Sentence Processing within the Competition Model

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ABSTRACT

The Competition Model was developed to account for sentence processing as well as language acquisition (MacWhinney & Bates, 1989). Based on lexical functionalism, the model assumes that language processing is an interactive process of form-function mappings mediated by competition and cooperation among lexical items. It also draws on connectionist modeling, and thus stresses the importance of frequency and the information value of linguistic input. The purpose of this paper is to review the Competition Model through a brief discussion of its main principles and empirical studies. The first part of the paper briefly reviews two major theoretical approaches in sentence processing research. In the next section, the Competition Model is presented with its theoretical background, principles, and predictions. Then, empirical studies investigating sentence processing within the model will be discussed. Finally, the paper will conclude with a discussion of methodological issues.

INTRODUCTION

The study of sentence processing seeks to understand how people rapidly analyze the structure of sentences and gain access to their meaning as a whole (Wingfield & Titone, 1998). It is concerned primarily with the dynamic process of language use (i.e., performance) rather than the abstract representation of language knowledge (i.e., competence) (Bialystok, 1990; Hulstijn, 2002). It aims to identify the mental operations responsible for the comprehension and production of sentences in real time. Of central concern is the description of how the different sources of knowledge (i.e., syntactic, lexical, pragmatic, discourse, context) interact during on-line performance in real contexts (Harrington, 2001).

As with other mental processes, determining the mechanisms of sentence processing is notoriously difficult. The data involved in sentence processing do not allow us to directly observe the mental operations. Because of this methodological limitation, it is "not possible to uniquely determine the mental structures and processes of knowledge" (Anderson, 1976, p. 15). We can only infer their existence indirectly from the subjects' behavior. This presents a great challenge to researchers who seek to establish a legitimate theoretical framework, yet at the same time develop more adequate experimental techniques (Harrington, 2001; Wingfield & Titone, 1998).

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Nonetheless, sentence processing research over the past three decades has enjoyed tremendous growth. A variety of models have been put forward to account for the complex mental processes associated with sentence processing. Representative models are the Garden Path Model (Frazier & Fodor, 1978), the Generalized Theta Attachment (GTA) Model (Pritchett, 1992), the Referential Model (Altmann & Steedman, 1988), the Constraint-Satisfaction Model (McClelland, Rumelhart, & Hinton, 1986), the Lexicalist Constraint-Based Model (MacDonald, 1997), Processability Theory (Pienemann, 1998), and the Competition Model (MacWhinney & Bates, 1989).

The aim of this paper is to review one of these theoretical models; namely, *the Competition Model* (Bates & MacWhinney, 1982, 1987; MacWhinney, 1987, 2001, 2002; MacWhinney & Bates, 1989). The Competition Model adopts a lexicalist, functionalist approach to language processing (MacWhinney, 1988), and thus lexical knowledge is emphasized as the main controller of parsing, processing, and acquisition. This basic tenet is compatible with the dominant view of current sentence processing research, which emphasizes the role of lexical knowledge in language processing (Ellis, 1998, 2002; Harrington, 2001). The model also draws on "connectionist modeling and parameterized mathematical modeling as tools to account for input driven learning" (MacWhinney & Pléh, 1997, p.70), which mirrors cognitive science's growing interest in connectionist models (Gasser, 1990). Given that current developments in linguistics and psychology allow for more theories of grammar to be built upon the lexicon through associative learning mechanisms (Ellis, 2002; Hulstijn, 2002; MacWhinney, 1997), the two fundamental assumptions of the model appear to be both important and in tune with current thinking. Hence, reviewing the Competition Model will allow a better understanding of the current research agenda in language processing and acquisition, and give insight into possible directions for future exploration.

The paper is organized as follows. First, before the specific model of interest, the Competition Model, is examined, I take a step back to briefly review the two major theoretical approaches in sentence processing research: (a) the principle-based approach, and (b) the constraint-based approach. Then, I introduce the Competition Model, and will include an extensive discussion of the theoretical assumptions and principles associated with the model. I will then discuss empirical studies investigating first language (L1)[2] sentence processing within the Competition Model framework. This section will consider both methods and findings with reference to the predictions made by the Competition Model. Finally, the paper will conclude with a discussion of methodological issues.

SENTENCE PROCESSING RESEARCH

Sentence processing research can be categorized into two broad theoretical approaches: (a) the principle-based approach, and (b) the constraint-based approach. The models differ with regard to three central assumptions (Fender, 2001; Harrington, 2001). Firstly, the research makes different assumptions as to the representation of language knowledge: *symbolic* versus *distributed* knowledge. Secondly, approaches vary in defining the degree to which syntactic

[2] There are a number of studies investigating second language processing within this framework. However, in this paper, I only focus on L1 empirical studies because the model was originally developed to account for L1 processing and the purpose of the paper is to give a broad overview of the model with reference to its key ideas and empirical support. L2 studies will be examined in a forthcoming paper.

processors interact with other sources of knowledge in real time: *modular* versus *interactive* processing. Lastly, the research takes different views on the manner in which processing is carried out: *serial* versus *parallel* processing. The following sections briefly summarize the two major approaches by focusing on these key ideas (for an extensive review of sentence processing research, see Fender, 2001; Harrington, 2001).

Principle-based Approach

The principle-based approach holds that knowledge is represented in symbolic form (Harrington, 2001). In addition, it describes knowledge of language as a distinct mental faculty, thus supporting the modular view of language (Chomsky, 1972). Within the language module, various sub-modules, such as a syntactic parser and a semantic processor, are identified. As one of the sub-modules, the language parser system exists and operates independently of real-world knowledge. A syntactic processor is solely responsible for the initial parsing of incoming word strings. Other sources of knowledge (i.e., lexical, pragmatic, real-world knowledge) become available later in the course of interpretation. Sentence processing, through means of the above mechanisms, is therefore carried out in a serial manner.

A prime example of a principle-based account is Frazier and Fodor's Garden Path Model (or the two-stage model) (Frazier & Fodor, 1978). In this model, comprehension entails two stages, and a syntactic parser is given a privileged role in the initial stage of processing. During the first stage, syntactic knowledge independently guides the initial parse of utterances, applying the incoming word strings to a general set of phrase-structure rules. In so doing, listeners attempt to interpret sentences by using the fewest phrase-structure nodes possible, which is known as the minimal attachment principle. In the second stage, thematic information is used to evaluate the appropriateness of the initial analysis.

The principle-based approach has been the dominant linguistic paradigm for language processing, providing important insights into the inner workings of the human speech processing mechanism (Fender, 2001). However, because of the highly restrictive role ascribed to lexical information, it has been seriously questioned by research demonstrating a much greater interaction among the various knowledge sources (lexical, semantic, and contextual) (Boland, Tanenhaus, & Garnsey, 1990), semantic or contextual effects on initial parsing (Tanenhaus & Trueswell, 1995), and frequency effects in sentence interpretation (MacDonald, Pearlmutter, & Seidenberg, 1994). As a result, more studies in this framework (Altmann & Steedman, 1988; Frazier & Clifton, 1996) have admitted weak interactive processes of syntactic processors with semantic and pragmatic processors. Nonetheless, the principle of syntactic autonomy has been rigidly preserved through all such models.

Constraint-based Approach

In contrast to the principle-based approach, the constraint-based approach assumes that language knowledge is distributed in an associated pattern in neural networks, rather than represented in symbolic form (Ellis, 1998; Kempe & MacWhinney, 1998; McClelland et al., 1986). In the associated patterns of networks, multiple sources of knowledge (e.g., syntactic, lexical, pragmatic, and context) interact simultaneously to constrain on-line comprehension from

the first stage of processing (Harrington, 2001). In this respect, the approach does not assume the autonomy of syntactic representations, but rather emphasizes the interactive processes of syntactic and lexical information in a parallel manner.

Influential constraint-based accounts are the Constraint-Satisfaction Model (McClelland et al., 1986), the Lexicalist Constraint-Based Model (MacDonald, 1997), and the Competition Model (MacWhinney & Bates, 1989). These models rest heavily on connectionist architecture and processing principles (McClelland et al., 1986). In this approach, sentence processing is viewed as the process of activating interconnections between units in the network, while several sources of information are concurrently activated. Connections between the information sources are weighted by incoming data, and thus language processing is tuned to input frequency (Ellis, 2002).

Recently, constraint-based theories have gained increasing support, as a growing body of empirical evidence demonstrates the early impact of various factors on comprehension. This also reflects the ongoing trend in both sentence processing research and linguistic theory that stresses the role of lexical information in language processing (Fender, 2001). Nonetheless limitations of such research have also been noted. The models in this approach have lacked an explanatory property theory, i.e., an account of grammar knowledge that explains the precise constraint mechanisms among different knowledge sources (Gregg, 2001; Harrington, 2001). Moreover, the data-driven nature of sentence processing requires frequency counts from large-scale corpora, which may be difficult to do on a practical level. Consequently, researchers have failed to make explicit predictions as to how the effects of frequency and context influence the course of online processing (Harrington, 2001).

As discussed above, current models of sentence processing are categorized into two seemingly incompatible accounts[3]. The opposition between these two approaches, nevertheless, has become a powerful driving force pushing researchers to establish more coherent accounts and clarify many issues in each approach. In addition, the conceptual and methodological tools developed in different models help enhance our understanding of language processing and acquisition (Harrington, 2001).

To date, the principle-based approach has been the dominant paradigm for studying language processing. However, there is currently an increasing amount of research, with strong empirical support, based on the constraint-based approach (e.g., Ellis & Schmidt, 1998; Kempe & MacWhinney, 1998, 1999). Moreover, there have been several attempts to integrate the two approaches[4] in the pursuit of a general cognitive theory that can encompass all aspects of language learning (e.g., Ellis, 1998; Hulstijn, 2002). This attempt to develop a unified theory of language has arisen because the strengths of each of the main approaches seem to compensate for the flaws of its counterpart. Following this line of thought, there is an urgent need to expand our knowledge of the newly developed claims in the constraint-based framework. The Competition Model, as noted earlier, is a good place from which to examine the key ideas addressed in the constraint-based approach.

[3] In fact, the theoretical assumptions of each model are far more complicated. However, a detailed explication is beyond the scope of the current paper. I refer the reader to Ellis (1998), Fender (2002), and Harrington (2001) for an extensive review of research in this area.

[4] The terms symbolist (for the principle-based approach) and connectionist (for the constraint-based approach), would be more appropriate in this broad sense (Hulstijn, 2002). However, since this paper is focusing on sentence processing, and specifically comprehension, I maintain the use of the terms principle-based and constraint-based.

THE COMPETITION MODEL

Theoretical Background

The issues that separate the different strands of sentence processing research characterize the controversy between formalists and functionalists (Bates & MacWhinney, 1982). The debate between these two schools centers on how they define the relationship between form and function. Formalists, including transformational grammarians, stress the autonomy and innateness of language forms. They are also committed to the arbitrariness of language forms with respect to function (i.e., meanings). Hence, linguistic forms are believed to be independent and irrespective of communicative functions. Functionalists, on the other hand, believe language is governed by human reason. Language forms emerge from functional pressures. They argue that functional constraints play a role in determining language forms diachronically (i.e., grammatical forms today have evolved or developed gradually from their original forms for the purpose of performing certain communicative functions) as well as synchronically (i.e., the ongoing interactions between forms and functions in real-time language use) (Bates & MacWhinney, 1982, 1989).

The Competition Model is a functionalist model (Bates & MacWhinney, 1982, 1987). As its functionalist belief is explicitly stated, "the forms of natural languages are created, governed, constrained, acquired and used in the service of communicative functions" (MacWhinney, Bates, & Kliegl, 1984, p. 128). Although it does not deny that innate biological and psychological mechanisms are responsible for language learning, the Competition Model does not assume that there is a special mental organ consisting of predetermined linguistic properties (i.e., a Language Acquisition Device, Chomsky, 1972). Instead, Bates and MacWhinney (1982) argue that language is governed by general cognition and the human mind. Since no mental organ specific to language is presupposed, the statistical and informative properties of linguistic input (i.e., frequency and information value) are of significance to language processing and acquisition.

The Competition Model adopts a minimalist approach, through which a minimal number of assumptions are made (Bates & MacWhinney, 1982, 1987). Only two levels of information structure are stated a priori: (a) a functional level where all meanings and communicative intentions are represented, and (b) a formal level where all surface features or expressive devices are represented (MacWhinney, 1987). Language acquisition and processing are viewed as the interactive processes of these two-level structures. In addition, only one major principle, cue validity, is proposed to account for language processing. Although some additional theoretical accounts (i.e., cue cost) have been elaborated, the model has maintained this parsimonious account.

Prior to further discussion, it is necessary to understand the fundamental principles of the Competition Model. These are the two-level structure of form-function mappings, competition, coalition, cue strength, cue validity, and cue cost. The following discussion addresses each of these, and follows with a summary of the predictions based on these six principles (for comprehensive accounts of the model, see Bates & MacWhinney, 1982, 1987; MacWhinney, 1987, 1988, 1989, 2001, 2002; MacWhinney & Bates, 1989).

Principles

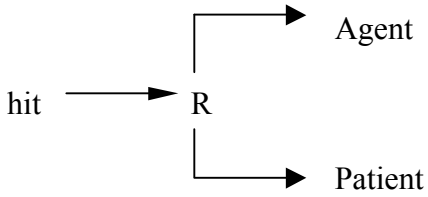
Two-level Structure of Form and Function Mappings

The first principle underlying sentence processing is the two-level system of form-function mappings. In order to understand the mechanism of form-function mappings, it may be useful to briefly sketch out the basic architecture of language assumed in the model. Influenced by a lexicalist approach (e.g., Lakoff, 1987; Massaro, 1987; Rosch, 1977; Whorf, 1956; see also MacWhinney, 1989), the core linguistic representation itself is strongly lexicalist (MacWhinney, 1988, 1989). The approach, therefore, emphasizes lexical functionalism where sentence processing is controlled by lexical items (Givón, 1979; MacWhinney, 1989). A lexical item is defined as a two-level structure of an internal function (i.e., semantic properties and concepts) and an external form (i.e., auditory properties). Learning lexical items therefore involves learning their functions and forms. For instance, through a particular experience of seeing a ball, a child creates his own individual semantic property about this object; in other words, his own unique impression about the ball. After seeing several types of balls on many different occasions, he will come to form the general concept of 'ball.'

This concept is not yet mapped onto a lexical item, but it is nonetheless developed in the child's thinking (MacWhinney, 1987). Whenever the child plays with a ball, he will hear and recognize a set of auditory segments [bɔ̃l]. As he recognizes this sound set, the child associates the semantic concept of 'ball' to its auditory properties [bɔ̃l]. In this sense, the acquisition of a lexical item is conceived of as the development of a connection between auditory properties ([bɔ̃l]) and semantic concepts (a general idea of *ball*) to a single lexical node (MacWhinney, 1987).

Lexical items are connected to other lexical items by means of role relations. For instance, the lexical item, *hit*, as the predicate, functionally specifies two arguments (nominals). The first argument is the agent who does the action (e.g., *John hits*). The second argument involves the patient, or the entity affected or changed by the hitting action (e.g., *hit the ball*). The functional connections of these lexical items then specify the roles of (a) the action and the agent and (b) the action and the patient. This can be diagrammed as follows

FIGURE 1
Relational Roles between Lexical Items
R = role
(Adapted from MacWhinney, 1987, p. 264)



As a child learns more lexical items by mapping his semantic concepts onto the auditory properties, he further develops a large set of functional associations between lexical items. These relational roles between lexical items exist at the functional level.

Language, at the surface level, has developed a way of indicating the functional relations of lexical items by utilizing surface forms such as word order patterns or morphological markings. For instance, in English, in order to indicate the agent role of a lexical item, it is often placed in the preverbal position in an utterance. In Korean, however, a subject case marker is used to express the agent role, usually in the initial position of an utterance (albeit not always). Like form-function relationships expressed among lexical items, grammar is also the mapping of relational functions (e.g., the agent role) and surface forms (e.g., the preverbal position cue or a subject case marker).

Surface forms, including word order patterns, lexical-semantic animacy, morphological markings, and prosodic cues (i.e., contrastive stress), are termed 'cues' in the model. (MacWhinney, 1982, 1992). This term encompasses any piece of information used by listeners and speakers to determine the relationship between form and meaning. According to this understanding, cues can refer to both forms and functions. For example, when the listener processes the sentence *the girls push the table*, he or she interprets *the girls* as the agent of the sentence by activating the preverbal position cue, animacy cue, agreement cue, and initial position cue. When the speaker produces the sentence *the boy is annoying the parrots*, he or she needs to think of the underlying functions of the agent 'the boy' (e.g., actor, topicality, perspective, givenness, and definiteness) as cues (MacWhinney, 1992, 2001). Since most work on the model has focused on sentence comprehension, cues generally refer to surface forms used by the listener to facilitate the activation of underlying functions.

The Competition Model posits a *direct* relation between the form and the function. That is, a given form explicitly maps onto a certain function. However, direct mappings do not mean that relationships between form and function are necessarily one-to-one. Indeed, natural languages rarely make one-to-one mappings (Bates & MacWhinney, 1981). A single form can map onto several functions, e.g., a preverbal position may connect to a topic as well as to an agent in English. A single function can also map onto several forms, as the role of an agent is often associated with the initial and preverbal positions in English. Therefore, these mappings are primarily composed of *many to many* relationships.

As previously mentioned, the child must first acquire the conceptual structure of lexical items and their relationships. In other words, before the child starts to develop the two-level structure of form-function mappings, he must first have a strong level of *functional readiness,* and already understand a large set of role relations at the functional level (Bates & MacWhinney, 1987). The notion of functional readiness therefore suggests *function-driven* learning in the initial acquisition of the language. However, the Competition Model assumes a mix of function-driven and form-driven learning (Bates & MacWhinney, 1989). For instance, when a child encounters an unknown word as in "show me *Zav*," he uses the syntactic form to deduce the meaning of the word *Zav* (MacWhinney, 1987, p.301). Form-driven learning, therefore, makes a significant contribution to language acquisition, along with function-driven learning.

Competition

Competition is held to be the processing principle that governs language processing and learning. Natural languages are characterized by a finite number of forms and an infinite number of functions. For instance, at the lexical level, there is the limited number of auditory properties available (i.e., the limited number of consonants and vowels in a language). On the other hand, there are countless semantic properties or concepts that we can create in our minds. Because of

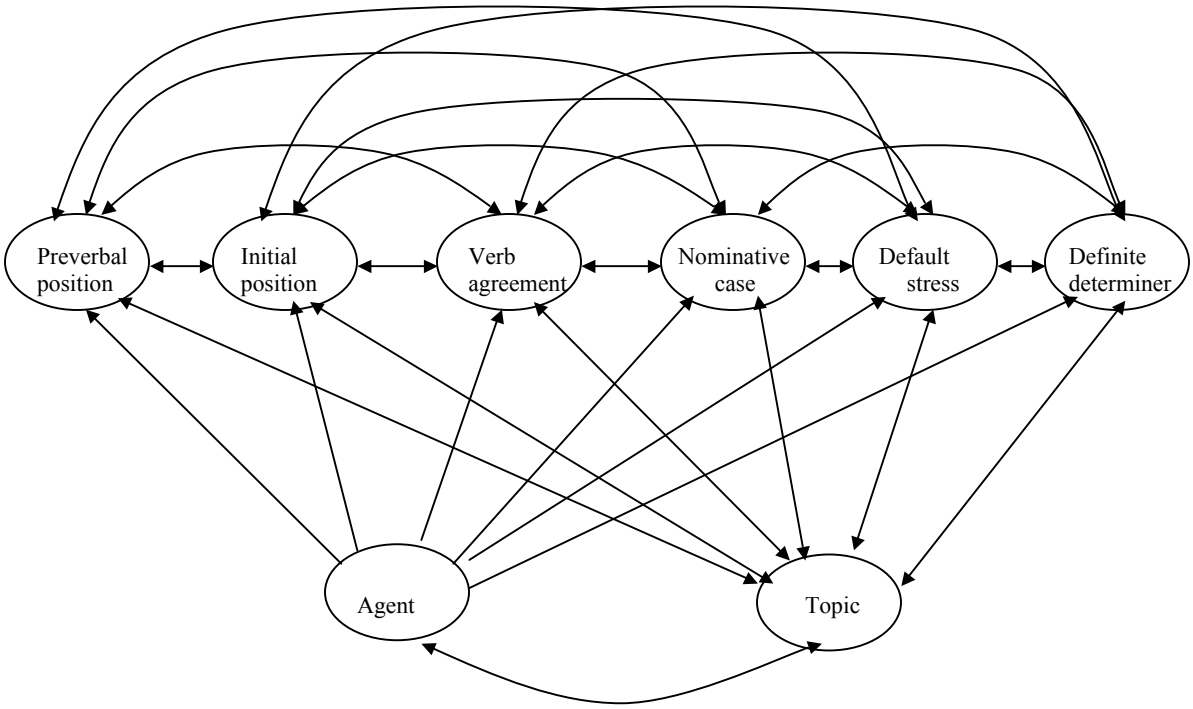
this mismatch, different semantic concepts often share with one another the same or partially overlapping auditory properties (i.e., [tu] for *two, to, too*; [mayn] as in *mine* and *minor*). When we hear [tu] in the utterance "*I went to the store*," all three semantic concepts *two, to* and *too* are activated and compete for an interpretation. In this competition, the item *to* wins because it is the only item that can be supported by the article *the*, and so the item *to* is given the greatest activation or strength.

In the same manner, the mappings between forms and functions at the sentence level involve the dynamic processes of *competition*. Lexical items can generate an unlimited number of role relational structures, whereas the surface forms available for the mapping of meanings are limited; only four forms are available (i.e., lexical items, word order, morphological systems, and intonational contours). The infinite set of functional categories, therefore, competes for control of these limited formal resources. When a certain function wins out in competition, the connection between the function and the cue is strengthened. In turn, the mapped connections between items that lose become weaker. This struggle between functions is the processing and learning mechanism that gives the model its name.

Coalition

In addition to the limited number of formal categories, our information processing system is constrained by our limited perceptual-mnemonic-articulatory resources (MacWhinney, 1987). To overcome these limitations, language is structured to maximize its efficiency by grouping related forms and functions. In other words, some functions prototypically go together (e.g., topic, agent, actor, perspective, animacy). Likewise, some forms (e.g., a preverbal position, subject-verb agreement, initial position, default stress in English) are closely related. These forms and functions again are tightly connected, thereby comprising *coalition*. Figure 2 (taken from Bates & MacWhinney, 1989, p. 48) illustrates the system of coalition. This prototypical coalition consists of a subsystem of the large network called *subject.* In this view, *subject* is not a single or unitary symbol but an associated network of many-to-many mappings between a coalition of associated functions and a coalition of associated forms (for a full psychological account, see Bates & MacWhinney, 1981, 1982).

FIGURE 2
Coalition



Cue Strength

As discussed, competition processing results in the strengthening or weakening of connections between function and form. In an associative network of form and function mappings, each link is assumed to carry a different weight or strength. The initial state of children's form-function mappings is assigned a strength value of zero. As children acquire language, they will assign strength to connections and gain more knowledge of the language system. Cue strength therefore reflects a psychological and subjective property of cue that the learner/child develops. Of course, the strength of a similar cue varies from language to language. For instance, a preverbal position in English is strongly associated with an agent, and thus it becomes the strong cue for an agent. In Italian, on the other hand, the preverbal position is more strongly associated with a topic than with an agent. Therefore, the strength of the preverbal position cue for an agent among English speakers is much greater than that among Italian speakers.

The primary determinants of cue strength are cue validity (discussed in further detail in the following section) and task frequency. The raw frequency of a task is deemed to be the most basic determinant of cue strength (MacWhinney, 2001). In this case, task refers to the identification of a relational structure (e.g., the task of determining the agent of the verb or determining anaphoric reference). Whenever we process a relational structure, the cues involved in the structure will be strengthened. Since most basic linguistic tasks are well above the threshold frequency (i.e., the frequency of task occurrence below which there is no acquisition of linguistic tasks and cue strength), task frequency is seldom addressed as an important

determinant of cue strength. However, in the case of second- or foreign-language learning, task frequency can play either a central role or become a major factor that produces a general slow-down in acquisition (MacWhinney, 2001)

Cue Validity

Cue validity is postulated as the most predictive determinant of cue strength (Bates & MacWhinney, 1989). Cue validity, a concept taken from Brunswik (1956), is an objective property of the cue. Language learning is the process by which speakers assign and adjust cue strength (i.e., an individual's knowledge of cues) according to cue validity. Bates and MacWhinney (1989) define cue validity as the product of cue *availability* and cue *reliability*. Cue availability indicates how frequently a cue is present or available within linguistic input. If a cue is always present in a task, its availability is maximally high. For instance, in English, the preverbal position cue is almost always available in a task of determining the agent of the sentence. This cue, therefore, is maximally available in English. Cue reliability represents how consistently a certain cue is mapped onto a particular form whenever it is present. If a cue always leads to the correct conclusion, it is maximally high in reliability. In most languages, case markings are maximally reliable in languages since they always indicate the same functions (e.g., nominative or accusative markers).

The Competition Model provides mathematical measures for cue availability and reliability. Cue availability can be computed as "the ratio of the cases in which the cue is available over the total number of cases in a task domain" (Bates & MacWhinney, 1989, p. 41). Reliability can be expressed numerically as "a ratio of the cases in which a cue leads to the correct conclusion over the number of cases in which it is available" (Bates & MacWhinney, 1989, p. 41). For instance, if there are 100 tasks that express the agent role relationship in Italian (e.g., an agent and a transitive verb), and 80 of these tasks have the preverbal position cue (20 tasks may reflect the omissions of subjects or imperative forms), then the availability of the preverbal position cue in this task domain is computed to be 80 out of 100, or 80%. Further, suppose 40 instances of these 80 preverbal position cues signal the agent role. Then, the reliability of the cue in assigning the agent role will be 50% (40 out of 80). Since the cue validity is the product of cue availability and cue reliability, the validity of the preverbal position cue is 40% (80/100 x 40/80).

Cue validity is further divided into *overall validity* and *conflict validity* (McDonald, 1986). Overall validity is cue validity in the general sense, as discussed above. That is, overall validity refers to cue validity, both in non-conflict sentences, where all cues available lead to the same interpretation (i.e., convergence), and conflict sentences, where cues are interpreted differently (i.e., competition). For instance, in the sentence *the boy hit the ball*, both the animacy and preverbal position cues signal 'the boy' as the agent; that is to say, cue convergence. Conflict validity, on the other hand, is concerned with cue validity only in conflict sentences. In the sentence, *the ball hit the boy* the animacy cue indicates the boy as the agent whereas the preverbal position cue signals the ball as agent, and therefore, the two cues are in competition for the agent role. In this instance, the ball is interpreted as the agent in English because the preverbal position cue is high in conflict validity. A cue high in conflict validity is usually maximally reliable. Taken together, a cue high in conflict validity becomes more reliable with more weight than a cue high in overall validity (for a full account of conflict validity, see McDonald, 1986, 1987).

In many languages, a cue high in overall validity is usually high in conflict validity. In such cases, this distinction does not make any difference in the relationship of cue validity and cue strength[5]. Yet in some languages (e.g., Dutch), cues high in overall validity are not necessarily also high in conflict validity. Put simply, some cues are used so infrequently that their availability is low. Whenever such cues are used, however, they are in competition with other high validity cues (usually for pragmatic purposes), and the rarely used cue always wins. In such a situation, the low availability cues are therefore maximally reliable with regard to conflict validity.

Conflict validity is of more importance when addressing the language processing of adults. Because children have not yet been exposed to many conflict sentences, the strength of cues in their systems are more influenced by overall validity than by conflict validity (MacWhinney, 1987). In this regard, conflict validity helps us to understand how relatively rare phenomena in a language play a role in acquisition and processing, and provides an explanation for certain late developments. A further discussion concerning conflict validity will be provided later, in the section on empirical studies.

Cue Cost

Theoretically, cue strength has direct relevance to cue validity. Yet, in our real lives, certain cues are hard to detect, or are costly to process, due to our limited working-memory and perceptual system, and also due to the cue itself. The notion of cue cost is attributed to such processing limitations (Bates & MacWhinney, 1989). The underlying assumption of cue cost is that the more difficult or costly it is to process a cue, the less reliance listeners will place upon it. Cue cost was not present in the earlier version of the model, but was added later based on the findings of empirical studies (e.g., MacWhinney, Pléh, & Bates, 1985; Kail, 1989). The model proposes two types of limitations: 1) *perceivability,* and 2) *assignability*. First, perceivability of cues denotes the degree of difficulty in detecting a cue. Some cues are inherently hard to detect (e.g., accusative *–t* after consonants in Hungarian). When a cue is difficult to detect, the initial acquisition of the cue can be markedly delayed. This construct provides a fine-grained account for a late onset of certain extremely strong cues (MacWhinney et al., 1985).

Another source of cue cost, assignability, arises from a limited working memory system. Different kinds of cues impose different processing demands. Some cues demand less information processing so these are highly assignable, while others are more taxing and thereby low in assignability (Kail, 1989). On the basis of the amount of information processing required, cues are classified into local cues and global cues (Kail, 1989). Local cues refer to cues that are involved in local processing. Local processing is "the identification and interpretation of a linguistic cue within a single lexical word without consideration of the other words in the clause" (Kail, 1989, p.97). Since a local cue can be interpreted within a single lexical word, it minimizes the amount of time that the cue must be held in working memory. This includes lexical animacy information, and case markers.

In contrast, global cues are involved cues that require "topological processing; the identification and interpretation of linguistic cues coded across words" (Kail, 1989, p.97). Examples of global cues are word order relations, suprasegmental stress patterns, as well as morphological agreement markers that span two or more items across a sentence (Kail, 1989).

[5] Therefore, cue validity and overall validity are interchangeably used in many studies based on the competition model. In this paper, these two terms are also used interchangeably.

For instance, to use the agreement cue in the third person, the child must store (a) the noun that will ultimately agree with the verb, (b) the verb itself, and (c) one or more competing noun phrases which could also agree with the verb (Bates & MacWhinney, 1989). Since global agreement cues place an overload on children with limited memory systems, children will be less likely to utilize these cues. Their initial reliance, therefore, will be on local cues. In this light, assignability is thought to directly affect cue acquisition in children. I will return to this issue when reviewing the findings of the empirical studies later.

Predictions

The Competition Model views language acquisition as the process of developing the links between forms and functions. Similarly, sentence processing is the process of activating the links between forms and functions in a network. The links are weighted according to their availabilities and reliabilities. Processing limitations (i.e., cue cost) also play a role in assigning the weights to the links. In this sense, language is not a set of properties of absolute value (i.e., grammar rules) but a set of probabilistic connections between forms and functions. Based on these theoretical conceptualizations, the model has made a number of explicit predictions regarding language acquisition and sentence processing (e.g., Bates, McNew, MacWhinney, Devescovi, & Smith, 1982; Bates & MacWhinney, 1987, 1989; Berger, Wulfeck, Bates, & Fink, 1996; Kail, 1989; Li, Bates, & MacWhinney, 1993; MacWhinney et al., 1985; McDonald 1986, 1987; Mimica, Sullivan, & Smith, 1994). The major predictions can be summarized as follows:

1. Languages differ in that
    a) different languages have different sets of cues
    b) validity of the same cue differs across languages (e.g., the preverbal position cue is maximally high in English, but low in Italian).
2. Cue validity is the primary determinant of cue strength.
    a) Both cue availability and reliability are important to child language development. The most frequent and reliable cue is first acquired.
    b) Cue reliability is the most important cue for adult speakers.
3. Cue cost operates in the acquisition of cues and their usage.
    a) A cue that is hard to hear will be acquired late.
    b) Local cues (e.g., case marking) are acquired earlier than global cues (e.g., word order).
4. There is a negative correlation between cue strength and online processing.
    a) There should be a monotonic relationship between cue strength and processing speed (i.e., stronger cues will lead to faster reaction times; weaker cues will be associated with slower reaction times).
    b) Converging cues should facilitate sentence interpretation and thus lead to faster response times than cues that occur alone or in competition with one another.
    c) Competing cues should inhibit sentence interpretation and thus lead to slower response times than cues that occur alone or converge with one another.
    d) If competition or convergence involves a very strong cue, reaction times may not be affected by the competition or convergence of other weaker cues.

EMPIRICAL STUDIES

Since the 1980s, a number of cross-linguistic studies based on the Competition Model have been conducted with both children and adults in over 15 languages. The languages studied include Chinese, Dutch, English, French, German, Italian, and Hungarian (see Appendix A for languages and studies). As discussed earlier, the Competition Model argues that cue strength (i.e., speakers' subjective knowledge about form-function mappings) is a function of cue validity (i.e., an objective property of a cue). This claim predicts that the hierarchy of cue strength in the adult native speaker should correspond to the hierarchy of cue validity in a language. It is also predicted that the order of cue acquisition in children reflects the interaction of cue validity and cost in their native language. The major focus of the early studies of the 1980s was to attest to whether cue availability (i.e., frequency) and cue reliability (i.e., consistency of information) would directly influence cue strength, and also to investigate how processing limitations (i.e., cue cost) affect processing and development. Another important prediction involves how cues with different strengths interact with one another in the case of convergence and competition. Cue interactions in collaboration and in competition are predicted to facilitate or inhibit the time course of sentence processing. To validate the predictions in this regard, studies in the 1990s and in recent years have used reaction time measures with computer presented speech (e.g., Bates, Devescovi, & D'Amico, 1999; Berger, et al., 1996; Devescovi, D'Amico, & Gentile, 1999).

Methods

The main methodology used in these studies is an agent-identification task in which the participant is presented with simple transitive sentences consisting of two nouns and a verb (e.g., the girls push the table). In the experiment, the participant's task is to decide which noun refers to the agent of the sentence. Model sentences used in these studies are constructed to represent various competing and converging combinations of cues, including word order, case-marking, subject-verb agreement, and semantic information. The following examples are typical stimuli used in the studies (taken from Devescovi et al., 1999. p.351)

TABLE 1
Orthogonal Combinations of Cues

Word order	Italian	English
NVN=noun-verb-noun	Il cane spinge il gatto	The dog pushes the cat
NNV=noun-noun-verb	Il cane il gatto spinge	The dog the cat pushes
VN=verb-noun-noun	Spinge il cane il gatto	Pushes the dog the cat
Agreement		
AG0=both nouns agree	I cani spingono i gatti.	The dogs push the cats.
AG1=first noun agrees	I cani spingono il gatto	The dogs push the cat
AG2=second noun agrees	I cani spinge il gatto	The dogs pushes the cat
Animacy		
AA=both nouns animate	Il cane spinge il gatto	The dog pushes the cat
AI=animate first noun	Il cane spinge la matita	The dog pushes the pencil
IA=animate second noun	La matita spinge il gatto	The pencil pushes the cat.

Most studies in the Competition Model framework have involved two methods: (a) the off-line measure, and (b) the on-line measure. The off-line measure refers to choice response data, i.e., counting the number of times a participant chooses the first noun as the agent. In the experiment, the participant is asked to identify the agent of the sentence, with this noun choice deemed as reflecting cue strength. For instance, in the Italian sentence *I cani spinge il gatto* (the dogs pushes the cat), there are two cues: (a) the preverbal position of the first noun (preverbal position cue), and (b) agreement between the second noun and main verb (subject-verb agreement cue). The preverbal position cue signals *I cani* (the dogs) as the agent of the sentence, whereas the agreement cue points toward *il gatto* (the cat) as the agent. If the second noun is chosen, then the agreement cue is interpreted to be stronger than the preverbal position cue. The orthogonal combinations of cues inevitably generated both grammatical and ungrammatical sentences. Although some studies have examined complex sentences (e.g., relative clauses, see Bates et al., 1999; MacWhinney & Pléh, 1988; Schelstraete & Degand, 1998), most studies have used simple transitive sentences for the task of agent-identification. As with many methodological issues in psycholinguistics, the use of ungrammatical stimuli, and a heavy reliance upon simple sentences, have been seen as the weakest points of the model. I will consider these methodological issues later.

The on-line measure assesses the time dimensions of processing by employing reaction time methods (Bates et al., 1982; MacWhinney et al., 1985; MacWhinney & Pléh, 1997; Mimica et al., 1994). In these studies, participants are encouraged to determine the agent as quickly as possible, even before the sentence is finished. The model predicts a negative correlation between cue strength and reaction time. The use of this reaction time analysis helps explore how the complex interaction between various cues unfolds on the millisecond scale.

Findings

Based on the principles of cue validity and cost, a number of hypotheses were formulated in these studies. The major hypotheses are as follows: First, the most valid cue will lead to the most consistent decisions and the most rapid reaction time. Second, given the importance of information value, adult speakers will tune into conflict validity, whereas children are more sensitive to overall validity. Next, due to processing limitations, the effects of cue cost are more evident in cue development. Finally, convergence of several cues eases sentence interpretation and speeds up processing times. Cue competition, on the other hand, inhibits processing, thereby resulting in slower reaction times. In this section, the major findings are presented with regard to cue validity (i.e., overall validity), conflict validity, availability, and cue cost. In addition, conflicting findings will be discussed.

The Role of Cue Validity

The results of most studies have supported the primary role of cue validity in cue strength (Table 2). In each study, the order of cue validity was first estimated based on written corpora. Cue validity was then tested to see whether the order of cue validity was congruent with the order of noun choices reflecting cue strength. I will briefly review the findings of the two languages primarily examined within this framework: English and Italian. Both languages have a basic word order of SVO, make case distinctions (e.g., *I* versus *me* in English), and have no

case markings on lexical nouns (e.g., nominative/accusative). English and Italian therefore belong to the same typological category. The two languages differ, however, in that Italian permits a wide array of word order variations for pragmatic purposes, whereas the SVO word order is fairly rigidly preserved in English. Italian also has a richer system of subject-verb agreement, while English only marks 3rd person singular by using *–s (she comes)*. These variations result in a different order of cue validity in the two languages. SVO word order is seen as the most valid cue in English, while subject-verb markings hold precedence in Italian. Consequently, the predominance of word order cues in English (almost always available and reliable) seems to reduce all other cues to lesser roles in sentence interpretation.[6] Although subject-agreement markings are high in cue validity in Italian, these are sometimes neutralized, meaning that the role of agent cannot be determined on the basis of the agreement cue (i.e., less available compared to word order in English). Alternatively, the second valid cue, animacy, is given a relatively high level of strength. In line with this estimation, the studies have reported that most adult English speakers rely heavily on the preverbal position, whereas the choices of adult Italian speakers reflect 1) the central role (or *key role*) of subject-verb agreement, and 2) reliance on the animacy cue. Similarly, Hungarian, Turkish, and Croatian speakers make extensive use of case markings, which reflect the order of cue validity in their languages (e.g., MacWhinney et al., 1985; Mimica et al., 1994; Slobin & Bever, 1982).

TABLE 2
Order of Cue Strength of Adult Speakers across Languages

Languages	Cue strength of adult speakers[7]	Study
Arabic	Gender agreement > case marking > animacy	Taman (1993)
Chinese	Passive marker bei > animacy > word order >object marker ba > indefiniteness marker yi	Li, Bates, & MacWhinney (1993)
Croatian	Case marking> word position (Initial position) = Gender Agreement>Animacy	Mimica, Sullivan, & Smith (1994)
Dutch	Case inflection>SVO> animacy	McDonald (1986)
English	Word order (SVO) > VOS, OSV > Case inflection> Agreement, Animacy	McDonald (1987)
French	Subject/object clitic pronoun agreement> Verb agreement> Noun animacy> Word order	McDonald & Heilenman (1991)
Spanish	Accusative preposition *a*> SV Agreement> Clitic Agreement> Word order	Kail & Charvillat, (1988)
German	Case marking> Animacy>Agreement> Word order	MacWhinney, Bates, & Kliegl (1984)
Hebrew	Object marker> Word order > Subject-verb gender Agreement	Sokolov (1989)
Hindi	Case marking	Vaid & Pandit (1991)
Hungarian	Case>SV Agreement > SVO, SOV> Animacy> V-O agreement	MacWhinney, Pléh, & Bates (1985)
Italian	SV Agreement> Clitic Agreement> Animacy>SVO> Stress, Topic	Devescovi, D'Amico, Smith, Mimica, & Bates (1998)
Japanese	Case > Animacy > SOV	Hakuta (1981, 1982)
Russian	Case marking=verb agreement> animacy> SVO> SOV > VSO	Kempe & MacWhinney (1998,

[6] It is interesting to note that in other languages, several cues make significant contributions, whereas word order is the only important cue in English (Bates et al., 1982).
[7] The order of cue strength for adult speakers mostly corresponds to the order of cue reliability in a language.

		1999)
Turkish	Case>Animacy>Word order	Slobin & Bever (1982)
Warlpiri	Case>semantics and event probability> word order	Bavin & Shopen (1989)

Findings also show that languages differ not only *qualitatively* (e.g., the types of cues) but also *quantitatively* (e.g., the degree of reliance) (Bates et al., 1999). For instance, if other cues such as agreement and animacy are neutralized in NVN word order, Italian speakers can make use of word order. However, it is expected that the degree of reliance of Italian speakers on word order is less than that of English speakers. Indeed, when English and Italian speakers were given reversible sentences[8] with a canonical word order (NVN), use of the SVO word order cue was much greater with native English speakers than with native Italian speakers (e.g., 92 % with Americans, and 71% with Italians, Bates et al., 1999). From this finding, the model argues that language knowledge is not viewed as a set of discrete and autonomous rules, but as a set of probabilistic mappings between form and meaning.

English speakers' heavy reliance on word order is also observed in non-canonical order structures (e.g., *the dog the cat chases*). Although English rigidly preserves SVO, some variations of word order in informal conversations are allowed. For instance, OSV word order is possible as in *the movie, I like,* and VOS is also permissible as in *really gets on my nerves, that guy*. In both non-canonical structures, the second noun denotes the subject or agent. The reliance on word order is further applied to these non-canonical structures, and most English speakers chose the second noun as the agent in such stimuli. That is, the majority of native English speakers interpreted NNV sentences as OSV and VNN sentences as VOS. This is termed *a second noun strategy* and it is a unique phenomenon found in English (Bates et al., 1982; Berger et al., 1996).

Furthermore, evidence of cue validity in cue acquisition casts doubt on the primacy of word order in child language acquisition (Pinker, 1981, 1982). According to the primacy of the word order hypothesis (Pinker, 1981), children learning case inflected languages, such as Hungarian, Japanese, and Turkish, will rely primarily on the canonical word order cue before they master case systems. By contrast, the Competition Model strongly considers the significant role of case markers in the language acquisition of children. In their study, Slobin and Bever (1982) show that although Turkish children learn quite early on to use the canonical word order cue (partially because of its high availability), they simultaneously make extensive use of case markers at an early age. Indeed, 2-year-old Turkish children have already reached adult levels in the use of case markers and appear to rely extensively on case cues rather than word order. Similarly, Japanese children are not particularly sensitive to word order alone and instead use case markers and word order with equal frequency when identifying the agent (Hakuta, 1981, 1982). It seems that children are sensitive to cue validity within their language, in a manner consistent with the level of importance placed on cue validity by their language. Based on these results, the Competition Model refutes the language universal perspective regarding word order and instead highlights language differences. In this respect, the Competition Model contrasts sharply with generative linguistics, which stresses the universal aspects of languages.

[8] Reversible sentences refer to those sentences in which the meaning underlying the sentence cannot be determined on the basis of the lexical items alone (e.g., the frog kissed the fly) (Hakuta, 1982, p.62).

The Role of Conflict Validity

The Competition Model originally proposed that cue validity in general (i.e., overall validity) was central to both cue acquisition in children and its use in adult language processing (Bates & MacWhinney, 1982). In a cross-linguistic study of English and Dutch, however, McDonald (1986, 1987) discovered that overall validity does not provide a sufficient account of cue usage by adults. In Dutch, noun animacy is considered to be the most valid cue (high in both availability and reliability) and was therefore predicted to control sentence processing. However, Dutch speakers appear to rely primarily on case inflection, which is not frequently used in their language, and occurs mostly in conflict sentences for pragmatic purposes (e.g., *Het boek las hij* = the book read he = he read the book). In the conflict sentences, case inflection leads to the final interpretation, thus being maximally high in terms of conflict validity. Nevertheless, the overall validity of case inflection is quite low, since case inflection in Dutch is low in availability, and cue validity is the product of cue availability and reliability. Overall validity in Dutch, therefore, is not a good predictor of cue strength. Instead, conflict validity provides us with a more accurate account. Based on these findings, McDonald (1987) has claimed that the sentence processing of adult speakers is tied to conflict validity rather than to overall validity.

Studies of French (Kail & Charvillat, 1988; Kail, 1989) have yielded similar results. In French, SV word order is a highly valid cue according to the computation of cue availability and reliability. Nevertheless, French adult speakers tend to act upon noun animacy when a SV word order is competing with noun animacy, because SV word order is low in conflict validity. French permits a variety of orders in the presence of clitic pronouns. Thus, a SV word order often competes with a clitic pronoun, and in these conflicting sentences, word order always loses. French speakers place less trust in SV word order because of its low conflict validity. Taken together, although overall validity is an important determinant of cue strength, the factor that ultimately determines cue strength for adult speakers is conflict validity. Since conflict validity is a function of reliability, cue reliability is therefore the primary determinant of cue strength among adult speakers.

The Role of Cue Availability

As has been found, cue *reliability* ultimately determines cue strength for adult speakers, and cue availability is seen to play a role only in the initial stage of acquisition. Hence, with regard to processing, the Competition Model puts more emphasis on the information value of a cue (i.e., reliability) than on cue frequency (i.e., availability). In contrast, the Lexicalist Constraint-based model has found that frequency has a pronounced effect on interpretation (MacDonald et al., 1994). Inspired by this finding, Kempe and MacWhinney (1999) closely investigated the effect of cue availability by comparing on-line processing in Russian and German. These two languages are similar in that they have an identical repertoire of case markings, and these are the maximally reliable cues (100 %) in both languages. For this reason, speakers of Russian and German behave similarly in determining agent role assignment. That is to say, the data on choices have shown that the sentence interpretations of Russian and German speakers are determined by case marking, the most reliable cue. However, the two languages differ markedly with respect to availability, in that the availability of the case marking cue in Russian is much higher than in German. This difference was expected to influence the reaction time when processing a sentence. Indeed, the results have demonstrated that Russian speakers

responded faster than German speakers. In other words, given the same reliability, higher availability shortened the reaction times of Russian participants. From these findings, it was concluded that the statistical properties of cues (i.e., frequency) can facilitate the time-course of activation during sentence processing.

In addition, cue availability is found to influence the role of other cues. In other words, if a cue is maximally reliable yet less available, the strengths of other cues in the network become relatively more important. As discussed above, in German, case marking is maximally high in reliability but low in availability. This makes German speakers rely on the cue with the second highest validity, animacy, much more than Russian speakers do (Kempe & MacWhinney, 1999). Similar findings are observed in cue development among Hungarian and Italian children. The most reliable cue in Hungarian is case marking, and in Italian it is subject-verb agreement. Case marking in Hungarian is high in both availability and reliability. On the other hand, subject-agreement cues in Italian are most reliable, but often not present, and thus low in availability. This difference makes Italian children rely on animacy cues for a longer period in their linguistic development than Hungarian children. Since case marking is overwhelmingly valid, Hungarian children at the age of 3 have already mastered the case marking system and rely little on animacy. Italian children, on the other hand, master the subject-verb agreement cue quite late (i.e., at the age of 6) and the shift from animacy to subject-verb agreement is slow due to the low availability of the agreement cue (and also partially due to cue cost effects). As the Competition Model suggests, both reliability and availability make unique contributions to sentence processing (MacWhinney et al., 1985, MacWhinney & Pléh, 1997).

The Effect of Cue Cost

The early version of the Competition Model predicted that cue validity would be the most predictive determinant of cue development in children. However, predictions based exclusively on cue validity have failed in many studies. These results are explained by processing limitations such as perceivability and assignability. In both Hungarian and Turkish, case marking is the strongest cue among adult speakers, the first cue acquired by children, and therefore the most valid cue. Despite this similarity, however, the two languages have also shown some disparity in terms of developmental pace. This difference is attributed to perceivability (MacWhinney et al., 1985; Pléh, 1989). In Hungarian, the accusative case marking –t occurs either after a vowel (e.g., pipa + t accusative) or after a consonant (e.g., mokus+t accusative). In the latter instance where the –t directly follows a dental obstruent, accusative –t becomes hard to hear and harder to produce (Pléh, 1989). Because of the difficulty caused by perceivability, the acquisition of this cue is relatively delayed in Hungarian children compared to Turkish children who do not have any difficulty in detecting the accusatives (-i, –u). A similar case occurs with Warlpiri children (Bavin & Shopen, 1989). Warlpiri uses a rich system of morphology, and thus case markings are the most valid cues. However, many of them are phonological allomorphs so they are hard to hear and low in perceivability (Bavin & Shopen, 1989). This tends to delay the acquisition of the cue, and indeed Warlpiri children, until the age of 5, rely on the animacy cue, and case marking does not yet come into play. At the age of 7, children can reach adult speaker usage of case markers.

With regard to assignability, several studies have proposed that local cues (e.g., case morphological markers) may be more easily acquired than global cues (e.g., agreement) due to greater ease of information processing (Kail, 1989; Kail & Charvillat, 1988). As shown in

Hungarian and Turkish, case markers as local cues are mastered quite early (at about 2 years of age in Turkish and 3 years of age in Hungarian). By contrast, French children younger than 6 years of age cannot or do not make consistent use of the most valid cue, morphological agreement, between a noun and a clitic pronoun. This form of agreement is high in cue validity and serves as a powerful cue to sentence meaning for French adults. Nevertheless, it is difficult to assign because the agreement cue by nature involves several processing steps. In order to use a clitic pronoun in French, children need to process the noun itself and then look for another noun that agrees with the clitic noun in terms of number and gender. It potentially demands greater information processing, and is thus low in assignability. Similarly, there are great delays in the use of subject-verb agreement (a global cue) among Italian children, despite the fact that this is the most valid and important cue in sentence processing (Devescovi et al., 1998; see also Sokolov, 1989).

Considering the profound effect of cue cost, Kail (1989) has suggested that "processing cost may be more important than cue validity in both cue acquisition and the cue usage of adult speakers" (p.112). However, McDonald and Heilenman (1991) argued against a major role for cue cost in adult processing. They showed that cue strength for adult French speakers corresponded to the transitional shifts from overall validity to conflict validity, rather than the order of cue cost. From these findings, it was concluded that the localness of a cue is not the primary determinant of strength of adult cue usage, although it may affect the developmental stages (see also Taman, 1993).

Yet, it is interesting to note that Table 1 seems to partially confirm the significant impact of cue cost on cue strength. In most languages, the hierarchy of cue strength roughly reflects the continuum from local cues (e.g., case marking) to global cues (e.g. word order). It seems that as cue cost influences the cue development of children, cue cost may have an effect on diachronic changes in cue strength. In other words, languages may have, as functionalists propose, gradually evolved to maximize their efficiency in terms of functional purposes and to overcome processing limitations. As a result, modern languages come to utilize local cues much more than global cues.

Conflicting Findings

The results from reaction-time analyses in general support the notion that competition and collaboration among cues constrain the mapping between surface forms and underlying functions. Most studies have observed slower participant responses when competing cues are processed (e.g., see Bates et al., 1982; Berger et al., 1996; Devescovi et al., 1999; Li et al., 1993). However, studies have not reached an agreement with regard to converging cues. According to the Competition Model, processing would be faster in a situation where several sources of information lead to the same interpretation. As predicted, Devescovi et al. (1996) found that convergence of word order and subject-verb agreement resulted in faster reaction times than did word order alone or with competition between the cues. Li et al. (1993) also showed that for Chinese speakers, the fastest reaction times were obtained in a convergence situation in which word order, animacy, and object marker (i.e., *ba*) cues promote assignment of the subject role to the first noun. Similarly, in a study of Hungarian (MacWhinney & Pléh, 1997), the fastest reaction times appeared in sentences where word order, case marking, subject-verb agreement, definiteness agreement, and animacy converged.

In contrast to such findings, some studies have reported that, although several cues cooperated in a sentence (by indicating that the first noun was the agent), cue convergence

actually led to a deceleration in processing. For example, Kail (1989, see also Kail & Charvillat, 1988) found that in both Spanish and French, when word order alone provides a cue, the reaction time was faster than in situations where clitic pronouns converged with the agreement cue. A similar result was obtained from the study of Croatian (Mimica et al., 1994). Croatian speakers' responses were fastest when case markers and gender agreement converged. Yet when the animacy cue was added and therefore three cues were in convergence, the responses were slower. From the findings, Mimica et al. (1994) concluded that presence of additional cues could slow processing in some instances, though they did not provide any concrete account of what these instances were. They simply described the cross-linguistic differences by stating that "as cues function differently in different languages, interaction between various cues will also vary from language to language" (p.257).

Hence, the empirical studies conducted within the Competition Model to date have not provided a unified account with regard to cue interaction. This may be due, in part, to difficulty in collecting data from large-scale linguistic corpora. Since the model emphasizes the statistical distributions of cues, the absence of accurate data from large-scale language resources does not permit explicit predictions of cue interactions. Within this model, cue interactions are the processes whereby information is transformed through incredibly complex and intricate networks, and is regulated on a millisecond-by-millisecond basis. Practically, it may not be possible to track such computational steps using current techniques. In sum, the findings of empirical studies have supported the major predictions regarding the role of statistical properties and the information values of cues. First, children from an early age are sensitive to cue availability as well as reliability. Because of children's sensitivity to availability (i.e., frequency), a cue that is high in availability and less reliable results in overgeneralization (Bates, MacWhinney, Caseli, Devescovi, Natale, & Venza 1984) Second, cue reliability is responsible for adult speakers' sentence processing, and thus cue strength in a language is a reflection of cue reliability. In this sense, part of language learning involves the transition in cue use from overall validity to conflict validity. Third, cue cost interacts with cue validity and influences the order of cue acquisition. Taken together, the first cue acquired by children will be the cue that is highly available, reliable, salient, and less costly in processing. Lastly, the results of reaction time data have failed to make explicit predictions as to how cue interactions affect the course of on-line processing.

Methodological Issues

Ungrammatical vs. Grammatical Sentences

The principle of competition involves a continual decision-making process. In the course of processing, all relevant cues are concurrently activated and compete with one another. The most strongly activated cue wins and leads to the final meaning decision. (MacWhinney, 1989). In order to validate this principle, it is crucial to test the various combinations of cues in experiments. By using a factorial design of all possible cues, the cross-linguistic studies inevitably entailed ungrammatical[9] sentences. For instance, to compare the cue strength of word

[9] In the literature, this type of ungrammatical stimuli is often referred to as *agrammatical* (i.e., where sentence construction and grammatical elements are partially changed or omitted, but content words remain intact). Here, for clarity, I will use the term ungrammatical.

order and subject-verb agreement in English and in Italian, the following sentences are generated: (a) *the cat are chasing the dogs,* and (b) *Il gatto inseguono I cani* (the cat are chasing the dogs). In this experiment, Italian participants process the grammatical sentence whereas English speakers process the ungrammatical sentence. This differential introduces an undesired element into the analysis. The use of ungrammatical stimuli has been pointed out as the weakest part of the model (Gibson, 1992; McLaughlin & Harrington, 1989).

MacWhinney and Bates also acknowledged this limitation, but justified using such methodology by introducing the Ecological Validity Hypothesis (MacWhinney et al., 1985). According to this hypothesis, the processing of ungrammatical sentences utilizes the same set of cues and processing patterns as the processing of grammatical sentences (MacWhinney et al., 1985, p.199). In response to Gibson's (1992) arguments, MacWhinney and Bates (1994) further provide five explicit justifications for ungrammatical stimuli: (a) First, the data from reaction times and choice percentages do not show a sharp discontinuity in speakers' interpretations of grammatical and ungrammatical sentences. (b) Experiments in Croatian and Hungarian (Smith & Bates, 1987; MacWhinney & Pléh, 1988) used the same syntactic form in two groups of grammatical and ungrammatical stimuli and gained nearly identical results. (c) The use of ungrammatical forms is analogous to the use of illusions in research on visual or auditory perception (Cornsweet, 1970). The same reasoning can be applied to the study of speech perception. In fact, results to date demonstrate that such ungrammatical sentences yield very systematic information about the sources of information that listeners prefer to use in their language. (d) The overall pattern of results is more important than the individual results for an individual sentence. When a large body of data shows a rich and orderly pattern, we should aim to understand these patterns, not to dismiss them. (e) Finally, many experiments within the Competition Model framework have used only grammatical stimuli. Overall, these studies have the same results and confirmed the predictions.

The Ecological Validity was, however, questioned by McLaughlin and Harrington (1989). They argued that when speakers are forced to decide the agent in a deviant sentence, such as 'the apple is eating the man', they might not process such sentences in the same manner that they would in actual communicative situations. Instead, listeners may employ a particular problem-solving strategy to obtain the meanings. The issue concerning ungrammatical stimuli is not an easy one to settle, as sentence processing is extremely rapid and its effects are highly transitory (Mitchell, 1994). Although the justifications cited in response to criticisms sound plausible, this issue will remain controversial until a more convincing methodology is developed.

Simple Sentence vs. Complex Sentence

As seen in the empirical study section, empirical support for the model is exclusively drawn from a single linguistic domain (the assignment of the sentential agent) in simple transitive sentences. Although recent studies have presented promising results for the model by examining more complex structures (e.g., relative structures) (Bates et al., 1999; MacWhinney & Pléh, 1988; Schelstraete & Degand, 1998), their major stimuli are still limited to the agent identification task. Given the complexity of language structures, the use of simple sentences makes it hard to generalize the findings to language processing as a whole. To demonstrate the full range of mental operations, it will be necessary to include a more varied set of linguistic structures and tasks.

CONCLUSION

This review has introduced the Competition Model as one potentially productive theoretical approach to language processing research, and has presented the major findings of empirical studies. The model has received limited attention in the L1 sentence processing literature, despite the number of cross-linguistic studies based on this model to date (Harrington, 2001). This is due, on the one hand, to its heavy emphasis on cross-linguistic variations in language processing, and on the other hand, to its lack of concern with ambiguity resolution tasks, which are the major focus in L1 sentence processing research (Harrington, 2001). Nevertheless, its theoretical claims and focus on cross-linguistic variations have appealed to many L2 researchers (e.g., Gass, 1987; Harrington, 1987; Kempe & MacWhinney, 1998; Sasaki, 1997; Su, 2001).

For the last 20 years or so, Bates and MacWhinney and their colleagues have investigated language processing based on the Competition Model, and have found the model productive for explaining not only the probabilistic nature of processing, but also cross-linguistic variation in sentence processing. As briefly mentioned, however, there are some obstacles that the Competition Model needs to overcome for further development. First, it must address the methodological limitations stemming from the use of ungrammatical stimuli and simple structures. Second, the empirical estimation of cue validities from a large range of language corpora should be established. Although the computation of cue validities is incredibly difficult, it is a major task facing all psycholinguists (Ellis, 1998). As part of that endeavor, MacWhinney (1991) has established the CHILDES (Child Language Data Exchange System) database. Third, the constraints operating on cue competition (i.e., the different effects of cue interactions in different languages), or the knowledge underlying cue mechanisms, need to be elaborated. Without such accounts, the notion of cue competition and interactions is vague and puzzling. Of course, no theories can provide complete descriptions of mental structures and processes, and, in fact, many theories describe fairly limited aspects of specific problems (Anderson, 1976; Bialystok, 1990). However, the theoretical principles and mechanisms that the Competition Model proposes will become increasingly important only if empirical techniques are developed that can investigate a wide range of linguistic structures and provide a detailed account of linguistic knowledge and processing.

The field of sentence processing research has generated considerable debate, as discussed earlier in this paper. Although the principle-based approach has been the dominant paradigm in this field, it seems necessary to understand language processing from a variety of different perspectives, such as the Competition Model. As Ellis suggests, “a complete understanding of language is not going to come from one discipline alone” (Ellis 1998, p.657). It is far more likely that our knowledge will be enhanced through interdisciplinary collaborations. Bialystok (1990) also proposes that the theories on different sides need to find complementary explanations for different problems, rather than competing descriptions (see also Hulstijn, 2002). Therefore, in order to understand the mental operations responsible for language processing, we should carefully investigate sentence processing from both principle-based and constraint-based approaches. Problems are likely to arise if we study accounts of language processing in isolation by completely dismissing or ignoring the opposite camp, because “theories of language acquisition are changing, and the wheel’s still in spin” (Ellis, 2002, p.658).

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APPENDIX A

Languages	**Studies**
Arabic	Taman (1993)
Chinese	Li, Bates, & MacWhinney (1993); Chen (1998)
Croatian	Mimica, Sullivan, & Smith (1994); Devescovi, D'Amico, Smith, Mimica, & Bates (1998)
Dutch	McDonald (1986, 1987); McDonald & MacWhinney (1991)
English	Berger, Wulfeck, Bates, & Fink (1996); McDonald, (1986); and many
French	Kail & Charvillat (1988); Kail (1989); McDonald & Heilenman, (1991); Schelstraete & Degand (1998)
German	Bates & MacWhinney (1981); MacWhinney, Bates, & Kliegl (1984); Kempe & MacWhinney (1999)
Hebrew	Sokolov (1989)
Hindi	Vaid & Pandit (1991)
Hungarian	MacWhinney & Pléh (1988, 1997); MacWhinney, Pléh, & Bates. (1985); Pléh (1989)
Italian	Bates, Devescovi, & D'Amico (1999); Bates & Macwhinney, (1981); Bates, MacWhinney, Caselli, Devescovi, Natale, & Venza (1984); Bates, McNew, MacWhinney, Devescovi, & Smith (1982); Devescovi, D'amico, & Gentile (1999); MacWhinney, Bates, & Kliegl (1984)
Japanese	Hakuta (1981, 1982[10])
Russian	Kempe & MacWhinney (1999)
Spanish	Kail & Charvillat (1988); Kail (1989)
Turkish	Slobin & Bever (1982)
Warlpiri	Bavin & Shopen (1989)

[10] In fact, Hakuta did not specify the Competition Model in the studies. Yet he assumed the same theoretical assumptions (form-function mappings) and used the same methods (the agent identification tasks using simple sentences) as those of the Competition Model.