the positive symptoms. This characterization is known as the Schneiderian First-Rank symptoms, which include hearing voices speaking one's thoughts aloud, hearing voices arguing about oneself, hearing voices commenting on one's actions as they are occurring, having bodily sensations imposed from outside, attributing one's feelings to external sources, experiencing one's drives as originating from powerful outside forces, moving and acting as a result of external controls, having one's thoughts withdrawn from the mind, having one's thoughts inserted into one's mind, broadcasting of thoughts, and attributing special personal significance to one's perceptions. Schneider's symptoms were thought to be pathognomonic signs, any of which was strongly indicative of a schizophrenic disorder.

Psychosis is not a unitary concept. The 'psychotic' designation is often applied to symptom presentation that may vary considerably, both biologically and behaviorally. The wide variety of psychiatric and medical conditions that present with 'psychotic' features attests to the heterogeneity of psychotic disorders. It is now recognized that schizophrenia is at least clinically a heterogeneous disorder (Ragland, 2003), and this characteristic necessarily has an impact on the presentation of language and speech impairments that may arise from that condition.

The heterogeneity of autism is also so well acknowledged (Eigsti and Shapiro, 2003) that the term autistic spectrum disorder (Rapin and Dunn, 2003) is frequently used to describe the different extents of severe functional deficits in sociability, communicative language, imaginative play, and range of interests that principally characterize this condition as per the DSM-IV (APA, 1994).