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Priming Sentence Production in Adolescents and Adults with Attention-Deficit/Hyper-Activity Disorder

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Abstract

Theoretical accounts of attention-deficit/hyperactivity disorder (ADHD) posit a prominent role for problems in response inhibition (Nigg 2006). A key avenue for impulsivity in children with ADHD is inappropriate language expression. In this study, we sought to determine whether poor inhibitory control affects language production in adolescents and adults with ADHD. One hundred and ninety-five participants (13–35 years old; 65% male) were presented with two pictures and a verb, and their task was to form a sentence. If deficits in response inhibition affect language production, then participants with ADHD should be more likely than non-ADHD controls to begin speaking before having formulated a plan that will allow a grammatical continuation. The results showed that the ADHD-combined subtype, in particular, was more likely to produce an ungrammatical sequence. Effects were not moderated by age or gender. These data suggest that response suppression deficits in ADHD adversely affect the basic processes of sentence formation.

Keywords

ADHD; Language production; Response inhibition; Conceptual accessibility; Grammatical encoding

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Attention-deficit/hyperactivity disorder (ADHD) affects approximately 6% of children, and has become increasingly recognized as persisting into adolescence and adulthood in a substantial percentage of cases (Barkley et al. 2002; Kessler et al. 2006). ADHD reflects impaired levels of behavioral hyperactivity/impulsivity, and/or inattention. The DSM-IV (APA 2000) identifies three subtypes: primarily-hyperactive/impulsive (ADHD-PH), primarily-inattentive (ADHD-PI), and combined (ADHD-C). However, the relationship

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between subtypes remains unresolved (Milich et al. 2001), especially in adolescents and adults.

The period of development from adolescence to young adulthood encompasses a period of massive changes in the consolidation of certain cognitive control processes, corresponding to the continued maturation of the prefrontal cortex (Giedd et al. 1999). In parallel, it has been unclear whether the clinical manifestation of ADHD from adolescence into adulthood is the same or changes with development, in particular due to the normative decline in activity level during this period (Hart et al. 1995). Thus, in evaluating the role of response control mechanisms in ADHD, it is particularly informative to evaluate this period of developmental consolidation. If inhibitory deficits are an epiphenomenon that fade over time while ADHD persists, then such deficits should be less apparent in adults than in adolescents with ADHD. Regardless of that outcome, clarification of cognitive difficulties in this older age period is crucial for a full understanding of ADHD.

A large literature has demonstrated that children and adults with ADHD have difficulty suppressing a motor or oculomotor response (Carr et al. 2006; Schachar et al. 1995; Willcutt et al. 2001). These response inhibition deficits have figured in major theoretical accounts of the disorder (e.g. Barkley 1997; Nigg 2001). Yet a key question concerning response suppression or inhibition is the extent to which it generalizes across output domains or is specific to the motor domain. If it is specific to one domain, this would suggest (a) that these domains of inhibition are dissociable and (b) that the deficit in ADHD may not be in a central inhibitory system, but in a later stage motor control system. In that light, it is surprising that so few studies have examined whether an ADHD response suppression difficulty extends to the language domain.

A hallmark behavioral characteristic of childhood ADHD is excessive language production–talking excessively, not awaiting turns in conversations, and poor topic maintenance (Tannock and Schachar 1996). Perhaps more importantly, Barkley (1997) emphasized the role of internalized language on behavioral control, so one possibility is that deficits in language control could have secondary consequences on behavior. It is currently unknown whether the same mechanisms that regulate language responses would lead to breakdowns in the regulation of motor responses, or whether such a breakdown in language is even formally apparent in ADHD.

Nonetheless, there is reason to think it might. In general, children with ADHD often have some co-occurring language impairments; estimates of this comorbidity range anywhere between 30 and 50 percent depending on whether the sample is clinically referred or community recruited (Beitchman et al. 1990; Cohen et al. 1992; Denckla 1996; Javorsky 1996; Tirosh and Cohen 1998; Willcutt and Pennington 2000). Language impairments include delayed onset of words, poor performance on standardized tests, and difficulty in conversation (Johnson et al. 1993; Rashid et al. 2001; Redmond 2004; Scott and Windsor 2000; Tannock et al. 1993).

In one relevant language production study, children with ADHD were asked to give instructions to a listener to construct some simple block patterns. The ADHD group used fewer descriptive instructions and more disruptive instructions than did non-ADHD children (see Blaskey 2004). Disruptive speech in this case meant more talking with the examiner and making more commands to the listener than was necessary for successful performance. Purvis and Tannock (1997) examined language production in children with ADHD using a story re-telling task. They found significant deficits in event sequencing and more misinterpretations when children with ADHD were compared to typically-developing controls. However, another set of studies found that children with ADHD showed age appropriate mean length utterances, and age appropriate grammatical errors, even as the stories became more complex and required more organization (Barkley et al. 1983; Lorch et al. 2000; Zentall 1988). In summary, most though not all language production studies show that the narrative speech of those with ADHD is marked by disorganization and poor cohesion (Flory et al. 2006; Hamlett et al. 1987; Purvis and Tannock 1997).

Less clear however, is at what level of language production these problems occur. The majority of previous work used a story re-telling task, which assesses language production in the context of an extended narrative. In such tasks, the overproduction or inefficient production of language could be due to a number of factors other than response control or suppression. For example, it might be due to distraction, poor attention, poor planning, or confusion about goals of the task, as well as poor output suppression. Therefore, the focus of the current study was to examine language production at a more basic level that attempts to better isolate response inhibition in language output. A secondary goal was to determine if these effects were constant across the developmental period from early adolescence to early adulthood, or whether they attenuate with age.

Language Production

To examine sentence-level language production, we turned to the psycholinguistics literature, wherein the role of inhibitory function in speech has figured prominently (Meyer et al. 2007), but without much study of psychiatric disorders. The psycholinguistics literature has shown that when a noun phrase is made accessible by showing someone a picture of an object or even a semantically related object, speakers have a tendency to begin their utterances with that primed concept (Bock 1987; Bock and Warren 1985; Christianson and Ferreira 2005; Ferreira 1994).

The process of converting thoughts into words, called *grammatical encoding*, is computationally demanding. As a result, the production system is moderately incremental (Bock and Cutting 1992; Ferreira and Engelhardt 2006). This means that in language production, the order in which concepts (or words) are activated and retrieved influences the order of words in the utterance. So if the word for GIRL were processed before the one for BICYCLE, then the resulting structure might be an active form, such as *The girl rode the bicycle.* Incremental production is viewed as a way to reduce processing demands during the production process. The basic idea is that at particular points in time certain concepts may be more available to a speaker than others, and the production system tends to begin with the activated concepts first.

Of course, there is some tradeoff in this process because incrementality might create a situation in which an activated word forces a more computationally demanding structure. If a speaker attempts to place a highly accessible concept in the most prominent syntactic position, and it happens that the most activated concept is a direct object, such as *bicycle*, then a passive structure (e.g. *The bicycle was ridden by the girl.*) will need to be produced in order to accommodate an object in an initial position. Based on this conception of language production, one can develop the hypothesis that under challenging circumstances the ability to control these initial response tendencies is necessary to consistently produce grammatical sentences. In turn, if ADHD is associated with breakdowns in response control functions, in particular, the ability to inhibit an activated word in order to protect language production, then participants with ADHD should be more likely to make errors under more demanding conditions.

Current Study

In the current study, we tested adolescents and adults rather than young children, for several reasons. By adolescence and beyond, basic language systems are relatively mature, whereas cognitive control is still rapidly evolving. Also by this age, socially sanctioned behavior, such as language, is expected to have to become more normalized over time—especially if difficulties in language control are not central to the disorder. On the other hand, if response inhibition is a core deficit in ADHD (Barkley 1997; Nigg 2001), then we expect language production problems to persist even in adolescents and adults. Therefore, the primary goal of the current study was to determine whether ADHD is associated with difficulty inhibiting primed concepts during sentence production when doing so is necessary to generate grammatical utterances, and secondly whether that effect varied with age across a broad developmental period. To investigate the primary goal, we took advantage of the fact that speakers have a tendency to place primed concepts at the beginning of a sentence. However, in some cases, speakers must inhibit this tendency when the primed concept cannot occur in an initial position. To evaluate the secondary goal, we assembled a sample spanning adolescence and early adulthood.

Method

Participants

Participants were 195 adolescents and adults between the ages of 13 and 35. Table 1 shows the demographic data for controls and two ADHD subtypes. The ADHD-PH subtype was infrequently identified, as expected based on previous literature (Hart et al. 1995), and so was excluded. Table 1 shows that the groups differed as expected with regard to the typical clinical profile of ADHD.

Participants were recruited from the community via widespread public advertisements designed to access as broad and representative a sample as possible. Participants were evaluated in a multistage screening and diagnostic evaluation procedure to identify ADHD cases and controls meeting the study criteria. The procedures were as follows. Prospective participants contacted the project office, at which point key rule-outs were checked (i.e., no sensory-motor handicap, no neurological illness, no non-stimulant psychiatric medications, and native speaker of English). Eligible participants were scheduled for a diagnostic visit wherein they completed a semi-structured clinical interview and assessment of IQ and reading ability (Wechsler 1997a, 1997b, 2001). IQ was estimated using a reliable and valid five subtest short form of the WAIS-III (16 years and younger) and WISC-IV (17 and older). The subtests were picture completion, vocabulary, similarities, arithmetic, and matrix reasoning. Reading was assessed with WRAT (17 years and older) and WIAT-II (16 and younger) word recognition subtests (Wilkinson 1993).

Procedures were altered slightly for children under the age of 18 to accommodate their developmental stage and legal status. In the case of adults (over age 18), assessment of ADHD requires retrospective assessment of their childhood ADHD status to establish childhood onset, in turn, mandating the inclusion of informant interviews to verify symptoms (Wender et al. 2001). A retrospective Kiddie Schedule for Affective Disorders and Schizophrenia (*K-SADS*; Puig-Antich and Ryan 1986) was administered by a masters-level clinician with extensive training, following previously published procedures for assessing adults (Biederman et al. 1990). This procedure assessed the adult's childhood ADHD, Conduct Disorder, and Oppositional Defiant Disorder symptoms and impairment. Because self-reported recall of these symptoms by adults with ADHD may lead to under-reporting (Murphy and Barkley 1996), an informant who had known them as a child (usually a parent) reported on the participant's childhood behaviors via an ADHD Rating Scale and a retrospective K-SADS ADHD module adapted to be appropriate for an informant. In the case of adolescents, a K-SADS interview of the parent was conducted to ascertain current and lifetime symptoms of ADHD, and all Axis I disorders in the same manner. Teacher ratings were obtained to evaluate cross-situational and cross-informant symptom display.

Current adult ADHD symptoms were assessed by self report and by interview with a second informant who currently knew the participant well (Wender et al. 2001), typically a spouse, roommate, or close friend. We again used K-SADS ADHD questions worded appropriately for current adult symptoms (Biederman et al. 1990). This interview was supplemented with Barkley and Murphy's (2006) Current ADHD Symptoms rating scale (as recommended by Weiss et al. 1999). To ensure that ADHD participants exceeded normative cutoffs for ADHD symptoms, adult participants also completed the Conners et al. (1999) Young Adult ADHD Rating Scale, Achenbach (1991) Young Adult Self Report Scale, and the Brown (1996) Adult ADHD rating scale. Their peer informants completed the Conners et al. (1999) peer rating form, as well as Barkley and Murphy peer ratings on adult symptoms, and a brief screen of antisocial behavior, and drug and alcohol use. The informant also completed a structured interview about the participant's current ADHD symptoms, using the modified K-SADS for current symptoms. All informant interviews were conducted by clinically trained interviewers via telephone after appropriate consent procedures. In the case of adolescents, all of this information was based on parent report, except that concurrent informant reports were also obtained from teacher ratings using the CBCL (Achenbach 1991), Conners et al. (1999) Rating Scale Revised, and the ADHD Rating Scale.

Best Estimate Diagnosis for ADHD—For all participants, a diagnostic team comprised of a licensed clinical psychologist and a board certified psychiatrist arrived at a "best estimate" diagnosis (Faraone et al. 2000). The same team evaluated all cases. Each member independently reviewed all available information from all interviews and all self and informant rating scales (including staff notes and observations) to arrive at a clinical judgment about ADHD present or absent, ADHD subtype, and comorbid disorders. They considered the option of using an “or” algorithm to reach a count of six symptoms, in cases in which there were at least four symptoms from each informant and there was clear evidence of cross-situational impairment, in keeping with the practice in the DSM-IV field trials. Because there is no agreement on age-appropriate cutoffs for adolescents and adults, the team conservatively followed DSM-IV criteria by requiring the six symptoms that DSM-IV specifies. This ensured minimal “false positives” in the ADHD group. False negatives (ADHD cases ending up in the control group) were minimized by requiring four or fewer symptoms of ADHD, no past history of ADHD diagnosis, and rating scale data not in the clinical range for any of the ADHD scales. The DSM-IV criteria regarding comorbidity were carefully followed, so that although comorbid disorders were diagnosed when present, the participant was excluded from the study if the clinicians agreed that ADHD symptoms were better explained by another disorder (APA 1994). This provided some control against obtaining a sample with extreme levels of comorbid disorders while still representing true cases of ADHD. Clinical interviewers rated and noted evidence of impairment (i.e. a rating of at least “moderate” on the KSAD rating scale), and the diagnostic team required such evidence to make the ADHD diagnosis.

Inter-clinician agreement on presence or absence of ADHD was satisfactory (k=0.80), and agreement on ADHD subtype was also adequate, ranging from k=0.74 to 0.90. Diagnostician reliability for comorbid disorders was excellent (past major depression, k=0.96; any current anxiety disorder, k=0.98; antisocial personality disorder, k=0.93; substance or alcohol dependence, k=0.97). Disagreements were handled by conference of the clinicians. It happened that consensus was readily achieved in all cases; had it not been, that case would have been excluded.

Exclusionary Criteria—Potential participants were excluded from all groups if they had a current major depressive or manic/hypomanic episode; current substance dependence preventing sober testing; history of psychosis; history of autism; history of head injury with loss of consciousness greater than 1 min, sensory-motor handicap, neurological illness; currently prescribed anti-psychotic, anti-depressant, or anti-convulsant medications. We also ruled out participants with an IQ<75, in keeping with the field’s consensus definition of mental impairment.

Medication washout—Participants prescribed psychostimulant medications (Adderall, Ritalin, Concerta, & Focalin) were tested after a minimum of 24 h (for short acting preparations) and after 48 h (for long acting preparations); actual mean washout time was from 24 to 176 h. Thirty-nine percent of the adolescents with ADHD and 43% of adults were on medication prior washout. (Treatment rates for ADHD in the community in this age range are estimated at 11% to 50%.) This degree of washout is considered sufficient to minimize medication effects on results.

Apparatus and Materials

The experiment was programmed using E-Prime experimental software (Version 1.1). Participants completed the experiment on a Dell Optiplex GX 400 computer with a 19 in. (48.26 cm) monitor. The stimulus materials consisted of 90 line drawings of easily namable objects, and 54 verbs. Half of the drawings were of animate objects and half were of inanimate objects. Eighteen of the verbs were ambiguous, meaning that the past tense and past participle forms were identical (e.g. *dropped*), eighteen were unambiguous participle verbs (e.g. *ridden*), and 18 were intransitive verbs, which do not passivize (e.g. *melted*). Participle verbs included both irregulars (e.g. *torn*) and *-en* affixes.

Design and Procedure

The design was 3×2 ×2 (diagnostic group×picture order× verb type). Picture order and verb type were within subject, and diagnostic group was between subjects. Picture order indicates which picture, animate or inanimate was presented first. The animate first order should bias towards an active construction (e.g. *The man moved the chair.*), and the inanimate first order should bias towards a passive construction (e.g. *The chair was moved by the man*). Verb type was either ambiguous or participle. Participle verbs are biased towards passives, and are in general more difficult, because they have fewer syntactic options compared to ambiguous verbs. The dependent variables were the type of sentence produced, and reaction time to begin speaking.

On each trial, participants were presented with two pictures and a verb, and their task was to produce a sentence using the pictures as arguments of the verb. Example stimuli are shown in Fig. 1. For this task, the pictures appeared one after the other and were followed by the verb. Participant responses were recorded to audiotape, and then transcribed and coded as described below. Voice onset was recorded by a speech trigger, and reaction time was recorded from the presentation of the verb. Each trial began with a fixation cross presented in the center of the computer screen that was the participants' cue that s/he could press the space bar to see the first picture. After 1 s a second picture appeared. It was then followed by the verb. For trials with intransitive verbs, participants saw only one picture followed by a verb. Participants were instructed to begin speaking as soon as possible. Participants were given four practice trials with feedback, followed by 54 regular session trials: nine in each of the four different conditions, and 18 intransitives. The order of trials was randomly determined for each participant, and participants were tested individually. The entire session lasted approximately 30 min.

Coding—Sentences were coded as active, passive, or other. Active sentences with ambiguous verbs could be either past tense or past participle (e.g. *The boy dropped the ball.* or *The boy had dropped the ball.*). However, the vast majority of sentences (> 94%) with ambiguous verbs resulted in past-tense constructions. For the participle verbs, only the past participle form is available for active sentences. Passive sentences have the inanimate object in the subject position (e.g. *The ball was dropped by the boy*). Sentences were coded as *other/ungrammatical,* if the tense on the verb was changed or if the utterance was ungrammatical. In addition, some of the participle verbs can be used as an adjective modifier (e.g. *The dog found the hidden bone.*). These constructions were also included in the *other* category; however, this type of construction was very rare.

Results

Sentence Type

The condition means for grammatical utterances are shown in panel A of Fig. 2. The results from a 3-way mixed model ANOVA conducted on the proportion of grammatical utterances are shown in Table 2. The results showed that all of the main effects were significant. The main effect of verb type was such that the participle verbs resulted in fewer grammatical utterances compared to the ambiguous verbs. Picture order produced a small, but significant effect, in which the animate first order resulted in fewer grammatical utterances. The main effect of group showed that the participants with ADHD were more likely to produce a deviant sequence compared to controls. There was an interaction between verb type and picture order, which was driven by the differences with the participle verbs. The participle verbs paired with the animate first picture order resulted fewer acceptable responses than did the participle verbs with the inanimate first order. The interaction of group and verb type was also significant. However, the group×picture order, and the three-way interaction were not significant (both ps>0.10).

The means in Fig. 2 suggest that the interaction of group and verb type is likely driven by the poor performance of the ADHD-C participants with the participle verbs. Follow up simple effects analyses within each of the participle verb conditions revealed significant differences with the animate first order $F(2, 192)=5.82$, $p<0.05$, and marginal differences with the inanimate first order $F(2, 192)=2.84$, $p<0.06$. For the animate first/participle verb condition, the ADHD-C group produced significantly more ungrammatical utterances than did controls $t(137)=3.29$, $p<0.05$, and the ADHD-PI group produced marginally more ungrammatical utterances compared to controls $t(141)=1.83$, $p<0.07$. The two ADHD groups were not significant from one another ($p>0.10$). A slightly different pattern was observed in the inanimate first/participle verb condition. Here the ADHD-C group produced significantly more ungrammatical utterances compared to controls $t(137)= 2.32$, $p<0.05$, but the ADHD-PI group was not different from either of the other two groups (both ps>0.10). We also examined grammatical utterances broken down into participles and passives (see panel B of Fig. 2). However, the results did not show any significant group differences.

These results show that the greatest difference between groups occurs in the most computationally demanding conditions, and that the ADHD-C group performs significantly worse compared to controls. The ADHD-PI group, in contrast, falls in between the other two. In the animate first condition, they pattern more similarly to the ADHD-C group, and in the inanimate first condition, they pattern more similarly to controls.

Reaction Time

The condition means for the voice onset data are shown in panel A of Fig. 3. The results from a 3-way (diagnostic group×picture order×verb type) mixed model ANOVA conducted on the reaction time to begin speaking are shown in Table 2. The results showed only a main effect of verb type. Consistent with the previous analysis, the participle verbs showed significantly longer reaction times compared to the ambiguous verbs. None of the other main effects or interactions were significant ($p>0.10$).

Examining the means in the top panel of Fig. 3 suggests that the only potential group differences are between controls and the ADHD-PI group when the animate picture is presented first. Paired comparisons however, showed no significant differences. We also examined the reaction times for trials that were coded as either *ungrammatical* or *other*. The means for the two conditions in which we observed variability in the utterance type analysis (i.e. the participle verb conditions) are presented in the bottom of Fig. 3. Again, none of the group differences were significant.

To investigate speed-accuracy tradeoffs, we examined the correlations between accuracy and reaction time for each of the four within subject conditions for each diagnostic group. The results showed only one significant effect out of 12 correlations. The ADHD-PI group showed a significant negative correlation in the animate first/participle verb condition ($r= -0.404$, $p<0.01$), which is inconsistent with a speed-accuracy tradeoff. Therefore, we can conclude that there are no speed-accuracy tradeoffs between groups in this task.

Age, Gender, and IQ

The inferential statistics presented in Table 2 have a series of superscripts which indicate the results from a series of ANCOVAs. The superscripts in Table 2 indicate when an effect remains significant with the inclusion of a covariate. The purpose of these analyses was to ensure that the effects reported above could not be explained by alternate variables. The first variable we examined was age. We were interested in whether there would be some attenuation of response suppression failures over the course of development. The results however, showed that adults produced very similar proportions of ungrammatical responses as did adolescents. The second variable was gender, and here, because the ADHD-combined subtype group was disproportionately male compared to the other two groups (see Table 1), we wanted to ensure that the observed results were not explainable by gender differences in overall language abilities (Berry et al. 1985). Gender and age did not produce a main effect, nor did they interact with any of the other variables. The final variable that we examined was IQ. As expected, IQ produced a main effect when included in the model. IQ also interacted with picture order and verb type, but it did not change the pattern of results with respect to group differences in any way. The ADHD effects remained with IQ covaried ($p<0.05$).

Discussion

The primary goal of the current study was to determine whether response suppression deficits in ADHD adversely affect sentence-level language production. Many of the key models of ADHD posit that deficits in inhibition lead to impairments, such as suppressing a motor response, inattention, and/or general executive dysfunction (Barkley 1997; Nigg 2001). Furthermore, one of the most commonly reported behavioral symptoms of childhood ADHD is excessive talking, and difficulty using language in conversational contexts. What was not known until now was whether these language production problems persist in adolescents and adults with ADHD. Our results showed that participants with ADHD were more likely to produce an ungrammatical string, suggesting that response suppression problems affect the basic processes of language production. Group differences emerged as the task demands increased, and the combined subtype, in particular, was more likely to begin speaking without having formulated a plan that would allow a grammatical continuation.

The secondary goal of this study was to determine if there was any attenuation of language production problems over time. As we noted earlier, the period from adolescence to young adulthood is a period that sees continued development of cognitive control processes, and so we were interested in examining language production over this developmental period. Our results however, showed no attenuation as adolescents and adults performed similarly. Even when age was included as a continuous variable, it did not account for a significant amount of variance in either of our dependent measures. These findings suggest little attenuation of response suppression failures over the course of later development.

Recall that our experimental hypotheses were based on the fact that speakers have a tendency to place activated concepts in sentence initial positions. So when subjects saw the animate picture first it should bias towards an active structure, and the inanimate first order should bias towards a passive structure. We also manipulated the type of verb that participants received. For the ambiguous verbs, virtually all utterances were active past-tense constructions (e.g. *The boy dropped the ball*). This result shows that when a verb has many options that subjects have an overwhelming preference for active over passives.

With participle verbs, which also bias towards passive structures, there was much more variability, so returning to panel B of Fig. 2, you can see the breakdown of grammatical utterances by sentence type. Participle sentences have the animate object in the subject position (e.g. *The girl had ridden the bicycle.*), and passive sentences have the inanimate object in the subject position (e.g. *The bicycle was ridden by the girl*). The active past-tense structure is not possible with this particular type of verb (e.g. *The girl ridden the bicycle.*). Therefore, the most difficult condition is the one in which the verb type and picture order conflict (i.e. the animate first/participle verb condition), and participants were more likely to make errors in this condition. The results in the bottom of Fig. 2 show that participants were more likely to produce a participle compared to a passive (51% vs. 32%) in this condition. When the inanimate picture was presented first (i.e. passive biasing), participants were equally likely to produce a participle sentence compared to a passive (42% vs. 42%).

This last finding is not surprising considering the frequency of passive sentences. Dick and Elman (2001) conducted several corpus searches, and they found that passives occur approximately 19% of the time in written language and only 3% of the time in speech. Based on these results, we can infer that the passive structure is fairly infrequent, and this is likely why there is general preference for actives, and why the inanimate first/participle verb condition resulted in approximately equal numbers of participle and passive constructions.

As we mentioned earlier, this is the first study to examine sentence-level language production in adolescents and adults with ADHD. Our results fit with the existing story re-telling/narration literature with two exceptions. The first is that Flory et al. (2006) reported that deficits in sustained attention, rather than inhibition accounted for most of the variance between controls and children with ADHD. However, in their task, children were required to narrate a story which requires the participant to maintain a connected chain of thoughts over time, ultimately leading to a coherent story. In our task, participants were presented with independent trials, each lasting no more than several seconds. And so one question that emerges is whether the effects reported in the current paper are due to inhibition or to attention. We have interpreted our findings in terms of inhibition for two reasons. The first is that the task (adopted from psycholinguistics) is specifically designed to tap response suppression processes in sentence formation. The second is that many of the main theoretical models of ADHD posit primary deficits in inhibition, which in turn lead to secondary problems with attention (see also Friedman et al. 2007). However, at this time we cannot conclusively rule out that some of the effects reported here could be due to attention problems.

The second difference between the current study and the existing literature concerns the subtypes of ADHD. Willcutt and Pennington (2000) collected data from almost one thousand participants (age 8–18). They found that inattentive symptoms were more correlated with reading and learning disability. In contrast, we found only marginal differences between controls and the ADHD-PI group. To further investigate differential effects of inattentive versus hyperactive/impulsive symptom dimensions, we ran a follow up regression analysis where we included the two symptom clusters as predictors (see Table 1). We created a difference score to reduce the two conditions of interest (i.e. the participle verb conditions) into a single dependent variable. We then regressed inattentive symptom score, hyperactive/impulsive symptom score, age, and gender on to the proportion of grammatical utterances produced using the entire sample. The results revealed only one significant predictor. The hyperactive symptom score significantly, $t=2.71$, $p<0.001$; $\beta=-0.206$, predicted performance on the number of grammatical sentences produced. The model with one predictor was significant $F(1,179)=7.90$, $p<0.01$, $R^2=0.042$. Age, gender, and inattentive symptoms were not significant ($p>0.30$).

Therefore, our results suggest that problems in language production are more linked to the hyperactive/impulsive symptom cluster, which makes sense considering that speech production involves a motor component, and so it is not at all surprising that we found the biggest differences with the combined subtype. Interestingly though, the combined group did not show evidence of speaking earlier and so our results suggest that the tendency to produce an ungrammatical sentence is most likely related to planning, rather than to the speed of responding.

Two limitations stand out. The first is that we were not able to obtain an adequate sample of ADHD-PH. This is unfortunate because it might have allowed us to clarify the differences between our results and those of Willcutt and Pennington (2000). However, there some literature suggesting that the ADHD-PH subtype is rare after the preschool years (Lahey et al. 2005; Willcutt et al. 2000), so it is not too surprising that we could not identify an adequate sample of this subtype. The second limitation is that some of the effects are rather small. The main effect of group and the group by verb type interaction account for roughly 5% of the variation in the utterance type analysis. On the one hand, it may seem as though the significance of these effects is partially due to the large sample size, and so a little qualification might be in order. However, our task involves forming a sentence using two pictures and a verb. Therefore, for this particular age group the task demands would not seem to be overwhelming. So the fact that we do get reliable group differences is an important finding. We leave it to future work to determine whether stronger effects will be observed under more challenging conditions or whether the differences are truly small.

These limitations aside, the current study provides a clear picture regarding the role of response suppression in language production in adolescents and adults with ADHD. The results suggest that inhibition problems associated with ADHD **do** affect sentence-level language production, such that as task demands increase, participants with the ADHD-C subtype are significantly more likely to produce an ungrammatical sequence. In the participle verb conditions, the ADHD-C group produced a deviant utterance on almost one out of every four trials. The primarily inattentive group was not clearly worse than controls; however, in the most difficult condition they did seem to pattern more closely to the ADHD-C group. These findings indicate that adolescents and adults with the combined subtype often begin speaking before having formulated a plan that will avoid a grammatical dead end.

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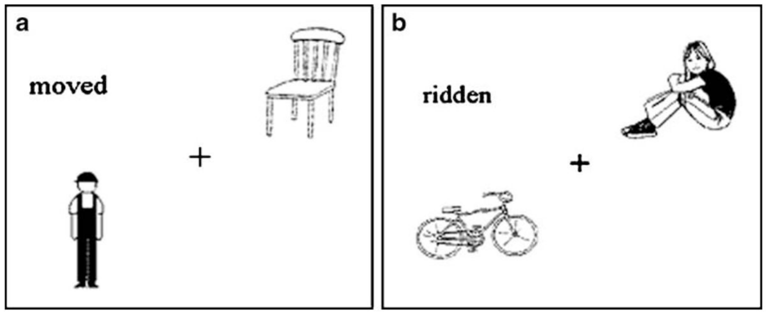

Fig. 1.

Example stimuli, panel **a** shows an ambiguous verb, and panel **b** shows a participle verb

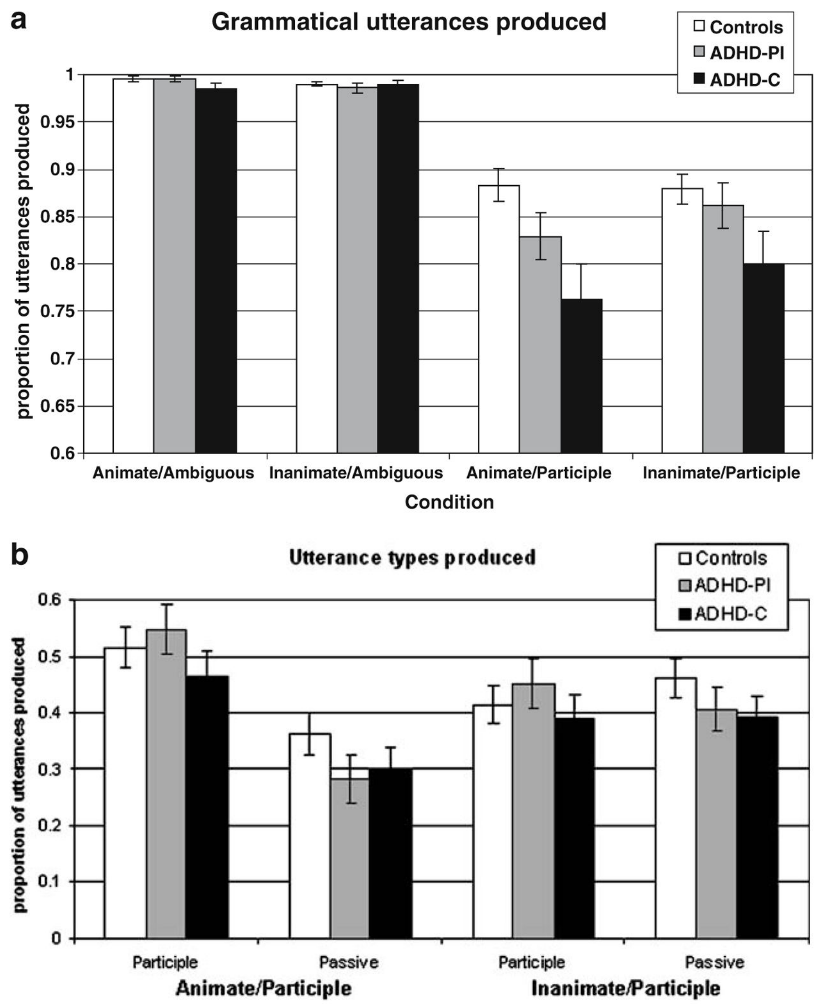

Fig. 2.

Proportion of grammatical utterances produced. Panel **a** shows the proportion in each of the four within subject conditions. Panel **b** shows the (grammatical) sentence types produced in the two participle verb conditions. Error bars show the standard error of the mean

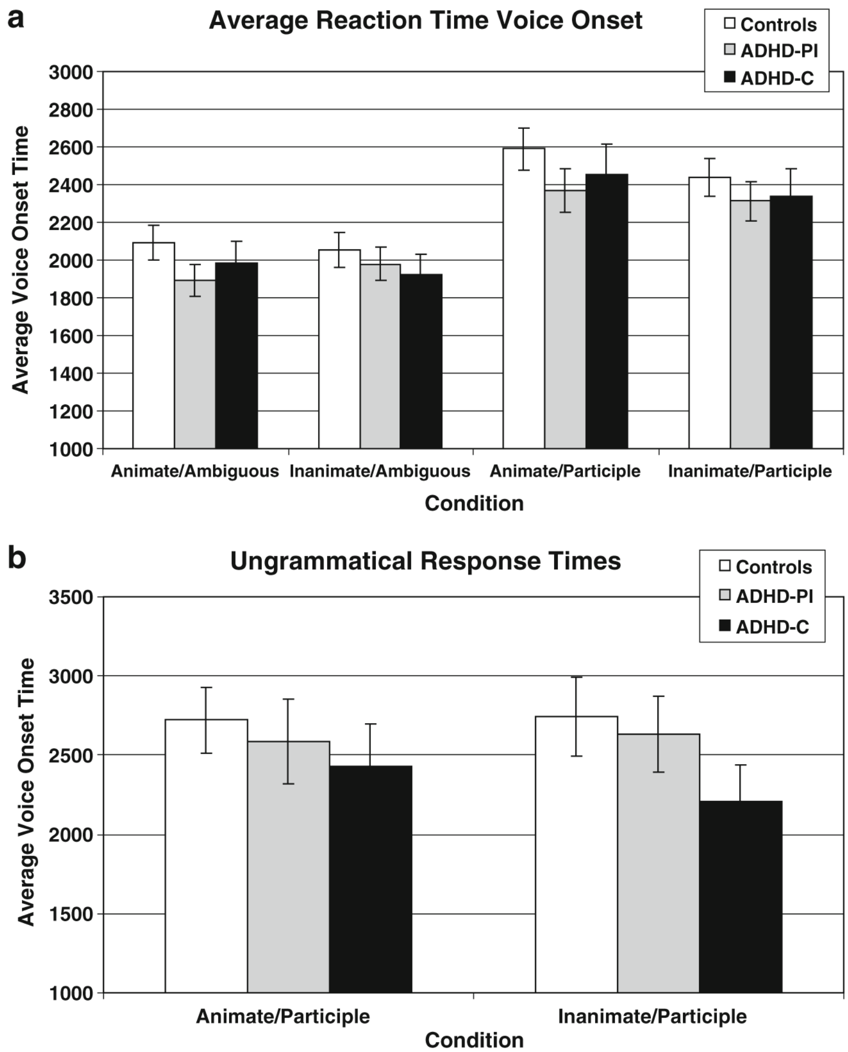

Fig. 3.

Reaction time for voice onsets. Panel **a** shows in the condition means for all utterances in each of the four within subject conditions. Panel **b** shows the reaction times for the ungrammatical utterances in the two participle verb conditions. Error bars show the standard error of the mean

Table 1

ADHD DSM-IV Sub-type Sample Characteristics: Means and Standard Deviations

Variable	Controls (n=87)	ADHD-PI (n=56)	ADHD-C(n=52)	p-value			
	Mean (SD)	Mean (SD)	Mean (SD)	1	2	3	4
Age (years)	17.65 (4.53)	18.21 (4.35)	18.50 (4.59)	0.53	0.47	0.74	0.29
Adolescents (n=130)	15.62 (1.08)	15.44 (1.26)	15.27 (1.01)	0.34	0.45	0.54	0.13
Adults (n=65)	24.05 (5.28)	22.5 (3.91)	22.91 (3.82)	0.49	0.28	0.73	0.42
Gender							
%Male	55.2	62.5	82.7	0.01	0.39	0.02	0.00
%Female	44.8	37.5	17.3				
Full scale IQ	112.37 (13.85)	106.66 (14.19)	105.66 (12.44)	0.01	0.02	0.70	0.01
Reading	104.89 (8.34)	101.94 (11.00)	99.77 (9.61)	0.01	0.08	0.28	0.01
Ethnicity							
%White	73.6	85.7	75.0	0.35	0.24	0.44	0.76
%African American	11.5	5.4	7.7				
%Latino	3.4	5.4	7.7				
%Other/mix/unreported	11.5	3.6	9.6				
Conner's (1)	48.27 (7.21)	65.94 (10.22)	67.78 (8.19)	0.00	0.00	0.33	0.00
Conner's (2)	47.99 (7.31)	57.83 (11.24)	72.57 (10.08)	0.00	0.00	0.00	0.00

Conner's scores are t-scores; (1) is "cognitive problems" which is closely related to DSM-IV Inattentive Symptoms; and (2) is the Hyperactive-Impulsive. Values represent average of informant and self-report for adults, and the average of mother and teacher ratings for adolescents. P-values are as follows: (1) is the 3 group comparison, (2) compares control vs. ADHD-PI, (3) compares ADHD-PI vs. ADHD-C, and (4) compares control vs. ADHD-C

Table 2

Analyses of Variance: Diagnostic Group (control, ADHD-PI, ADHD-C)×Verb Type×Picture Order

Interactions/Main effects	**Proportion of grammatical utterances**	**Reaction time**
3-way		
Group×Verb Type×Picture Order	$F(2,192)=1.89$, $p>0.10$ ($\eta^2=0.02$)	$F(2,192)=0.103$, $p>0.10$ ($\eta^2=0.00$)
2-way		
Group×Verb Type	$F(2,192)=4.10$, $p<0.05$ ($\eta^2=0.04$) [a b c]	$F(2,192)=1.10$, $p>0.10$ ($\eta^2=0.01$)
Group×Picture Order	$F(2,192)=1.79$, $p>0.10$ ($\eta^2=0.02$)	$F(2,192)=0.146$, $p>0.10$ ($\eta^2=0.00$)
Verb Type×Picture Order	$F(1,192)=4.26$, $p<0.05$ ($\eta^2=0.02$) [c]	$F(1,192)=2.06$, $p>0.10$ ($\eta^2=0.01$)
Main effects		
Group	$F(2,192)=5.40$, $p<0.05$ ($\eta^2=0.05$) [a b c]	$F(2,192)=0.756$, $p>0.10$ ($\eta^2=0.01$)
Verb Type	$F(1,192)=137.68$, $p<0.05$ ($\eta^2=0.42$) [a b c]	$F(1,192)=151.9$, $p<0.05$ ($\eta^2=0.45$) [a b c]
Picture Order	$F(1,192)=4.30$, $p<0.05$ ($\eta^2=0.02$) [c]	$F(1,192)=2.76$, $p>0.09$ ($\eta^2=0.02$)

Superscripts indicate that the effect remains significant when including a covariate (*a*=age, *b*=gender, & *c*=IQ)