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# Executive function and intelligence in the resolution of temporary syntactic ambiguity: an individual differences investigation

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## Abstract

In the current study, we examined the role of intelligence and executive functions in the resolution of temporary syntactic ambiguity using an individual differences approach. Data were collected from 174 adolescents and adults who completed a battery of cognitive tests as well as a sentence comprehension task. The critical items for the comprehension task consisted of object/subject garden paths (e.g., *While Anna dressed the baby that was small and cute played in the crib*), and participants answered a comprehension question (e.g., *Did Anna dress the* baby?) following each one. Previous studies have shown that garden-path misinterpretations tend to persist into final interpretations. Results showed that both intelligence and processing speed interacted with ambiguity. Individuals with higher intelligence and faster processing were more likely to answer the comprehension questions correctly and, specifically, following ambiguous as opposed to unambiguous sentences. Inhibition produced a marginal effect, but the variance in inhibition was largely shared with intelligence. Conclusions focus on the role of individual differences in cognitive ability and their impact on syntactic ambiguity resolution.

### Keywords

Executive function; Intelligence; Syntactic ambiguity resolution; Individual differences; Garden-path sentence

In this study, we examined the role of executive function and intelligence in syntactic ambiguity resolution. A commonly reported finding is that readers often retain the garden-path misinterpretation in the final representation derived from many temporarily ambiguous sentences (Christianson, Hollingworth, Halliwell, & Ferreira, 2001; Engelhardt, Ferreira, & Patsenko, 2010; Ferreira, Christianson, & Hollingworth, 2001; Patson, Darowski, Moon, & Ferreira, 2009; Van Gompel, Pickering, Pearson, & Jacob, 2006). The finding that readers

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only partially reanalyse garden-path sentences has led to a view of comprehension in which people develop shallow and superficial representations, which is referred to as good-enough comprehension (Ferreira, Bailey, & Ferraro, 2002; Ferreira, Engelhardt, & Jones, 2009; Ferreira & Patson, 2007; Sanford & Sturt, 2002; Sturt, 2007). The good-enough view of language comprehension is based on a central assumption of resource limitation, and it suggests that when confronted with difficulty, participants will adopt an effort-conservation strategy in which time and processing effort may be curtailed (Czerlinski, Gigerenzer, & Goldstein, 1999; Gigerenzer, 2008; Gigerenzer & Goldstein, 1996; Gigerenzer & Selten, 2001; Tversky & Kahneman, 1974). However, within a resource-limitation perspective, it is not entirely clear how individual differences affect the generation of good-enough representations. Previous work has generally assumed that individuals with lower abilities should be more even more susceptible to garden-path errors (Christianson et al., 2001; Ferreira, 2003). However, if flexible strategies and good-enough processing are adaptive, then perhaps the reverse might be true. That is, individuals with higher cognitive abilities may also commonly show the types of errors that have been associated with good-enough processing, particularly if success on the task does not depend on accurate comprehension. Therefore, the main goal of this investigation was to further understand the relationship between individual differences and ability to overcome (or revise) syntactic ambiguities.

## Executive functions

The most commonly postulated executive functions are inhibition, set shifting, and updating/retrieval from working memory (P. W. Burgess, 1997; Denckla, 1996; Miyake & Friedman, 2012; Miyake et al., 2000). These abilities are believed to be general-purpose control mechanisms that regulate everyday behaviours and underlie performance on many, if not all, complex cognitive tasks (P. W. Burgess, Alderman, Evans, Emslie, & Wilson, 1998). A large literature has focused on how executive functions are related to one another and how they relate to different types of intelligence (for an overview see Friedman et al., 2006). In general, executive functions tend to correlate with one another, and they also correlate with intelligence (Ackerman, Beier, & Boyle, 2005; Ardila, Pineda, & Rosselli, 2000; Blair, 2006; Dempster, 1991; Larson, Merritt, & Williams, 1988; Logan, 1985; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001; Teuber, 1972). There are a couple of points that can be made in summarizing the literature on executive functions and intelligence. The first is that there is both shared and unique variance (i.e., general mental abilities are correlated with one another but at the same time dissociable). The second is that executive functions represent specific low-level control mechanisms (Miyake et al., 2000), whereas intelligence represents functioning across much wider and broader neural networks (Gray, Chabris, & Braver, 2003). The theoretical model of intelligence that we subscribe to is the three-stratum theory of intelligence (Carroll, 1993), which was based on a comprehensive survey of factor-analytic studies (see also, Bates & Stough, 1997; Deary, 2001). In this theory, *g* is represented as the highest level (Spearman, 1927). Within Stratum 2, there are eight broad-based factors, including (for our purposes) fluid intelligence, crystallized intelligence, and speed of processing. The bottom stratum encompasses even narrower abilities, which map onto those assessed by various intelligence tests (e.g., the Wechsler Intelligence Scales).

One of the most comprehensive investigations of the relationship between executive functions and intelligence was conducted by Friedman et al. (2006). They reported that working memory ability is highly predictive of both fluid and crystallized intelligence (both βs > .74) (see also Colom, Rebollo, Palacios, Juan-Espinosa, & Kyllonen, 2004). In contrast, inhibition and set shifting share much less variance with intelligence (both βs < .30). In a more recent paper, Miyake and Friedman (2012) proposed a theory called the unity–diversity framework, which specifically addressed the issue of shared and unique variance in executive functions (see also, Duncan, Johnson, Swales, & Freer, 1997; Long & Prat, 2002; Teuber, 1972). In short, the unity–diversity framework assumes that inhibitory control represents shared variance with other executive functions and that there is no "unique" variance associated with inhibition. Updating working memory and set shifting, in contrast, both have unique and shared variance.

## Sentence comprehension and executive function

The most extensively studied executive function in relation to sentence comprehension is working memory, which is typically measured with some version of the reading span task (Baddeley, 1986, 1996; Baddeley & Logie, 1999; Caplan & Waters, 2002; Daneman & Carpenter, 1980; Kane et al., 2004; MacDonald & Christiansen, 2002; MacDonald, Just, & Carpenter, 1992; Waters & Caplan, 2001). Much of this research has focused on whether the memory resources underlying language comprehension are domain-specific (Just & Carpenter, 1992) or domain-general (e.g., Fedorenko, Gibson, & Rohde, 2006). Some studies have not found overlapping variance between sentence comprehension measures and domain-general working memory, which is consistent with the idea that the memory system underlying language comprehension is inherent to the architecture of the comprehension system (Baddeley, 1986, 1996; Caplan & Waters, 1999; King & Just, 1991; Lewis & Vasishth, 2005; Lewis, Vasishth, & Van Dyke, 2006; Waters & Caplan, 2001). This issue is further complicated by results showing that online processing and offline comprehension dissociate. For example, Dede, Caplan, Kemtes, and Waters (2004) found that working memory capacity was a mediator of comprehension accuracy but not online processing (see also, Caplan & Waters, 1999).

A second issue associated with attempts to relate working memory to language comprehension is whether individual differences in working memory are related to capacity per se or to interference from items that are retained in memory (Gordon, Hendrick, Johnson, & Lee, 2006; Gordon, Hendrick, & Levine, 2002; McElree, Foraker, & Dyer, 2003; Van Dyke & McElree, 2006). Gordon et al. (2002) tested a memory-interference hypothesis by having participants memorize a short list of words before reading a syntactically complex sentence. After reading the sentence and answering a comprehension question, participants had to recall the list of words. Gordon et al. found that when items in the list were referentially similar to the words in the sentence, participants performed more poorly on the comprehension measures, a finding that supports the idea that individual differences in working memory are in part attributable to interference among co-present items/information.

The issues of domain-specificity versus domain-generality and interference versus capacity are important, but considerably less research has focused on how individual differences in the other executive functions (i.e., inhibition and set shifting) affect language comprehension (cf. Booth & Boyle, 2009; January, Trueswell, & Thompson-Schill, 2009; May, Zacks, Hasher, & Multhaup, 1999; Novick, Trueswell, & Thompson-Schill, 2005, 2010; Vuong & Martin, 2013). There are two other studies that investigated the role of inhibitory control in syntactic ambiguity resolution (Christianson, Williams, Zacks, & Ferreira, 2006; Engelhardt, Nigg, Carr, & Ferreira, 2008). The question addressed in these two studies was whether individuals with deficits in inhibitory control have additional difficulty suppressing the temporary misinterpretations arising from syntactic ambiguity (see Table 1). The main assumption was that garden-path sentences require participants to resolve competition between two simultaneously competing interpretations, and that perhaps successful ambiguity resolution relies on inhibiting the “incorrect” interpretation. In Example Sentence 1, the misinterpretation is that *the baby* is the direct object of *dressed*. Christianson et al. (2006) tested younger and older adults, under the assumption that aging leads to reduced inhibitory control (Chiappe, Hasher, & Siegel, 2000; Hasher & Zacks, 1988). As in Table 1, sentences were either ambiguous or unambiguous, and two types of verb were tested. After reading a sentence, participants were asked a comprehension question that probed thematic role assignment. They found only an Age × Verb Type interaction: Older adults were more likely to answer “yes” when the verb was optionally transitive.

In a study with similar logic, Engelhardt et al. (2008) examined how adolescents and adults with attention-deficit/hyperactivity disorder (ADHD) process object/subject garden-path sentences. Theoretical models of ADHD have traditionally assumed a prominent role for deficits in response inhibition (Barkley, 1997; Casey et al., 1997; Nigg, 2001; Nigg, Carr, Martel, & Henderson, 2007; Pennington & Ozonoff, 1996; Schachar, Tannock, Marriott, & Logan, 1995; Tannock & Schachar, 1996). However, Engelhardt et al. (2008) reported a different pattern of results compared to Christianson et al. (2006). ADHD status interacted with sentence structure (i.e., ambiguous vs. unambiguous), such that participants with ADHD showed significantly poorer performance on the unambiguous (or non-garden-path) sentences. The difference between participants with ADHD and typically developing controls was also significant for the ambiguous (garden-path) sentences, but this effect was not robust once age standardized reading ability was covaried. Thus, Engelhardt et al. (2008) did not find evidence that the ability to “inhibit” the garden-path misinterpretation had a substantial effect on comprehension accuracy. Neither study, then, firmly established that individuals with deficient inhibitory control have additional difficulty in resolving syntactic ambiguity.

More recently, Vuong and Martin (2013) looked at the relationship between syntactic ambiguity resolution and both verbal and non-verbal Stroop performance. Successful performance on the Stroop task is believed to rely primarily on inhibitory processes, because participants need to inhibit automatic word reading in order to quickly and accurately name the colour of the ink in which the word is printed (Friedman et al., 2007; Friedman & Miyake, 2004). Vuong and Martin examined individual differences in a sample of undergraduates ($N = 48$). They found that non-verbal Stroop did not correlate with either verbal Stroop or a garden-path comprehension task. In contrast, the verbal Stroop task correlated with the tendency to revise garden-path misinterpretations. Verbal Stroop performance accounted for approximately 13% of the variance in comprehension accuracy, and on the basis of that result, Vuong and Martin concluded that domain-specific executive control influences syntactic reanalysis (see also Protopapas, Archonti, & Skaloumbakas, 2007).

In their discussion, Vuong and Martin (2013) raised an important issue: They noted that previous studies (e.g., Christianson et al., 2006), which examined both working memory and syntactic reanalysis, could not rule out a domain-specific executive control account. This is because working memory tasks also involve executive control and thus are not pure measures of working memory. Of course, task impurity issues are a problem with virtually all complex cognitive tasks (Miyake et al., 2000), and working memory span tasks are no exception. Moreover, the Vuong and Martin study is subject to the same criticism that they noted in other work. Christianson et al. (2006) and Engelhardt et al. (2008) were interested in how inhibition deficits affect the comprehension of sentences containing temporary syntactic ambiguities. Both of those studies also assessed working memory and, thus, attempted to differentiate (or control) for variance in at least two separate executive abilities. In contrast, Vuong and Martin did not assess working memory, and, therefore, their study cannot rule out that part of the 13% of variance accounted for by verbal Stroop on comprehension performance is shared with variance in working memory (or shifting abilities).

In an even more recent study, Van Dyke, Johns, and Kukona (2014) conducted one of the most comprehensive assessments of sentence comprehension and its relationship to individual differences ever conducted. They used a battery of 24 different cognitive tasks. The goal of the study was to determine which factor(s) contribute to poor comprehension, and, in particular, they focused on capacity versus interference explanations of working memory. To do so, they used the Gordon et al. (2002) comprehension paradigm, which involves a memory load and presence/absence of interfering information. As mentioned previously, many studies have examined working memory “capacity” as a central feature of comprehension (Gibson, 1998). However, more recent work has tended to focus on interference effects (e.g., Gordon et al., 2002; May, Hasher, & Kane, 1999; Van Dyke & McElree, 2006) as primary determinants of comprehension performance. These newer perspectives emphasize factors that affect retrieval at the time when past information is needed for current processing, for example to establish long-distance dependencies within a sentence.

In order to analyse their data, Van Dyke et al. (2014) partialled the shared variance between intelligence and working memory. The rationale for doing so is that intelligence is a broad (domain-general) factor that accounts for a substantial proportion of variance in all human performance. After variance in intelligence was removed, working memory capacity was no longer a significant predictor of comprehension, which led Van Dyke et al. to conclude that the relationship between working memory and sentence comprehension is spurious and attributable to (shared) domain-general variance. The only factor that remained after intelligence was partialled out was receptive vocabulary (Nation, 2009). With respect to reading time data, the pattern was such that individuals with smaller vocabularies sped up more under memory load than did high-vocabulary individuals. This pattern was interpreted as evidence that low-vocabulary participants read faster because they tended to prioritize recall over comprehension. Therefore, not surprisingly, individuals with poorer vocabulary scores also performed more poorly on comprehension questions, especially when interference was present. Based on these findings, Van Dyke et al. support a model of memory that relies primarily on a rapid cue-based retrieval mechanism, which is consistent with interference- as compared to capacity-based theories of working memory.

## Current study

In the current study, we examined individual differences in order to investigate the role of both executive function and intelligence in the resolution of syntactic ambiguity. Throughout the remainder of this paper, we use the term “intelligence” to refer to a more domain-general measure, which was based on several Wechsler (performance and verbal) subtests, and when we refer to domain-specific intelligence (e.g., verbal intelligence), we explicitly note it. Our primary aim was to follow up the idea that executive functioning plays a significant role in garden-path reanalysis. Recall that Vuong and Martin (2013) reported that performance on the verbal Stroop task accounted for approximately 13% of the variance (as measured by simple bivariate correlations) in garden-path comprehension accuracy. The Stroop task is typically taken as a measure of inhibitory control (Friedman & Miyake, 2004). However, most of the variance in garden-path reanalysis remains unexplained, and, thus, other individual difference variables remain to be investigated (Van Dyke et al., 2014). In addition, because Vuong and Martin did not assess intelligence, working memory, or shifting, it is unclear how much of the 13% variance explained by inhibitory control is shared and how much is unique. If the variance is shared as the unity–diversity framework assumes (Miyake & Friedman, 2012), then Vuong and Martin’s conclusions require substantial qualification.

In this study, we assessed a large sample of participants on a battery of cognitive tasks that assessed both executive functioning and intelligence. We used linear mixed effects models that included fixed factors for ambiguity (structure type) and verb type (see Table 1). We assessed *intelligence* using several subtests from the Wechsler intelligence scales (Wechsler, 1997a, 1997b), *speed of processing* using simple “go” reaction time, *inhibitory control* using a verbal Stroop task (Stroop, 1935) and stop-signal reaction time (Logan, 1994), and *shifting* using the Trails task (Partington & Leiter, 1949) and perseveration errors from the Wisconsin Card Sorting Task (Heaton, Chelune, Talley, Kay, & Curtiss, 1993). The rationale for selecting this set of measures is that we wanted to assess intelligence and the two executive functions that have the least shared variance with intelligence.

A second aspect of the study feeding into the rationale is the sample. We wanted to avoid restriction of range problems due to the use of convenience (i.e., undergraduate) samples, and also we wanted to ensure sufficient power so that results would be stable and likely to generalize. Our sample contained nearly 20 participants for each individual difference variable, and participants were community recruited. The use of community-recruited participants ensures a greater range of abilities. In summary, debates continue as to whether the memory system associated with language processing is domain-general or domain-specific, and whether individual differences in memory are captured by capacity or the ability to control interference. In this study, we elected to set those issues aside and instead to focus on whether (and how strongly) intelligence and executive functions, specifically inhibition and shifting, are related to ambiguity resolution. Moreover, by assessing several individual differences variables in a large sample, we are in a better position to isolate *unique* variance.

# Experimental study

## Method

**Participants—**Participants were 174 adolescents and adults, who were recruited through local schools and widespread public advertisements. Table 2 contains a demographic summary of the sample. All participants completed a comprehensive testing procedure that took place across two testing sessions. During the first visit, participants completed a semi-structured clinical interview (i.e., for adults the Structured Clinical Interview for DSM–IV, where DSM–IV is the *Diagnostic and Statistical Manual of Mental Disorders–Fourth Edition*; American Psychiatric Association, 1994; and for adolescents and their parents the Kiddie Schedule for Affective Disorders and Schizophrenia). During this visit, participants also completed the assessments of intelligence. In the second visit, participants completed a battery of cognitive tasks, which were administered in a fixed order. Table 3 contains descriptive statistics, and Table 4 shows bivariate correlations between the variables that were examined in the study.

### Measures

**Intelligence:** Participants 17 years of age and older completed five subtests of the Wechsler Adult Intelligence Scale–3rd edition (Wechsler, 1997a), and participants 16 years of age and younger completed five subtests of the Wechsler Intelligence Scale for Children–4th edition (Wechsler, 1997b). The subtests used in this study were Vocabulary, Similarities, Picture Completion, and Matrix Reasoning from the Wechsler, 1997a and Block Design from the Wechsler, 1997b. Vocabulary requires participants to provide the definitions of words and measures the degree to which one has learned and is able to express meanings verbally. Similarities requires participants to describe how two words are similar, with the more difficult items typically describing the opposite ends of a “unifying continuum”. The Similarities subtest measures abstract verbal reasoning. The Picture Completion task requires participants to identify a missing detail within a picture and, thus, measures the ability to perceive missing visual details. Block Design and Matrix Reasoning measure non-verbal abstract problem solving and spatial perception. In Block Design, participants must use red and white blocks to construct a pattern, and in Matrix Reasoning, participants must identify a missing pattern from an array.

**Wisconsin Card Sorting Test:** Participants completed a computerized version of the Wisconsin Card Sort Test (Heaton et al., 1993). This task requires participants to match a card to one of four other cards based on different attributes (shape, colour, quantity, or design). Participants are given feedback after every decision. After 10 correct decisions, the sorting attribute changes. Number of perseveration errors was the dependent variable (i.e., the number of incorrect decisions based on a previous match attribute). Perseveration errors indicate poorer shifting (or flexibility) in the face of changing task requirements (Anderson, Damasio, Jones, & Tranel, 1991).

**Trail Making Test:** The Trail Making Test is a common paper-and-pencil measure of shifting (Reitan, 1958). In Part A, the participant rapidly connects a series of numbers in sequential order. In Part B, the participant must rapidly draw a line between alternating numbers and letters in sequential and alphabetical order, respectively. PART B, therefore, requires the ability to rapidly shift between two mental sets (Arbuthnott & Frank, 2000). The time to complete Part A was subtracted from the time to complete Part B, and so higher scores indicate worse set shifting performance.

**Stroop task:** The Stroop task requires the ability to monitor response conflict and suppress a competing response in order to successfully execute the task requirements (Stroop, 1935). Thus, it requires inhibition (or interference control processes). Participants completed a paper-and-pencil version of the Stroop Color–Word Interference test (Golden, 1978), in which individual trials occurred at 45-s intervals. An interference control composite score was calculated by regressing the colour–word naming speed on the word- and colour-naming speeds and then saving the unstandardized residual (Martel, Nikolas, & Nigg, 2007). This statistical procedure follows recommendations for isolating the Stroop effect from processing speed and thereby avoiding the most common psychometric problems with alternative scoring methods (Lansbergen, Kenemans, & van Engeland, 2007). The different conditions used blocked trials. Higher scores indicated better performance.

**Stop task:** The Stop task assesses response inhibition —that is, the ability to suppress a prepotent motor response (Dempster & Corkill, 1999; Logan, 1994). In this task, participants saw an X or an O on a computer screen and had to respond as rapidly as possible with one of two keys. These are “go” trials, and they served as a measure of simple reaction time. On 25% of trials, a tone sounded shortly after the X or O was displayed. The tone signalled that participants should withhold their response. These are “stop” trials. A stochastic tracking procedure was used to calculate stop signal reaction time (SSRT), or how much warning each participant needed to interrupt the button response. Stop signal reaction time was calculated by subtracting the average stop signal delay from average reaction time (Logan, 1994).

**Sentence comprehension:** A total of 24 critical items were created, 12 for each verb type (see Table 1). For each item, there were both ambiguous and unambiguous versions, and, thus, two lists were created. Each participant saw only one version of each critical item, and the correct response for each question was “no”. There were also 72 filler sentences that each had an associated comprehension question. Twenty-four filler questions required a “no” response, and 48 required a “yes” response.

Participants were seated at a computer workstation and were given a written description of the task. This was followed by spoken instructions after which participants were free to ask questions. Each trial began with a fixation cross, which appeared for 500 ms. The full sentence replaced the fixation cross, and after the participants had finished reading the sentence, he or she pressed a button to view the comprehension question. The sentence and question were separated by a delay of 500 ms, and the question remained on the screen until the participant responded “yes” or “no”. Participants completed 10 practice trials, and they then saw all 96 sentences in the experimental session. The order of sentences was randomly determined for each participant. Comprehension performance was measured as proportion of correct responses, and, thus, higher scores reflect better comprehension.

**Design and analysis procedures—**The design of the sentence comprehension task was 2 × 2 (Structure Type × Verb Type). Both variables were manipulated within subject. The statistical analysis consisted of three main parts, and, where possible, we followed the analysis procedures of Van Dyke et al. (2014). In the first part, we submitted the cognitive tasks to an exploratory factor analysis in which we saved the retained factors as variables. To preview the findings, we observed unique factors for intelligence, inhibition, and processing speed. Shifting, in contrast, did not emerge as a unique factor. In the second part of the analysis, we utilized linear mixed effects models that contained fixed factors for ambiguity and verb type and random factors for subjects and items. To assess intelligence and executive function we added the individual difference variables to the mixed effects models. However, to avoid problems associated with multi-collinearity and the interpretation of four-, five-, or six-way omnibus models, we added each of the individual difference variables to the model separately. The third step in the analysis focused on isolating the unique variance due to inhibition and processing speed. Therefore, similar to Van Dyke et al., we regressed intelligence onto inhibition and processing speed and saved the unstandardized residuals as variables.[1] Crucially, this allowed us to ascertain whether the *unique* variance associated with inhibition and processing speed was related to ambiguity resolution.

**Data screening and preparation—**Data points that were more than 4.0 standard deviations from the mean for each variable were considered outliers, and there were six data points meeting this criterion (i.e., less than 1% of the total). Because there were so few outliers, we elected to replace each with the mean score on that variable (McCartney, Burchinal, & Bub, 2006; Shafer & Graham, 2002; Wilcox, Keselman, & Kowalchuk, 1998). To assess multivariate outliers, we examined Cook's *D*, and used the criterion that any value greater than 1 was an outlier (Stevens, 2002). No data were excluded based on this criterion. Inferential tests are also sensitive to deviations from normality (R. B. Kline, 1998). We applied transformations (i.e., square root, logarithm, or inverse) to the skewed variables in the dataset (see Table 3).

**Reliability—**The standardized measures used in the current study are all well-established tests with widely accepted reliability. The Wechsler intelligence tests (and the subscales) typically have reported reliabilities in the .85–.95 range (Friedman et al., 2007; Friedman et al., 2006; Wechsler, 1997a, 1997b). The mean reliability for our sample was $\alpha = .71$. The Stroop task and the Stop task have reported reliabilities in the .80–.90 range (Friedman et al., 2007; Friedman & Miyake, 2004), and the Trails task and the Wisconsin Card Sort task typically have lower/borderline acceptable reliability ~.70 (for extended discussions of reliability in standardized executive function tasks see Denckla, 1996; Friedman & Miyake, 2004; Rabbitt, 1997). For the non-standardized measure (i.e., the sentence processing task), we computed split-half reliabilities. Because there were only six items in each of the within-

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[1] Recent work (Wurm & Fisicaro, 2014) has suggested several problems with this kind of procedure, specifically regarding the interpretation of the "residualized" variables. In order to be as transparent as possible we report a follow-up in the Discussion to ensure that results are not due to any artefact of residualizing our predictors.

subjects conditions, we used Spearman–Brown prophecy formula corrected coefficients (Brown, 1910; Spearman, 1910). The mean reliability was $\alpha = .71$, which is just above the traditionally acceptable value of .70 (Nunnally, 1978).

## Results

**Factor analysis—**We began the analysis by submitting the individual differences measures to an exploratory factor analysis with oblimin rotation. This rotation procedure allows factors to correlate with one another, and we extracted factor score estimates, which were saved as variables (Thurstone, 1935). The factor analysis produced three factors (with eigenvalues of one or greater), which accounted for approximately 53.8% of the total variance. Matrix loadings are presented in Table 5 and the correlations between factors are presented in Table 6. We used .384 as the critical value for interpreting significant factor loadings. Stevens (2002) recommends that interpretation of factor loadings should take sample size into account. Moreover, he recommends using a more stringent $\alpha$ level (i.e., $\alpha = .01$ for two-tailed tests) and based on the sample size, doubling the critical value for a significant bivariate correlation at $\alpha = .01$. Therefore, for our sample, we only interpret factor loadings of .384 or more. The three factors are straightforwardly interpretable as intelligence, inhibition, and processing speed. Intelligence was significant for all four of the Wechsler subtests and perseveration errors. The second factor was significant for the two measures designed to assess inhibition (i.e., stop signal reaction time and the Stroop task). The second factor also showed a significant factor loadings on the Trails task, which is typically taken as a measure of shifting. However, the fact that it patterns similarly to the inhibition tasks is not unsurprising. In opposite-world trials, participants must inhibit the tendency to name the numbers according to their “correct” names, and, thus, the Trails task does involve some amount of inhibitory control. The third factor only had one significant factor loading, and it was “go” reaction time. Thus, this factor represents processing speed. As a final point to note, we did not find a unique factor for shifting.

**Linear mixed-effects models—**In the second stage, we analysed the data using logit mixed effects models (Baayen, 2008; Baayen, Davidson, & Bates, 2008; Barr, 2008; Jaeger, 2008). Logit mixed models are more appropriate for binomial data than are analyses of variance (ANOVAs) over arcsine transformed proportions (Jaeger, 2008). (Comprehension accuracy, the main dependent measure, is binomial.) Both the structure type and verb type variables were dummy coded with unambiguous sentences and optionally transitive verbs as baseline. Parameter estimates were determined with maximum likelihood modelling using Laplace approximations, and the significance of fixed effects was determined with the Wald-*Z* statistic. We included both subjects and items as random effects, as well as by-subjects and by-items random slopes. In cases where model convergence was not achieved, we simplified item random slopes and, if necessary, subject random slopes (Barr, Levy, Scheepers, & Tily, 2013). If the model still failed to converge, then we used *glmer* instead of *lmer*. Convergence problems are more likely for categorical data (C. Scheepers, personal communication, October 4, 2013).[2]

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[2] Example code for the first linear mixed effects analysis is presented in Section A of the supplemental material.

To begin, we first examined the sentence comprehension task, which had a 2 × 2 (Structure Type × Verb Type) repeated measures design. As can be seen in first lines of Table 7, there were significant effects of structure and verb, and the interaction was likewise significant. This is consistent with results of previous studies that used similar materials (e.g., Christianson et al., 2001). Moreover, all of the paired comparisons were significant (all $p$s $< .01$). We then added the individual difference variables (i.e., the extracted factor scores from the first analysis) to the mixed effects models. The results of the analyses with intelligence, inhibition, and processing speed are shown in Table 7. In all three analyses, the significant interaction between structure type and verb type remained significant. The individual difference variables showed a significant effect of intelligence and processing speed, as well as two significant (two-way) interactions. Intelligence was positively related to comprehension, and processing speed was negatively related to comprehension (see Table 6). The significant interactions were between intelligence and structure type, and between processing speed and structure type. The first interaction is that correlations between comprehension and intelligence were stronger for the ambiguous than for the unambiguous conditions (see Figure 1). This pattern indicates that higher performing individuals did better on the ambiguous sentences and that intelligence matters somewhat less for the unambiguous sentences. However, the correlation between intelligence and the unambiguous–optional condition was also marginally significant ($r = .14$, $p = .06$).[3] In contrast, the second interaction reflects the fact that the correlations with processing speed were clearly split based on ambiguity (structure type), suggesting that slower processors were less likely to answer comprehension questions correctly for the ambiguous sentences in particular. As can be seen in Table 7, there was also a marginal effect of inhibition ($p = .07$), and, as with processing speed, individuals with poorer inhibitory control were less likely to answer the comprehension questions correctly. This effect was driven primarily by performance with the ambiguous sentences containing optionally transitive verbs ($r = -.15$, $p < .05$). The other three conditions were not significantly correlated with inhibition ($p$s $> .10$).

**Isolating unique variance—**In the final section, we partialled the variance due to intelligence by regressing intelligence onto each of the other two factors (i.e., inhibition and processing speed) and then saving the unstandardized residual. The rationale for this is similar to that adopted by Van Dyke et al. (2014). Because intelligence is a domain-general construct that accounts for a large amount of variance in virtually every cognitive task, we wanted to exclude it from the other individual difference variables to determine whether there was “unique” variance associated with inhibition and processing speed.

After partialling variance in intelligence, there was only one change as compared to the patterns reported in Table 7: Inhibition no longer produced even a marginal effect (see Table 8). The correlations between inhibition and comprehension and between processing speed and comprehension dropped once variance in intelligence was removed. However, the effect of processing speed and the interaction between processing speed and structure type

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[3] At the suggestion of a reviewer, we have included an additional analysis of the Intelligence × Sentence Structure interaction in Section B of the Supplemental Material. There is some concern over the degrees of freedom with $z$-statistics and the fact that they are anti-conservative. However, the model comparison presented in the Supplemental Material confirms a significant improvement in model fit.

remained. The significant interaction was similar to the one reported above. Individuals with higher mean reaction times (RTs) showed worse comprehension performance and, specifically, for the ambiguous than for the unambiguous sentences. Processing speed was unrelated to comprehension performance with unambiguous sentences. As one side-note, the demographic variables of age, gender, and years of education were not significantly correlated with comprehension accuracy in either ambiguous or unambiguous sentences (see Table 4).

## General Discussion

The purpose of this study was to investigate the role of individual differences in the resolution of temporary syntactic ambiguity. From a theoretical and statistical point of view, the current study represents a more thorough investigation of intelligence and the two least studied executive functions (i.e., inhibition and shifting) with respect to ambiguity resolution than has been done previously. Our primary focus was whether individual differences in executive function and intelligence are related to individual differences in syntactic ambiguity resolution and, if so, the magnitude of those effects. In the remainder of the discussion, we first summarize the results and discuss the implications with a particular view towards building upon the most recent and relevant research (i.e., Van Dyke et al., 2014; Vuong & Martin, 2013). In the second section, we address the issue of shared and unique variance between different individual differences measures of cognitive ability. Lastly, we present the strength and limitations.

To summarize the main findings, we observed that intelligence and processing speed interacted with the structure type manipulation such that individual differences (in intelligence and processing speed) were related to performance on ambiguous sentences and less so on unambiguous sentences. Inhibition also produced a marginal effect on comprehension, and individuals with better inhibitory control were more likely to answer correctly on comprehension questions regardless of whether ambiguity was present. Recall that Vuong and Martin (2013) argued that domain-specific executive control (i.e., verbal Stroop performance) plays an important role in syntactic ambiguity resolution, accounting for approximately 13% of the variance. More specifically, they argued that control mechanisms employed during ambiguity resolution are specific to the verbal domain and primarily inhibitory in nature. In the current study, we utilized an exploratory factor analysis to extract variance across many tasks. Our test battery contained one verbal inhibition task (Stroop) and one non-verbal inhibition task (stop signal reaction time). Results of the factor analysis showed that both loaded on the same factor. The loading was slightly greater for the nonverbal task (.70 vs. −.63), and, thus, our “inhibition” variable may be slightly biased toward non-verbal inhibition. Moreover, the bivariate correlations (between Stroop performance and ambiguous conditions) in our dataset were non-significant and substantially lower than those reported by Vuong and Martin (2013). Recall that Christianson et al. (2006) and Engelhardt et al. (2008) also did not establish a strong link between groups with deficits in inhibitory control and garden-path reanalysis. The current results are more in line with those studies. There are several differences between studies that may preclude direct comparisons (e.g., different type of ambiguity, different type of reading, etc.). However, our sample was nearly three and a half times larger and consisted of a wider range of ages and abilities. The sample in the Vuong and Martin (2013) study consisted of ~50 undergraduate students attending one of the most selective universities in the United States. Thus, the coefficients produced from our models are likely more stable and more generalizable. On the basis of our data, we conclude that ambiguity resolution does not rely heavily on inhibitory processing and, in addition, that most of the variance in inhibition is shared with individual differences in intelligence (G. C. Burgess, Gray, Conway, & Braver, 2011; Miyake & Friedman, 2012).

One possibility for the lack of a significant effect of inhibition concerns the type of ambiguity. We know from many studies that the object/subject ambiguity is a particularly difficult one to process (e.g., Ferreira et al., 2001), and so, if the ambiguity is extremely strong, then perhaps there is not much "competition" between the two interpretations.[4] Sturt (2007) found that full reanalysis was more likely in situations where there was also a semantic cue (i.e., plausibility information) present in the sentence. From our data, we cannot exclude this possibility, but we think it is unlikely for several reasons. First, there are a substantial number of correct responses (i.e., approximately one third of the ambiguous sentences were interpreted correctly). Second, a pupillometry study involving auditory versions of these exact same sentences showed graded responses in pupil diameter, rather than a bimodal distribution, which would be indicative of full versus partial reanalysis (Engelhardt et al., 2010; Farmer, Anderson, & Spivey, 2007). Finally, many prominent models of sentence comprehension assume parallel interpretations of syntactic ambiguity (e.g., MacDonald, Pearlmutter, & Seidenberg, 1994). However, at this juncture, we are not in a position to rule out a "strength of ambiguity" argument concerning the null effect of inhibition (Novick et al., 2010), which would require a study examining individual differences in inhibitory control and a range of different syntactic ambiguities (Frazier & Clifton, 1996). We can say definitively that inhibition does not play a significant role in the interpretation of object/subject ambiguities investigated here, which is consistent with prior research (e.g., Christianson et al., 2006; Engelhardt et al., 2008).

With respect to interactions, we observed a significant interaction between intelligence and comprehension accuracy. Intelligence was more related to performance on the ambiguous sentences than to that on the unambiguous sentences. In order to understand the role of (domain-general) intelligence in sentence processing, we tested two verbal subtests and two performance subtests. Our factor analysis showed that the highest loading on Factor 1 was vocabulary, which requires participants to provide the definitions of words. Van Dyke et al. (2014) reported that vocabulary was most consistently and uniquely associated with interference problems during reading (see also Joshi, 2005). It is important to keep in mind that the Van Dyke et al. comprehension task also involved a memory load component, which is very different from the straightforward reading task used in the current study. Whereas our task focused on syntactic processing, the Van Dyke et al. task is more complex insofar as it included a dual-task memory component on top of comprehension. However, to explain the vocabulary effect, Van Dyke et al. stressed the importance of the quality of lexical representations in the mental lexicon, which is a substantial departure from most of the

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[4] The same may also be true of particularly weak ambiguities as well (e.g., coordination ambiguity).

previous work looking at executive functioning (and in particular working memory capacity) in language comprehension (e.g., Caplan & Waters, 1999, 2002; Daneman & Carpenter, 1980; Daneman & Merikle, 1996; Fedorenko et al., 2006; King & Just, 1991; Lewis & Vasishth, 2005; Lewis et al., 2006; Waters & Caplan, 2001). To follow up on Van Dyke et al.'s conclusion, we tested vocabulary in a model with structure type and verb type. Results indicated that individual differences in vocabulary were more related to performance with the *verb type* manipulation (see Table 9). With vocabulary in the model, verb type was no longer significant, and neither was the Structure Type × Verb Type interaction. This finding indicates that participants with better knowledge of word meanings (i.e., individuals who can provide definitions for increasingly complex and abstract words) show fewer differences between the reflexive and optionally transitive verbs.[5] For the most part, we agree with the conclusion that qualitative differences in the mental lexicon are associated with performance differences in reading (Guo, Roehrig, & Williams, 2011; Nation, 2009; Perfetti, 2007; Perfetti & Hart, 2002; Protopapas, Mouzaki, Sideridis, Kotsolakou, & Simos, 2013; Tunmer & Chapman, 2012). In particular, we believe that higher performing individuals probably have greater precision and breadth of information for words stored in the lexicon. Moreover, these differences, like other forms of crystallized intelligence, are probably derived through variations in experience with both oral and written language (Cunningham & Stanovich, 1990; Wells, Christiansen, Race, Acheson, & MacDonald, 2009).

The final predictor of comprehension accuracy was processing speed. We also attribute this effect to individual differences in domain-general intelligence (Bates & Stough, 1997; Bickley, Keith, & Wolfle, 1995; Der & Deary, 2003; Martin, 2001; Salthouse, 1996). Processing speed is a second-level factor in the three-stratum model of intelligence (Carroll, 1993). However, processing speed has the lowest factor loading (.672) of all second-level factors on *g* in Carroll's model. With respect to the current data, processing speed showed a clear dissociation between the ambiguous and unambiguous sentences. Processing speed was significantly correlated with performance in the ambiguous conditions in sentence comprehension and correlated with no other measures, except vocabulary. The correlation between speed and full-scale intelligence was marginal, but at this point, it remains an open issue why processing speed, if it is indeed a general factor, did not correlate with more measures in the test battery. One possibility is that if processing speed is a borderline predictor of *g,* then it makes sense that correlations with other individual difference measures would also tend to be non-significant or, at best, mixed (Deary, Der, & Ford, 2001). Another issue to keep in mind is that the Wechsler tests do not map perfectly onto fluid and crystallized intelligence, which tend to be the focus of models of intelligence (e.g., Carroll, 1993) and studies that attempt to explain individual differences in basic mental abilities (Das, 2002; Deary, 2001; P. Kline, 1991; Spearman, 1927).

Our data indicate that faster processors are better able to understand syntactically ambiguous sentences than unambiguous sentences. Because in our study we did not record eye movements, we are not in a position to make claims regarding how processing speed is

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[5] It should also be noted that vocabulary also showed some relationship with structure type, as there was a marginal interaction between vocabulary and syntactic structure. However, the bivariate correlations with vocabulary were highly similar to extracted intelligence variable (compare Tables 4 and 6).

related to reading times and how that may (or may not) affect comprehension accuracy (Kuperman & Van Dyke, 2011). However, one possible explanation of the relationship between speed of processing and success in comprehending temporarily ambiguous sentences is that individuals who process information more slowly suffer because alternative lexical argument structures and syntactic frames have substantially decayed once the disambiguating information is encountered. Essentially, faster processors would be better able to maintain multiple interpretations in parallel, which would allow them to select and settle on the correct one when disambiguation occurs (MacDonald et al., 1994). Another potential explanation focuses on how long the misinterpretation is maintained. Christianson et al. (2001) varied the position of the head in the subject noun phrase in the main clause and found that head-early sentences had lower comprehension than head-late sentences (Ferreira & Henderson, 1991). One possibility that our data do allow us to rule out is how long participants spent reading the sentence, as sentence reading times were not correlated with comprehension accuracy in any of the four within-subjects conditions (all $p$s $> .10$).

The final point we want to draw from the current study concerns shared versus unique variance among executive functions and intelligence (Friedman & Miyake, 2004). Vuong and Martin (2013) highlighted this issue: To make conclusions about how individual differences in general mental abilities impact on sentence processing, the issue of shared variance must be addressed. In the current study, we attempted to deal with shared variance using a two-stage process. In the first stage, we submitted the test battery to an exploratory factor analysis. Some might argue that the exploratory nature of these types of tests is less than ideal. However, if the results of the analysis map onto the theoretically based explanations of what those tests measure, then the likelihood of a purely chance result is dramatically decreased. Moreover, the results of our factor analysis clearly did not necessitate any post hoc explanations. Instead, the results of our factor analysis were relatively straightforward: The intelligence measures loaded on the same factor, and the two inhibition tasks also loaded on the same factor. The only exceptions were the Trails task, perseveration errors, and one of the Wechsler subtests. However, the Trails task is a timed task, and, as mentioned previously, it requires inhibiting the normal (and highly overlearned) symbol-to-word mapping involved in naming numbers. The second stage that we used to eliminate (shared) variance was to partial the variance in intelligence from both inhibition and processing speed. With both, removing variance in intelligence resulted in lower correlations with the sentence processing task. However, significant variance remained for processing speed, which indicates unique variance. One caveat to note is that there has been some recent controversy about the interpretation of residualized predictors, despite the widespread use of this technique in the literature. Wurm and Fisicaro (2014) ran several simulations, which suggested that residualizing frequently does not change results in the intended way. In our study, there were no substantial differences when intelligence was partialled from either inhibition or processing speed, except that inhibition went from a marginal predictor (.077) to clearly not significant (.471). We also ran the mixed model analysis with both predictors in the model (one of the options suggested by Wurm & Fisicaro, 2014), and results showed that intelligence and the Intelligence × Ambiguity interaction were significant (both $p$s $< .05$) but inhibition was not ($p = .28$). We included the results of this follow-up analysis in Table 9.

## Strengths and limitations

The main strength of the study is that it simultaneously tested a broad set of predictor variables, which allowed us to more accurately assess the individual contributions of several theoretically relevant constructs. An obvious problem with studies that examined one or two measures of executive control is that they do not account for shared variance. In the introduction, we noted this as a limitation of the Vuong and Martin (2013) study, which reported that 13% of the variance in garden-path comprehension was attributable to verbal Stroop performance. It is highly likely that part of the variance reported by Vuong and Martin is attributable to shared variance with other executive functions and/or intelligence. A second strength of the current study concerns the sample: both its size and its breadth. Sentence comprehension studies of community-recruited participants rather than undergraduates are rare but important if the goal is to obtain a clear understanding of individual differences in language processing ability and their relationships to other cognitive variables. Our study is also unusual in its use of such a large sample, which gave us greater power to detect significant relationships and more confidence in the stability of the results.

Two limitations are also worth noting. The first is that our test battery did not include measures of working memory. When the study was designed, the focus was predominantly on executive functions relating to inhibitory control and mental flexibility. Future studies should include measures of working memory as well in order to gain an even more comprehensive understanding of the role of executive function in garden-path reanalysis, although we note that working memory capacity has already received a great deal of attention in the language processing literature, whereas the variables investigated here have been much less explored. The second limitation is that we did not collect online processing measures. Thus, we cannot identify how executive functions or intelligence affect word-by-word processing of temporary ambiguities. Nonetheless, we believe the results we have obtained for comprehension set the stage for follow-up studies with online measures, such as eye tracking. Also, our data concerning the likelihood of successfully interpreting a garden-path sentence should help to inform predictions concerning effects of executive functions on measures of online, incremental interpretation (Kuperman & Van Dyke, 2011; Prat & Just, 2011; Van Dyke et al., 2014).

## Conclusions

The current results provide an important stepping stone as psychological theories and computational models of reading become more sophisticated and incorporate lower level control mechanisms (i.e., executive abilities), as well as domain-general abilities such as intelligence (Adlof, Catts, & Little, 2006; Johnston & Kirby, 2006; Joshi & Aaron, 2000; Protopapas, Simos, Sideridis, & Mouzaki, 2012; Tiu, Thompson, & Lewis, 2003; Ye & Zhou, 2009a, 2009b). In general, we feel that greater attention should be paid to these sorts of issues, and, until very recently, this has been an empirically neglected research area. The dearth of research may be in part due to the fact that acquired knowledge, such as vocabulary, is not as interesting from a cognitive psychological point of view as more domain-general abilities, such as working memory. This study makes an important contribution to the literature by addressing these particular knowledge gaps. On the basis of these data, explicit predictions can be made about how individual differences in mental abilities affect language comprehension. We observed that intelligence and processing speed have reliable and unique contributions with regard to overcoming temporary misinterpretations arising from syntactic ambiguity. Thus, this study represents a step towards integrating findings from sentence comprehension within the larger task of understanding individual variation.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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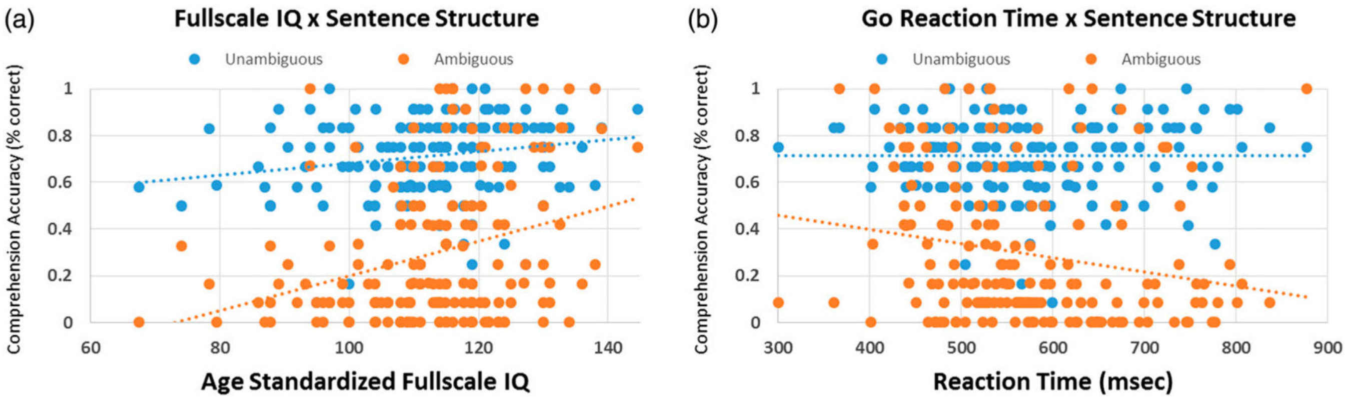

**Figure 1.**

Left panel shows the Intelligence × Sentence Structure interaction and the right the Reaction Time (RT) × Sentence Structure interaction. To view this figure in colour, please visit the online version of this Journal.

## Table 1

Example stimuli for object/subject garden-path sentences.

*Reflexive verbs*

**1.** While Anna dressed the baby that was small and cute spit up on the bed. (Ambiguous)

**2.** The baby that was small and cute spit up on the bed while Anna dressed. (Unambiguous)

*Comprehension question*

**3.** Did Anna dress the baby?

*Optionally transitive verbs*

**4.** While Susan wrote the letter that was long and eloquent fell off the table. (Ambiguous)

**5.** The letter that was long and eloquent fell off the table while Susan wrote. (Unambiguous)

*Comprehension question*

**6.** Did Susan write the letter?

## Table 2

Means and standard deviations for demographic variables.

| **Variable** | **Mean (*SD*)** | **Minimum** | **Maximum** |
|---|---|---|---|
| Age (years) | 19.91 (5.36) | 14.0 | 37.0 |
| Gender (% male) | 43.7 | | |
| Education (years) | 12.90 (2.61) | 9.0 | 19.0 |
| Full-scale IQ | 112.92 (12.84) | 67.57 | 144.59 |
| Ethnicity | | | |
| African American (%) | 9.8 | | |
| Asian/Asian American (%) | 2.3 | | |
| Native American (%) | 1.1 | | |
| Latino (%) | 1.7 | | |
| White (%) | 78.2 | | |
| Other/mixed/unreported (%) | 6.9 | | |

## Table 3

Descriptive statistics for the intelligence subtests, executive function measures, and garden-path task.

| Measure | *N* | Mean | *SD* | Min | Max | Skew | Kurtosis |
|---|---|---|---|---|---|---|---|
| *IQ subtests* | | | | | | | |
| Vocabulary | 174 | 12.38 | 2.73 | 5.00 | 19.00 | 0.012 | 0.203 |
| Similarities | 174 | 12.03 | 2.94 | 4.00 | 19.00 | 0.337 | −0.164 |
| Picture Completion | 174 | 11.46 | 2.74 | 4.00 | 17.00 | −0.129 | −0.861 |
| Matrix/Block Design | 174 | 12.11 | 2.86 | 1.00 | 18.00 | −0.568 | 1.122 |
| *EF tasks* | | | | | | | |
| Stop signal RT[a] | 174 | 5.44 | .23 | 4.55 | 6.13 | −0.065 | 1.724 |
| Go RT[a] | 174 | 6.33 | .18 | 5.71 | 6.78 | −0.079 | 0.149 |
| Stroop | 174 | 10.52 | 7.93 | −11.39 | 36.25 | 0.261 | 0.773 |
| Trails B – A[b] | 174 | 5.08 | 1.21 | 1.98 | 8.98 | 0.412 | 1.073 |
| Perseveration errors[c] | 174 | .18 | .06 | .06 | .33 | 0.412 | −0.062 |
| *Garden-path task* | | | | | | | |
| Unambiguous optional | 174 | .52 | .24 | .00 | 1.00 | −0.082 | −0.467 |
| Unambiguous reflexive | 174 | .91 | .15 | .17 | 1.00 | −2.150 | 5.369 |
| Ambiguous optional | 174 | .21 | .30 | .00 | 1.00 | 1.421 | 0.833 |
| Ambiguous reflexive | 174 | .39 | .36 | .00 | 1.00 | 0.590 | −1.105 |

Note: EF = executive function; RT = reaction time.

[a] Logarithm transformation;

[b] square root transformation;

[c] inverse transformation.

## Table 4

Bivariate correlations between intelligence, executive function, and garden-path tasks.

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Age | — | .10 | .85** | .02 | .01 | −.04 | .13 | −.02 | −.04 | −.08 | −.03 | −.04 | .08 | .06 | .00 | .02 | .11 |
| 2. Gender | | — | .11 | −.15* | −.15* | −.06 | −.10 | −.03 | −.05 | .03 | .03 | −.09 | .03 | .07 | −.06 | .07 | .02 |
| 3. Education | | | — | .10 | .10 | .07 | .10 | .06 | −.15* | −.12 | .06 | −.09 | .15* | .12 | .06 | .04 | .12 |
| 4. Full-scale IQ | | | | — | .66** | .60** | .54** | .67** | −.09 | −.11 | .16* | −.24** | .31** | .18* | .15* | .26** | .32** |
| 5. Vocabulary | | | | | — | .50** | .26** | .37** | −.12 | −.18* | −.06 | −.13 | .25** | .18* | .14 | .21** | .30** |
| 6. Similarities | | | | | | — | .21** | .39** | −.06 | −.01 | .13 | −.21** | .20** | .10 | −.07 | .09 | .13 |
| 7. Picture Completion | | | | | | | — | .33** | .01 | −.08 | .08 | −.02 | .23** | .08 | .09 | .04 | .07 |
| 8. Matrix/Block | | | | | | | | — | −.10 | −.06 | .21** | −.35** | .21** | .07 | .10 | .15* | .19* |
| 9. Stop signal RT | | | | | | | | | — | −.04 | −.22** | .23** | −.19* | −.17* | −.17* | −.02 | −.02 |
| 10. Go RT | | | | | | | | | | — | .05 | .07 | .02 | .02 | −.07 | −.18* | −.22** |
| 11. Stroop | | | | | | | | | | | — | −.18* | .09 | .06 | .02 | .12 | .11 |
| 12. Trails B – A | | | | | | | | | | | | — | −.23** | −.08 | .00 | −.20** | −.12 |
| 13. Perseveration errors | | | | | | | | | | | | | — | .01 | .16* | .11 | .10 |
| 14. Unambiguous–optional | | | | | | | | | | | | | | — | .40** | .42** | .34** |
| 15. Unambiguous–reflexive | | | | | | | | | | | | | | | — | .24** | .22** |
| 16. Ambiguous–optional | | | | | | | | | | | | | | | | — | .76** |
| 17. Ambiguous–reflexive | | | | | | | | | | | | | | | | | — |

Note: Gender coded 0 = male and 1 = female.

[*] $p < .05$.

[**] $p < .01$.

## Table 5

Factor loadings from maximum likelihood factor analysis.

| Variable | F1 | F2 | F3 |
|---|---|---|---|
| 1. Vocabulary | .75 | −.07 | −.31 |
| 2. Similarities | .72 | −.15 | −.06 |
| 3. Picture | .63 | .03 | .08 |
| 4. Matrix/Block | .71 | −.39 | −.17 |
| 5. SSRT | −.07 | .70 | −.05 |
| 6. Go RT | −.07 | −.06 | .90 |
| 7. Stroop | .11 | −.63 | .22 |
| 8. Trails B – A | −.27 | .68 | .29 |
| 9. Perseveration | .48 | −.36 | .16 |

Note: RT = reaction time; SSRT = stop signal RT.

## Table 6

Inter-factor correlations and correlations with garden-path task.

| **Variable** | **F1** | **F2** | **F3** | **Amb–opt** | **Amb–rat** | **Unam–opt** | **Unam–rat** |
|---|---|---|---|---|---|---|---|
| F1. IQ | — | −.20** | −.07 | .18* | .25** | .14 | .11 |
| F2. Inhibition |  | — | −.04 | −.15* | −.10 | −.12 | −.10 |
| F3. Processing speed |  |  | — | −.21** | −.23** | −.02 | −.04 |

Note: Amb = ambiguous; unam = unambiguous; opt = optional; rat = reflexive.

* $p < .05$.

** $p < .01$.

## Table 7

Mixed model results for structure type, verb type, and individual differences

| **Model/predictor** | **Estimate** | ***SE*** | **Wald-*Z*** | ***p*** |
|---|---|---|---|---|
| (Intercept) | −0.6583 | 0.3992 | −1.649 | .0992 |
| Structure | 3.8543 | 0.5543 | 6.954 | 3.56e-12 *** |
| Verb | −1.1704 | 0.5443 | −2.150 | .0315 * |
| Structure × Verb | −1.9253 | 0.7753 | −2.483 | .0130 * |
| (Intercept) | −0.6701 | 0.3972 | −1.687 | .0916 |
| Structure | 3.8549 | 0.5527 | 6.975 | 3.06e-12 *** |
| Verb | −1.1636 | 0.5427 | −2.144 | .0320 * |
| Intelligence | 0.5756 | 0.1379 | 4.173 | 3.03e-05 *** |
| Structure × Verb | −1.9243 | 0.7731 | −2.489 | .0128 * |
| Structure × Intelligence | −0.2820 | 0.1457 | −1.937 | .0528 * |
| Verb × Intelligence | −0.1669 | 0.1279 | −1.305 | .1919 |
| Structure × Verb × Intelligence | 0.0854 | 0.1879 | 0.454 | .6496 |
| (Intercept) | −0.6585 | 0.3982 | −1.654 | .0982 |
| Structure | 3.8569 | 0.5537 | 6.967 | 3.17e-12 *** |
| Verb | −1.1799 | 0.5436 | −2.170 | .0300 * |
| Inhibition | −0.2413 | 0.1364 | −1.769 | .0769 |
| Structure × Verb | −1.9192 | 0.7745 | −2.478 | .0132 * |
| Structure × Inhibition | −0.0274 | 0.1407 | −0.195 | .8455 |
| Verb × Inhibition | −0.1381 | 0.1270 | −1.088 | .2767 |
| Structure × Verb × Inhibition | 0.2219 | 0.1858 | 1.194 | .2323 |
| (Intercept) | −0.6726 | 0.3983 | −1.689 | .0913 |
| Structure | 3.8559 | 0.5534 | 6.967 | 3.2e-12 *** |
| Verb | −1.1918 | 0.5438 | −2.191 | .0284 * |
| Speed | −0.4867 | 0.1352 | −3.599 | .0003 *** |
| Structure × Verb | −1.8933 | 0.7743 | −2.445 | .0145 * |
| Structure × Speed | 0.3532 | 0.1513 | 2.334 | .0196 * |
| Verb × Speed | 0.0087 | 0.1183 | 0.073 | .9417 |
| Structure × Verb × Speed | 0.1215 | 0.1892 | 0.642 | .5207 |

[*] $p < .05$.

[***] $p < .001$.

## Table 8

Mixed model results for structure type, verb type, and individual differences

| **Model/predictor** | **Estimate** | ***SE*** | **Wald-*Z*** | ***p*** |
|---|---|---|---|---|
| *Intelligence partialled from inhibition* | | | | |
| (Intercept) | −0.6587 | 0.3990 | −1.651 | .0988 |
| Structure | 3.8576 | 0.5543 | 6.959 | 3.42e-12 *** |
| Verb | −1.1749 | 0.5443 | −2.159 | .0309 * |
| Inhibition | −0.1010 | 0.1399 | −0.722 | .4705 |
| Structure × Verb | −1.9240 | 0.7754 | −2.481 | .0131 * |
| Structure × Inhibition | −0.0828 | 0.1436 | −0.577 | .5642 |
| Verb × Inhibition | −0.1698 | 0.1281 | −1.325 | .1853 |
| Structure × Verb × Inhibition | 0.2246 | 0.1888 | 1.189 | .2344 |
| *Intelligence partialled from processing speed* | | | | |
| (Intercept) | −0.6698 | 0.3990 | −1.679 | .0932 |
| Structure | 3.8580 | 0.5541 | 6.962 | 3.35e-12 *** |
| Verb | −1.1894 | 0.5444 | −2.184 | .0290 * |
| Speed | −0.4086 | 0.1366 | −2.992 | .0028 ** |
| Structure × Verb | −1.8991 | 0.7753 | −2.449 | .0143 * |
| Structure × Speed | 0.3310 | 0.1526 | 2.169 | .0300 * |
| Verb × Speed | −0.0064 | 0.1180 | −0.054 | .9567 |
| Structure × Verb × Speed | 0.1904 | 0.1904 | 0.626 | .5315 |

* $p < .05$.

** $p < .01$.

*** $p < .001$.

## Table 9

Mixed model results for structure type, verb type, and individual differences

| Model/predictor | Estimate | *SE* | Wald-*Z* | *p* |
|---|---|---|---|---|
| *Vocabulary* | | | | |
| (Intercept) | −3.80891 | 0.73373 | −5.191 | 2.09e-07*** |
| Structure | 5.08442 | 0.86997 | 5.844 | 5.09e-09*** |
| Verb | −0.25154 | 0.78968 | −0.319 | .7501 |
| Vocabulary | 0.25313 | 0.04955 | 5.108 | 3.25e-07*** |
| Structure × Verb | −2.09173 | 1.15189 | −1.816 | .0694 |
| Structure × Vocabulary | −0.09896 | 0.05574 | −1.775 | .0758 |
| Verb × Vocabulary | −0.07328 | 0.04521 | −1.621 | .1050 |
| Structure × Verb × Vocabulary | 0.01303 | 0.06963 | 0.187 | .8516 |
| *Four-way interaction with intelligence and inhibition* | | | | |
| (Intercept) | −0.6913 | 0.3986 | −1.734 | .0829 |
| Structure | 3.8769 | 0.5547 | 6.990 | 2.76e-12*** |
| Verb | −1.1814 | 0.5447 | −2.169 | .0301* |
| Intelligence | 0.5631 | 0.1418 | 3.971 | 7.15e-05*** |
| Inhibition | −0.1511 | 0.1384 | −1.092 | .2750 |
| Structure × Verb | −1.8875 | 0.7759 | −2.433 | .0150* |
| Structure × Intelligence | −0.3049 | 0.1545 | −1.974 | .0484* |
| Structure × Inhibition | −0.0705 | 0.1457 | −0.484 | .6286 |
| Verb × Intelligence | −0.2011 | 0.1297 | −1.551 | .1208 |
| Verb × Inhibition | −0.1759 | 0.1293 | −1.360 | .1738 |
| Structure × Verb × Intelligence | 0.0968 | 0.1974 | 0.491 | .6237 |
| Structure × Verb × Inhibition | 0.2728 | 0.1915 | 1.425 | .1542 |
| Structure × Intelligence × Inhibition | −0.0268 | 0.1321 | −0.203 | .8394 |
| Verb × Intelligence × Inhibition | −0.0417 | 0.1150 | −0.363 | .7167 |
| Structure × Verb × Intelligence × Inhibition | 0.1770 | 0.1625 | 1.089 | .2760 |

[*] $p < .05$.

[**] $p < .01$.

[***] $p < .001$.