

The Role of Cognitive Control in Language Comprehension

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Abstract

Successful language comprehension involves complex higher-order processing that must function fluidly in real time. While progress has been made in understanding the foundations of language processing, the mechanisms underlying the dynamic higher-order aspects of comprehension remain somewhat of a mystery. This review proposes that these higher-order aspects of language comprehension depend on cognitive control mechanisms. Specifically, the two components of cognitive control, conflict monitoring and intentional control, contribute distinctly to language comprehension. Conflict monitoring is necessary for recognizing linguistic ambiguities and attending to errors in interpretation; control works to suppress irrelevant information and engage correct interpretations. By examining the effect of cognitive control on language processing in light of these two components, this review provides a perspective that can offer novel insights into interventions for linguistic difficulties.

The Role of Cognitive Control in Language Comprehension

On average, an individual speaks approximately 16,000 words every day (Mehl, Vazire, Ramirez-Esparaza, Slatcher, & Pennebaker, 2007). Somehow people are able to understand and communicate meaning, both simple and profound, by way of these verbal symbols that are combined to form coherent narratives. How we are able to process meaning through language is a significant question that various lines of research have attempted to address (e.g., Demichelis & Weibull, 2008; Glenberg & Robertson, 2000; Koelsch et al., 2004). Perhaps one of the most intriguing aspects of the use of language is how we are able to dynamically receive and interpret information in real time, often while simultaneously preparing a response. This ability to monitor incoming information and appropriately attend to what is relevant lies at the heart of communicating through verbal language (Carroll, 2008).

While language comprehension is usually a fluid and successful process, this process can fail to take place normally in some individuals. For example, aphasias are neurological disorders resulting from brain damage that cause language impairments (Rosen et al., 2000). People with aphasias can have difficulties using the correct word for an idea, understanding speech, or speaking at all (Damasio, 1992). Autism spectrum disorders—characterized by social impairment, stereotyped behaviors, and communication problems—represent another class of disorders characterized by language deficits (Wisdom, Dyck, Piek, Hay, & Hallmayer, 2007). Approximately six out of 1,000 people currently have an autism spectrum disorder, and, by definition, suffer from linguistic or communication difficulties; many are even nonverbal (Boucher, 2012). Similarly, schizophrenia—a disorder characterized by delusions, disorganized behavior, and unusual perceptions—affects around 1% of the general population, and some argue that language deficits represent a core symptom of schizophrenia (e.g., Barch & Caesar, 2012).

The language impairments in these and many other disorders have various negative effects on individuals' daily lives—related to academics, vocations, self-esteem, and social relationships, for example (Clegg, Hollis, Mawhood, & Rutter, 2005; Johnson, Beitchman, & Brownlie, 2010). There is thus a pertinent need for interventions to improve linguistic abilities in order to address these significant difficulties. Such interventions might be informed by an advanced understanding of some of the underpinnings of language processing.

One such underpinning of language processing may be cognitive control. The concept of cognitive control is somewhat elusive, yet it has a central role in our ability to conduct higher-order thought processes. In the most general sense, “cognitive control” can refer to any controlled process—in other words, any information processing that entails effortful, conscious attention. More precisely, cognitive control is the modulation of thoughts or actions for the sake of long-term goals (Miller, 2000). It is comprised of two basic components, which function harmoniously to accomplish this process (Botvinick, Braver, Barch, Carter, & Cohen, 2000). First is the conflict monitoring element, necessary for recognizing errors or conflicts that arise and registering the need for control. Second is the intentional control element, which involves the act of changing behaviors and thoughts in response to the perceived need for control. Inherent in the concept of cognitive control is a critical flexibility (Rougier, Noelle, Braver, Cohen, & O'Reilly, 2005); monitoring incoming information and altering behaviors in response requires a high degree of flexibility in order to be successful. The evaluative, adaptive process of cognitive control shares striking similarities with the dynamic process of communication through verbal language.

How, specifically, are cognitive control and verbal communication related? This question could be investigated from numerous directions, and to explore the relationship fully would take

considerable search. To narrow this discussion to a feasible scope, this paper does not address the specifics of language production, but focuses distinctly on the relationship between language perception and cognitive control. This paper proposes that cognitive control contributes to language perception in two essential ways: by allowing individuals to dynamically attend to relevant information and to revise misinterpretations through both conflict monitoring and intentional control. Each of these two chief constituents of cognitive control has a clear role in the mechanics of language perception. The conflict monitoring component of cognitive control enables real-time corrections of misinterpretations in language perception. The intentional control component allows for deliberate suppression of irrelevant language information and for attending to language input that is germane.

To consider the effect of cognitive control on language in light of these two categories, this paper will review the literature on cognitive control's relation to language, looking specifically for ways to interpret the findings within this theoretical framework. This review will first examine those articles that fall under the conflict-monitoring category of cognitive control. This will be followed by those articles that discuss intentional control. The main findings relating language perception to these two realms of cognitive control will then be summarized. Additional means by which cognitive control affects language certainly exist; these will be touched on briefly to provide a more balanced perspective. This review will present its limitations, including findings that are not adequately addressed by the thesis. Finally, the review will explore ways that this theory can be applied to interventions for language difficulties, and address additional implications for further research.

Review

Conflict Monitoring

In order to successfully adjust thoughts and actions in service of long-term goals, it is necessary to be alert for conflicts that arise (Botvinick, Braver, Barch, Carter, & Cohen, 2000). The conflict monitoring aspect of cognitive control is what begins the process. Individuals must be aware of when attentional adjustment is required in order to be able to achieve favorable outcomes and avoid negative results. It is thought that the anterior cingulate cortex (ACC) comprises the core neural basis of conflict monitoring (MacDonald, Cohen, Stenger, & Carter). This is based on findings that activity in the ACC relates to overriding prepotent but irrelevant responses (Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003), choosing between multiple valid responses (Barch, Braver, Sabb, & Noll, 2000), and the detection and anticipation of errors (Carter et al., 1998; cf Botvinick et al., 2000). Conflict monitoring likely serves many purposes in language comprehension. For listeners to understand language properly, they must realize when to inhibit incorrect interpretations of words or sentences (Gernsbacher & Faust, 1991), avoid attending to irrelevant information (Lorsbach, Wilson, & Reimer, 1996), and even consider ways in which they might have misunderstood a message when there is confusion (Ferreira & Patson, 2007). Comprehending verbal language thus relies heavily on the ability to monitor for errors. This review now turns to empirical articles that speak to the role of conflict monitoring in language production.

Choi and Trueswell (2010) conducted a study that related children's difficulties revising language misinterpretations to cognitive control. They used garden paths—sentences that begin by sounding as if they should be interpreted one way, which turns out to be incorrect—in order to investigate whether cognitive control is truly the driving force behind overcoming these

automatic yet incorrect language interpretations. A previous study by Novick, Trueswell, and Thompson-Schill (2005) indicated that children's difficulties in overriding automatic interpretations might be due to an immature cognitive control system. Choi and Trueswell note, however, that this study does not rule out the fact that children tend to rely on verb information over contextual information in interpreting sentences. They investigate this alternative explanation by repeating the garden path experiment in Korean—unlike English, Korean is a verb-final language. If children's difficulty overriding misinterpretations was in fact due to a developmental pattern relating to cognitive control deficits, the Korean participants would exhibit the same difficulty. If the problem was simply due to reliance on the verb cue and its position in the sentence, Korean children would be capable of overcoming earlier interpretations when they reach the verb at the end of the sentence. The authors found that even when encountering critical information from the verb at the sentence's end, children were reluctant to change their previous interpretations. Thus reliance on the verb's significance over contextual cues was not the issue; if so, there would not be this obstacle in revising earlier responses. Choi and Trueswell hold that it is indeed the lack of a fully developed cognitive control system that leads to children's common inability to revise earlier misinterpretations, even when they encounter disambiguating evidence at the end of the sentence.

Having the ability to override a previous interpretation of a sentence relates to cognitive abilities in general. Examining the skill of overriding previous interpretations, though, reveals that it depends heavily on the conflict monitoring aspect of cognitive control. Successful revision of previous interpretations requires that the individual be attentive to the influence of additional information (Haviland & Clark, 1971). Possible incompatibilities of previous ideas with new cues must be watched for, despite already holding an interpretation in mind. Even more, the

listener must sometimes accept the insufficiency of the previous idea and realize that revision is needed. This study demonstrates conflict monitoring in a quite tangible sense—the varying interpretations of a sentence’s meaning are examples of conflicting information that the listener must handle. This is a skill often needed in the domain of language, beyond garden path sentences. When an individual receives verbal communication, errors must be recognized and addressed as they come up.

Another study revealing evidence of conflict monitoring ability contributing to language perception looked specifically at contextual sensitivity. Khanna and Boland (2010) were interested in how young children employ contextual information in resolving lexical ambiguity; the authors sought to discover whether children differ from adults in this ability and, if they do, possible reasons for the distinction. Khanna and Boland approached the question through two experiments. Participants experienced several trials; in each, they were presented with an auditory prime and homophone, and they attempted to read the correct target word as quickly and accurately as possible, based on the context of the prime. The authors used naming latencies to measure the ability of participants to successfully utilize contextual information in resolving ambiguity. In the first experiment, there were priming effects in older children and adults on responding with the correct target, if they were told that the context was relevant. Younger children had no priming effects. In the second experiment, the authors found that children’s ability to use context in choosing the correct target was predicted by cognitive control abilities; this finding was not mirrored in adults because the paradigm was modified into a simpler task in order to capture difference in the younger children, and adults were thus successful due to reasons other than cognitive control. Children were given a variety of cognitive tasks; the key finding in the second experiment was that working memory and purported inhibition both

explained unique variance in the ability to use context when resolving ambiguity. The role of working memory in language perception will be addressed in the next section of this paper.

Khanna and Boland counted children's response times on go trials in the Go/No-Go task as index of inhibition; however, experiments have shown that this variable can more accurately be categorized as a measurement of conflict monitoring, as greater successful Go reaction times relate to greater ERP indices of conflict monitoring (Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003). Conflict monitoring, then, explains unique variance in the ability to utilize context in resolving lexical ambiguity. This finding makes clear the significance of the conflict monitoring component of cognitive control in language perception. Lexical ambiguity arises naturally during verbal communication; heeding ambiguity as evidence for possible misinterpretation, though, is crucially reliant on conflict monitoring. Attending to contextual cues via conflict monitoring is thus essential for adequate language perception.

A fitting demonstration of the process of revising a misinterpretation during language comprehension is seen in a study by Knoll, Obleser, Schipke, Friederici, and Braurer (2012). In this study, the authors examined the neural basis of German children's syntactic processing of ambiguous sentences. The authors explain that German speakers have certain cues regarding how to understand syntactic meanings; the word-order cue takes priority over the case-marker cue. Thus, the dominant understanding of an object-initial sentence will attribute the subject's role to the object; only when secondarily recognizing the case-marker cue will the listener realize the error of that interpretation. Knoll et al. investigate this reinterpretation in German preschool children, in order to discover which brain regions are at work in this process.

This study's protocol took place in two parts. First, the authors used fMRI scans of German preschool children and found that they were able to understand object-initial sentences,

indicating that their brain activity could reliably reflect understanding of these sentences. The fMRI findings were used to determine the neural basis of the reinterpretation that is necessary for correct understanding of object-initial sentences.

One relevant finding of this study was that across all participants, ACC activation predicted word order. In other words, for all children, activation in the ACC rose for object-initial sentences in comparison to subject-initial sentences; it differentiated between the sentence types. This activity reveals a meaningful distinction in how the ACC responds to the sentence types, rather than resulting from basic sentence processing or grammatical understanding, as might be the case in the absence of a significant difference. Because the ACC has been shown to be the primary region in conflict monitoring, this study helps affirm the role of conflict monitoring in resolving lexical ambiguity and revising interpretations. The differing activity of the ACC depending on sentence type shows that it seems to be responsible for the conflict monitoring activity. In addition to its role in revising misinterpretations, as mentioned earlier, conflict monitoring is activated when recognizing dissonance between various thoughts or incongruity between expectancies and results. Each of these instances occurs in the setting of language perception. As in this study, listeners must notice and deal with incongruities in order to gain proper understanding of the message; it is through this use of conflict monitoring that individuals were able to proficiently override misinterpretations to derive the correct meaning

Intentional Control

As stated earlier, the second aspect of cognitive control is the control part itself (e.g., MacDonald, Cohen, Stenger, & Carter, 2000). While the conflict monitoring component is crucial for recognition of when cognitive control processes should be initiated, the aspect that does the initiation of action is intentional control. This element is what actually alters thoughts or

behavior in service of long-term goals (Botvinick, Braver, Barch, Carter, & Cohen, 2000; Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004). When faced with environmental distractions, temptations, and other stimuli, intentional control works to inhibit irrelevant information and maintain goals. Though usually considered a voluntary or effortful process, control is not always a wholly conscious choice.

One study that demonstrates the importance of this intentional control component for language comprehension was performed by Engel de Abreu, Gathercole, and Martin (2011). They sought to establish the relationship between working memory and language, specifically with the intention of controlling for cognitive control—which previous studies on the link between working memory and language had failed to do. The authors investigated two factors of working memory—short-term storage and cognitive control—and explored how each of these factors specifically relates to language.

The study involved 119 kindergarten age participants. Participants were assessed on measures of complex span, simple span, fluid intelligence, vocabulary, rhyme awareness, syntax, and reading. Using structural equation modeling, the authors found that syntax and reading abilities were predicted by the cognitive control aspect of working memory, and vocabulary was related to the verbal short-term storage aspect of working memory. Importantly, the authors found that the capacity for controlled, or regulative, processing fully accounted for the role of cognitive control in links between working memory and language. This study thus demonstrates the significance of the intentional control aspect of cognitive control in regards to language comprehension, as syntax and reading skills were strongly tied to this control. Also important to note is the fact that many of the associations between working memory and language that have

been found in previous literature (e.g., Gathercole & Baddeley, 1993) can in fact be understood to be mediated by cognitive control (cf Daneman & Merikle, 1996).

An example of intentional control being responsible for working memory effects on language is seen in the aforementioned study by Khanna and Boland (2010). As stated earlier, they found that working memory predicted children's ability to use context in resolving lexical ambiguity. This is a fitting example of the role of control in mediating the effect of working memory because, more than just holding information in memory, children were attending to material that they gained from the syntactic context; they were thus employing intentional control to heed relevant information.

One way in which a listener picks up on meaning in a sentence is through lexical association, such as between the words "bread" and "butter Boudewyn, Long, and Swaab (2012) conducted a study seeking to understand how individuals rely on lexical associations in processing meanings of words. Participants were given three measures: a listening span to measure working memory, a modified Stroop task to measure cognitive control, and the Nelson-Denny to measure reading skills, to account for individual differences in data. To measure sensitivity to lexical association, the authors used Event Related Potential (ERP)—a method in which EEG measures an individual's brain activity in response to the same stimulus given multiple times. Activity that is common throughout trials can then be averaged out, so that what remains is the relevant brain wave (cf. Kutas & Federmeier, 2000).

Boudewyn, Long, and Swaab (2012) found no effects of working memory on lexical association. However, their measure of cognitive control predicted sensitivity to lexical association in that higher cognitive control abilities were associated with less sensitivity to lexical association. The findings regarding cognitive control were explained in terms of

suppressing irrelevant information in order to attend to relevant information. This finding relates to the significance of regulatory control because those with higher control abilities were better able than those with lower control abilities to suppress irrelevant information, and thus did not get distracted by lexical associations that were irrelevant in the bigger syntactic picture. Capacity to attend to relevant information and disregard noticeable but irrelevant information is what allows an individual to choose the correct interpretation of a word and thus communicate successfully in real time.

After finding these results on cognitive control and working memory, Boudewyn, Long, and Swaab (2013) conducted another study, seeking to expand their findings to discourse processing. Because the authors did not find an association between working memory and lexical association in the previous study, they hypothesized that working memory would be associated with sensitivity to discourse congruence—as listening to discourse naturally involves holding more information in storage than listening to a single sentence does (Sachs, 1967). They also expected an association between cognitive control and lexical association, parallel to the previous finding, as well as a possible association between cognitive control and discourse processing.

As in their previous study (2012), Boudewyn, Swaab, and Long (2013) used ERP to determine sensitivity to the information of interest—in this case, lexical association and discourse congruence. Participants also completed behavioral testing measures—a behavioral battery, a listening span, and a modified Stroop task. The listening span measured individuals' maintenance abilities (Osaka et al., 2003), while the modified Stroop measured suppression abilities (Polk, Drake, Jonides, Smith, & Smith, 2008). The findings of this study were unexpected; unlike in their previous study (2012), the measure of cognitive control used by

Boudewyn, Long, and Swaab (2013) was not associated with sensitivity to either lexical association or discourse congruence. Also contrary to the previous study, working memory was here associated with sensitivity to lexical association. Important to this review, there was a difference in how individuals with high and low listening span processed discourse in that different areas of the brain were involved.

One explanation for the lack of association between cognitive control and either lexical association or discourse congruence is that the measure for cognitive control—the modified Stroop—did not convey the relationship. Individuals could have used a different strategy on the Stroop task in this study than in the previous one. The modified Stroop task might also not be the proper measure for displaying the aspects of cognitive control involved in language comprehension. As far as the association between working memory and lexical association, the authors' use of prime-target pairs within discourse involves added maintenance of information; thus controlled maintenance of information over time was especially relevant to the setting of lexical associations in this study. Finally, the distinction between brain areas involved in discourse processing in those with high and low listening span reveals the significance of working memory on language processing. The authors found that participants with higher listening span displayed larger effects of discourse congruence in right hemisphere areas, which has been related to complex linguistic understanding. Thus the association of working memory with discourse processing involving certain brain areas reveals importance of working memory in understanding complex language. As noted earlier in this review, working memory's language effects can be understood to be mediated by cognitive control (Engel de Abreu, Gathercole, & Martin, 2011; listening span performance has also been specifically linked to activity in the ACC

and other cognitive control-related areas, see Osaka et al., 2003). It is clear, then, that cognitive control processes are foundationally related to complex linguistic processing.

Discussion

Language processing appears to rely heavily on the use of cognitive control; the ways in which cognitive control benefits language comprehension can be understood within the context of conflict monitoring and regulatory control. Recognizing misinterpretations in spoken and written linguistic messages depends on constant conflict monitoring (e.g, Ye & Zhou, 2009; van Herten, Chwilla, & Kolk, 2006). Control is necessary for disregarding irrelevant semantic information and engaging appropriate meanings (Rodd, Johnsrude, & Davis, 2010; cf. Egner & Hirsch, 2005; Zanto & Gazzaley, 2009). This perspective is supported by the literature outlined here and may lead to novel interventions for language difficulties.

It is important to note that there are alternative ways in which cognitive control may relate to language. Some argue that deficits in cognitive control actually benefit language, specifically regarding language acquisition. Chrysikou, Novick, Trueswell, and Thompson-Schill (2011) argue that a lack of cognitive control allows for data-driven rather than rule-based processing, which they say is beneficial in acquiring a language. While this approach is quite distinct from the perspective of this review, both have valuable insights. Perhaps children successfully acquire language because of an underdeveloped system of cognitive control, and the fully functioning control that comes later in life then allows for the complex use of that language.

Another approach to the relationship of cognitive control and language is seen in a study conducted by Novick, Trueswell, and Thompson-Schill (2005; cf. Novick, Trueswell, & Thompson-Schill, 2010). These authors argue that the left inferior frontal gyrus, a brain region commonly thought to support language, is actually better understood in terms of supporting

cognitive control, as lesions in this area produce deficits in cognitive control. In this perspective, rather than aspects of cognitive control supporting linguistic abilities, language itself is seen as a form of cognitive control. Future research should investigate this relationship further in order to determine which theory is best supported.

Several studies have found a link between bilingualism and cognitive control in that individuals who are bilingual tend to be better at cognitive control tasks than monolingual individuals (Colzato et al., 2008; Bialystok, Craik, Klein, & Viswanathan, 2004; Garbin et al., 2010). This finding represents another perspective of the relationship between cognitive control and language; it is thought that bilingual individuals utilize control in language situations because they repeatedly switch between languages and maintain the proper use of one language at any given time (Colzato et al., 2008; Garbin et al., 2011). It seems that cognitive control is thus improved through relevant linguistic processing, demonstrating that the relationship between cognitive control and language can be bidirectional.

This review does suffer from a few apparent limitations. In examining the effect of cognitive control on language, it did not touch on the area of language production. Comprehension and production are closely related, and omitting one while investigating the other has the possibility of obscuring important details. A second limitation concerns the breadth of this review. To the author's knowledge, there is not an abundance of literature on the benefits of cognitive control in language—though the inverse is certainly true. It may be premature, then, to develop a theoretical model of this relationship. However, the model proposed herein does seem to be an appropriate fit with the current literature.

Given the influence of cognitive control on processes that are critical to linguistic processing, it would only be right to apply this model to benefiting language abilities.

Specifically for individuals with linguistic difficulties, the knowledge of some of the foundational processes of language can improve communication in concrete ways. For example, interventions aimed at improving communication troubles in people with autism spectrum disorders or schizophrenia might incorporate this perspective through training that targets cognitive control (e.g., Novick, Hussey, Teubner-Rhodes, Harbison, & Bunting., 2013).

If conflict monitoring is as relevant to interpreting messages as this review holds, it could be predicted that linguistic tasks might produce various indices of cognitive control. When an individual hears a garden-path sentence, for instance, researchers might expect to see an ERP signature of conflict monitoring, such as the N2 potential. Additionally, if the use of context in resolving ambiguity depends on regulative control, this can be tested by studying activity in brain regions involved in regulative control, such as the dorsolateral prefrontal cortex, during comprehension of ambiguous sentences. Many other experiments can be done in order to further investigate the particularities of this theory.

Verbal communication is immeasurably important, and individuals who face linguistic obstacles have pervasive difficulties in many aspects of life. Cognitive control relates to language processing because of its role in higher-order processes; this paper investigated cognitive control and language in order to heighten understanding that has direct applications with individuals suffering from language disorders. This paper sought to examine the effects of cognitive control on language through a model involving the two distinct components of cognitive control. Specifically, the conflict monitoring component of cognitive control works to maintain the goal of understanding in language, such as by attending to possible errors of interpretation and by recognizing ambiguities. The intentional control component handles the regulative processes that are needed, such as suppressing irrelevant contextual information and

other irrelevant stimuli, and using context to resolve ambiguity. Alternative ways to understand the relationship of cognitive control to language involve viewing language as a type of control and viewing language skills as influential to cognitive control; neither are necessarily opposed to this paper's approach. Further research can aim to illuminate the details of the model proposed herein by studying activity in brain regions involved in control processes. Extensive applications of this model are possible; essentially, interventions aiming to improve language skills can incorporate cognitive control training in order to address linguistic issues on a fundamental level. Understanding cognitive control's role in language through the approach of this paper thus has the possibility of helping refine theoretical knowledge and result in concrete applications in the realm of language disorders.

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