Use of private speech during math computation in children with Attention Deficit Hyperactivity Disorder: Methodological challenges, task performance and effects of stimulant medication.

By

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A thesis submitted in conformity with the requirements
For the degree of Doctorate of Philosophy
Graduate Department of Education
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ABSTRACT

Objective: To delineate and utilize a rigorous methodological approach to investigate private speech and the effects of stimulant medication in children with Attention Deficit Hyperactivity Disorder (ADHD). Multiple distinct objectives were included: 1) to explore a rigorous methodological approach to the study of private speech in children; 2) to examine task performance and its relationship to private speech; 3) to examine the effects of stimulant medication on private speech in children with ADHD and 4) to investigate private speech in children with ADHD and their normal peers.

Method: Three approaches were used in this thesis. The first approach was to systematically review the literature for methodological differences in the study of private speech using a ‘rating scale’ approach. Secondly, task performance, error patterns and overt behavior of children with ADHD, on and off medication, explored the relationship between private speech and task performance. The third approach was to conduct an empirical investigation to test the hypothesis that children with ADHD are deficient in their production of private speech and/or inefficient in their use of private speech to regulate behavior. This was accomplished by conducting both a comparative study between children with ADHD and their typically developing peers and a randomized double blind placebo controlled medication trial for children with ADHD.
Results: First, it was found that methodological differences in the study of private speech in children are innumerable. Second, children with ADHD demonstrated lower levels of academic efficiency, used more immature computational strategies and exhibited increased levels of inattention and disruptive behavior during a math computation task. The comparative study demonstrated that ADHD and non-ADHD children differed in the sub-types of private speech emitted but not in overall amounts of private speech produced. Children with ADHD produced more overt on-task private speech and less internalized private speech compared to their non-affected peers. Furthermore, the medication trial showed that the effects of stimulant medication were positive, resulting in increased developmental maturity of private speech. ADHD children were produced more internalized private speech and less overt private speech.

Conclusions: Results across the three approaches suggest that the study of private speech in atypical populations, particularly ADHD is a promising avenue of research. Two of these studies support the notion that a systematic approach to the study of private speech is warranted. When children with ADHD are given tasks that are individually mapped to ability level they are not deficient in their production of private speech, but rather exhibit a functional deficit. It would be beneficial for future research to address the potential misuse of global matching of tasks at age or grade level to elicit private speech in children. Lastly, this thesis speaks to the two prevailing theories (Vygotsky & Barkley) on the relationship between private speech and behavior. Should the results of the empirical study of private speech contained in this thesis be replicated in future research it suggests that children with ADHD may have a higher order difficulty that affects a number of behavioral responses, including but not necessarily limited to private speech.
This thesis is dedicated to my daughter Emily Catherine Nasho.

"Children need to believe that they can make a contribution, make a difference in their families."

Barbara Coloroso
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Parts of this thesis have been published (Chapter 3) and submitted for publication (Chapter 4).


CHAPTER 1

Statement of the Problem
Private speech is defined as speech that is directed toward the self or not explicitly addressed to another person. The phenomenon where children speak to themselves without any apparent attempt at social communication has been investigated since the early 20th century. Two contemporaries observed the same behavior in young children hypothesizing different origins and functions for this behavior. Piaget (1923/1962) believed that speech 'not clearly directed to another' was an unmediated result of the immaturity of the cognitive system and the egocentric quality of children's social exchanges. This speech was perceived as being a rudimentary stage in language development that had little to do with children’s cognitive development. Vygotsky observed the same phenomenon, yet he ascribed an alternate origin and a very unique role to this language in the cognitive development of young children.

Vygotsky (1934/1986) postulated that 'speech to the self', private speech, was born of early social exchanges with more expert members of society, namely adults, during cognitively demanding tasks. Repeated collaboration with adults within the Zone of Proximal Development (ZPD), the zone of functioning where children collaborate with more expert members of their culture on challenging tasks, was hypothesized to allow children to use the adults' regulatory utterances to move from other-regulation to shared-regulation to self-regulation. He believed that this facilitated children learning to regulate their own behaviors such as focusing their attention and providing themselves with positive feedback (Diaz et al., 1990; McCarthy, 1992; Schunk & Zimmerman, 1994; Winsler, Diaz, & Montero, 1997).

Vygotsky further hypothesized a developmental pathway of private speech whereby the ability to use speech as a self-regulatory tool improved over the preschool years. Initially private speech is external, preceding action, it then occurs simultaneously with action, finally it becomes internalized as it gains control of behavior and becomes self-regulatory inner verbal thought.
Over time, through the use of private speech, children gain independent control of their own behavior (Berk & Winsler, 1995; Diaz, Neal, & Amaya-Williams, 1990; Winsler, Diaz, & Montero, 1997).

The majority of research into children’s use and function of private speech has been interpreted as supportive of Vygotsky’s hypotheses (see Berk, 1992, for a comprehensive review). Private speech during cognitive tasks follows a developmental path from external self-stimulating forms, through to external self-guiding speech, to internal self-directed language (Berk, 1986, 1992; Berk & Garvin, 1984; Berk & Potts, 1991; Bivens & Berk, 1990; Fraunglass & Diaz, 1985; Kohlberg, Yaeger & Hjertholm, 1968; Winsler, 1995). The function of private speech is that of self-guidance: an increased use of private speech during cognitively demanding tasks is well documented (Beaudichon, 1973; Behrend, Rosengren, & Perlmutter, 1989, 1992; Berk, 1986; Berk & Garvin, 1984; Kohlberg et al., 1968; Goodman, 1981). Private speech, behavior and future task success are positively related. On-task private speech has been consistently associated with on-task behavior and improved performance over time (Azmitia, 1992; Beaudichon, 1973; Behrend et al., 1992; Bivens & Berk, 1990; Gaskill & Diaz, 1991; Winsler et al., 1997). And lastly, internalization of private speech has been shown to be associated with improved self-regulation (Berk & Potts, 1991; Berk & Landau, 1993; Diaz, Winsler, Atencio, & Harbers, 1992; Winsler, 1998).

Private speech refers to the use of language for the purpose of self-regulation and despite a lack of definitive evidence of a cause and effect association between private speech and self-regulation there is ample evidence that can be interpreted to be supportive of such a relationship (Krafft & Berk, 1998). All types of children, with both hypothesized strengths and weaknesses in self-regulation, produce private speech during cognitively challenging tasks (Berk, 1986; Berk
& Garvin, 1984; Berk & Landau, 1993, 1997; Berk & Spuhl, 1985; Daugherty, 1993, Frauenglass & Diaz, 1985; Jamieson, 1995). Task-facilitating behaviors such as focused attention and motor quiescence are often positively related to on-task private speech and off-task behaviors such as self-stimulatory body movements and inattention are negatively associated with on-task private speech (Berk, 1986; Berk & Landau, 1993, 1997; Bivens & Berk, 1990). Immediate and future task success are both positively correlated with private speech (e.g., Montero & Diaz, 1992).

Two issues are paramount in the study of private speech. First is the existence of two theoretical positions on the relationship between private speech and self-regulation. Both views however, lead to the hypothesis that children with deficits in self-regulation, such as those with ADHD, are impaired in their production and use of private speech. Second are the numerous methodological challenges that exist in the study of private speech. No standard methodology has been adopted and very few studies exist investigating private speech in clinically diagnosed children with ADHD.

**Challenge #1: Theory**

Vygotsky (1934/1987, 1930-1935/1978) suggested that private speech is a uniquely human ability that enables children to control their own behavior and allows them to master their attention. This has been interpreted by some to mean that Vygotsky believed in a unidirectional pathway between private speech and self-controlled behavior (Berk & Potts, 1991). He asserted that private speech served to guide children's behavior. His comment "with the help of the indicative function of word, the child begins to master his attention" (1978, p. 35) does not necessarily imply that one does not need additional attentional control in order to further develop the effectiveness of private speech in self-regulation. This is in agreement with the argument that it is equally as likely that private speech improves attention as attention improves private
speech (Pressley, 1979). Following the Vygotskian premise that private speech permits children to master their attention, it has been assumed that children with behavioral and attentional difficulties are deficient in verbal self-regulation.

Within a contemporary model of ADHD, Barkley (1997) hypothesizes a somewhat different pathway between private speech and behavioral self-regulation. He suggests that private speech is one of four executive functions that rely on behavioral inhibition for its effective execution. Behavioral inhibition refers to three processes: 1) the ability to stop the initial prepotent response to a particular event, 2) the ability to stop an ongoing response and 3) the ability for interference control during the period of time between 1 and 2. This model specifically predicts deficits in behavioral inhibition and thus private speech in children with ADHD.

ADHD is the most common childhood disorder presented to children’s mental health services (APA, 1994; Barkley, 1990; Schachar, 1991) and is characterized as having three core symptoms: difficulty in attention, impulsivity and hyperactivity (APA, 1994). It often presents itself with a number of other features including neurological, intellectual, academic, and social impairments (i.e., Barkley, 1990; Schachar, 1991). It is estimated that three to six percent of school-aged children are diagnosed with this disorder (APA, 1994; Barkley, 1990; Schachar, 1991). In children that receive intervention for this disorder, stimulant medication is one of the primary forms of treatment (Szatmari et al., 1987).

Challenge #2: The Empirical Investigation of Private Speech

The theoretical position that deficits in self-regulation lead to deficits in private speech have led researchers to the empirical question: Do children with behavioral and attentional difficulties, including but not limited to children with ADHD, have deficits in verbal self-
A number of challenges arise in the attempt to investigate this question: lack of consistency in diagnostic criteria, pervasiveness of symptomatology, the existence of comorbid conditions, the use of varied assessment tools, and difficulties in defining core features of the disorder (i.e., attention deficit, impulsivity and methodological difficulties in the study of private speech). One of the results of such challenges has been limited empirical investigations into the private speech of children with ADHD.

As mentioned, the study of private speech in both typical and atypical populations is wrought with methodological challenges. The foremost challenge has been in the reliable elicitation of adequate quantities of private speech across studies. For example, research has consistently found discrepant amounts of private speech produced by children of the same age. Berk & Spuhl (1995) point out that in some studies as much as 50% of the children studied produced no private speech at all. This raises the question of whether or not the lack of production of private speech by children is representative of a lack of inner speech or rather a reflection of its internalization. While the experimental environments under which private speech have been studied has been multifaceted, few studies have investigated the effects of specific experimental design variables such as setting, task type, task difficulty and the effect of the presence of others to determine if there is an optimal set of variables for the study of private speech.

It is also apparent that the literature includes studies that use tasks that potentially constrain children’s spontaneous production of private speech. And for atypical populations, the relationship between private speech and task type may be of particular importance since private speech production and task performance may be confounded by task related skill deficits. Various tasks have been used to elicit private speech with various levels of success. A differentiation has
been made between tasks that are visually-spatially oriented and tasks that have a semantic base (Fraunglass & Diaz, 1985) as well as tasks that are open-ended versus closed ended (Krafft & Berk, 1998). It is now believed that verbally mediated tasks unlike visual spatial tasks are more likely to encourage the use of private speech. More recently this premise has been extended to the use of private speech during pretend play, a highly language-based activity. Krafft and Berk (1998) reported that the incidence of private speech was much higher during open-ended activities, especially pretend play that is intrinsically social in nature and requires the child to determine both the complexity and the goal of the task. Closed-ended activities that had difficulty level and goals pre-determined (Krafft & Berk, 1998) were less likely to produce high levels of private speech. This leaves open to investigation what type of task would be best suited to optimizing the production of private speech.

In line with the discussion of task type, is the belief that the production of private speech is facilitated by tasks that are cognitively challenging (Berk & Garvin, 1984; Fuson, 1979; Vygotsky 1934/1978). Most often global measures are taken to ensure a match between task difficulty and children's skill level. This typically takes the form of equating task difficulty by age or grade level (i.e., Berk & Landau, 1993; Winsler & Diaz, 1995; Daugherty, 1993; Daugherty, White, & Manning, 1994). Winsler, Diaz and Montero (1997), in their laboratory based study, are the only researchers to date who have taken into account Diaz's (1992) observation that the relationship between private speech and task performance is likely to be dependent upon competence within a particular task. That is, during parts of a task that can be performed with little effort, little private speech should be observed. As a task becomes more difficult the use of private speech should increase as the child attempts to gain mastery over the task and lastly as the child gains more skill at that particular task, private speech should decrease.
once again. This potential variation in the need to produce private speech within tasks has just begun to be addressed in the literature. This is evident if one looks at the reported relationship between concurrent task performance and private speech. There is evidence of a positive relationship, a negative relationship and no relationship at all (Azmitia, 1992; Beaudichon, 1973; Bivens & Berk, 1990; Frauenglass & Diaz, 1985; Gaskill & Diaz, 1991; Goudena, 1987; Goodman, 1981; Zivin, 1972). Although it makes task selection more difficult, if the role of private speech is self-guidance then only a task that is individualized to a particular child’s skill level will optimize the child’s production of private speech. Consistent with this hypothesis, laboratory investigations that use appropriate tasks and that ensure difficulty levels are matched to children’s skill level, find that all children produce private speech (Berk & Spuhl, 1995).

Previous research on private speech has provided many insights into factors associated with its production. However, striking differences in methodology make it impossible to integrate findings across the laboratory-based studies and draw firm conclusions. Research on private speech in atypical populations has been hampered further by the limited number of studies available. For example, only three studies to date have investigated the private speech of children with a clinical diagnosis of ADHD. Copeland (1979) suggested that children with ADHD produced more private speech overall and specifically higher levels of immature private speech. Berk & Potts (1991) found that the overall incidence of private speech was almost identical for ADHD and non-ADHD children. They hypothesized that differences between groups reflected an increased use of immature forms of private speech for the children with ADHD. Winsler (1998) found similar weaknesses in his sample of boys with ADHD, finding that their private speech contained more off-task language and that their speech was less related to ongoing task activity. Although these studies are clearly not definitive it has been suggested
that children with ADHD are not deficient in their production of private speech but rather it is their ability to use private speech as a self-regulatory tool that may be compromised.

Chapter 2 is a review of the literature since Diaz's review in 1992 where he clearly delineated a number of methodological challenges that if taken into consideration by future researchers would likely help in the empirical investigation of private speech. This paper examines the inconsistencies across studies since then in the study of private speech and discusses the potential affects this may have on our understanding of the phenomenon. A descriptive 'rating-scale' approach is used to highlight methodological differences in terms of setting, task type, task difficulty, presence of others and the reporting of explicit instructions. In addition three pilots studies are discussed in their relation to the selection of an optimal task. The goal of this critique of the literature, in addition to the pilot studies was to identify a more systematic approach to the elicitation of private speech in children.

Chapter 3 represents an in-depth examination of the behavioral and performance data collected during the private speech study reported in Chapter 4. This included a non-ADHD comparison group study in addition to a medication trial for the children with ADHD. The purpose of this study was to provide a clearer picture of task performance in order to interpret the interplay between task performance and private speech.

Chapter 4 presents data from a study that first examined the production and function of private speech in children with ADHD and a non-ADHD comparison group during academic seatwork in the laboratory. Secondly, a randomized double blind placebo controlled medication trial was conducted with the children with ADHD. This medication trial represents the only one of its type found in the literature to date. The goals of this thesis are multiple: 1) to explore a rigorous methodological approach to the study of private speech in children; 2) to examine task
performance and its relationship to private speech; 3) to examine the effects of stimulant medication on private speech in children with ADHD and 4) to investigate private speech in children with ADHD and their normal peers.

Chapter 5 is an integration of the findings across the three approaches found in this thesis. This chapter also includes the limitations of the present research, suggestions for future research and clinical implications.

Footnote

1 This thesis is comprised of several published and submitted manuscripts. In making each of these self-contained, overlap of the text of some of the chapters was unavoidable.
CHAPTER 2

Abstract

Objective: To critically review the literature with respect to methodological differences in the study of private speech.

Method: A Medline and Psychlit literature search was performed to identify studies investigating private speech since 1992 when a methodological review was conducted by Diaz (1992). Each study was described and rated with regards to methodological variables: task type, task difficulty, statement of instructions and the presence of others. Level 1: all 4 variables addressed, Level 2: 3 variables addressed, Level 3: 2 variables addressed, and Level 4: no variables addressed.

Results: Since 1992, 51 entries were found: five dissertations, five peer-reviewed theoretical papers, seven chapters, 16 peer-reviewed empirical studies dealing with children, and four peer-reviewed empirical studies addressing private speech in adults. No studies were rated as Level 1 or 2, three studies were rated as Level 3 and 13 studies as Level 4.

Conclusion: Despite Diaz's methodological recommendations in 1992 the methodology of the majority of studies reviewed here did not follow optimal practice. Further understanding of the phenomenon of private speech will continue to be hampered until researchers agree to follow a 'best-practice' approach to the study of private speech. This approach would minimally include: 1) use of semantic based tasks, particularly academic seatwork, 2) individual titration of task difficulty and child skill level, and 3) inclusion of explicit statements of instructions to children.
Research into children’s language has resulted in the differentiation of two types of speech: that which is directed at others for the purpose of social interaction and that which is directed to oneself for the purpose of self-regulation. The latter phenomenon is termed ‘private speech’. Vygotsky (1934/1987, 1978) proposed that private speech begins in early social language, that it represents thought spoken aloud, that it is the developmental pathway of external reasoning to internal thought and that its function is that of self-guidance. He saw private speech as a uniquely human ability that empowers higher cognitive ability.

Before children are able to use language as a tool for regulating behavior, adults are responsible for monitoring and regulating their actions. As development proceeds, a transition takes place, a period of joint regulation, where children and adults are conjointly responsible for behavior. Finally, early in the preschool years, after children have acquired language, another transition takes place where children begin to self-regulate their own behavior through language. Many theorists, including Vygotsky, claim that the ability to use language to self-regulate is one of the most important milestones in cognitive development (Diaz, Neal & Amaya-Williams, 1990; Flavell, 1977; Vygotsky, 1934/1978, 81; Wertsch, 1985). Private speech thus represents a significant area of inquiry.

The study of private speech in typically developing children has supported the Vygotskian model. There is a developmental sequence, the function of private speech is self-guidance and private speech, behavior and task performance are typically positively related (e.g., Azmitia, 1992; Behrend, Rosengren, & Perlmutter, 1989, 1992; Berk, 1986; Berk & Garvin, 1984; Berk & Potts, 1991; Frauenglass & Diaz, 1985; Gaskill & Diaz, 1991; Winsler, 1995). Investigations of atypical development, namely children with Attention Deficit Hyperactivity Disorder, Learning Disabilities and ‘Gifted’ children also support Vygotsky’s hypotheses (e.g.,
Although the production and use of private speech in these populations differs somewhat from typical development many of Vygotsky's premises have been upheld. The finding that all children, produce and use private speech at some level, despite varying disabilities or differences in language skill, supports Vygotsky's premise that 'private speech' is a universal stage in cognitive development.

Vygotsky, himself, delineated two 'methodological' obstacles in the investigation of private speech. First, he found that the self-regulatory function of private speech was most pronounced at times when the child was faced with a cognitively challenging task. Specifically, he demonstrated that the frequency of children's private speech increased with task difficulty. Second, he demonstrated that the presence of an adult decreased the amount of private speech produced. These findings have continued to be supported empirically in contemporary research (Beaudichon, 1973; Behrend, Rosengren, & Perlmutter, 1989; Berk & Garvin, 1984; Berner, 1971; Kohlberg, Yaeger, & Hjertholm, 1968; Murray, 1979; Rubin, Hultsch, & Peters, 1971).

Private speech has been characterized as a phenomenon that is highly sensitive to experimental manipulation and wrought with methodological difficulties associated with its study (Diaz, 1992). It is low in frequency (Fuson, 1979), barely audible as it is internalized (Berk, 1986), facilitated or constrained by social variables (Berk & Garvin, 1984; Berk & Spuhl, 1994; Berner, 1971; Diaz, Neal, & Vacchio, 1991; Goudena, 1987; Rubin, Hultsch, & Peters, 1971), highly dependent on setting (Berk & Garvin, 1984) and task instruction (Fraunglass & Diaz, 1985), and associated with both current and future task performance (Gaskill & Diaz, 1991; Goodman, 1981; Montero & Diaz, 1992). Of most relevance to the present paper is how
these factors make it difficult to elicit private speech in sufficient quantities and with comparable design features to effectively study the phenomenon.

Vygotsky was the first to realize that to be effective in eliciting optimal or 'true' amounts of private speech, methodological considerations were essential. The suggestion that methodological variables, such as task difficulty, have a significant impact on the production of private speech is one that has been consistently highlighted in more recent writings (Diaz, 1986). Nonetheless, Diaz's (1992) chapter 'Methodological Concerns in the Study of Private Speech', is the only document to date that specifically discusses the methodological difficulties associated with the study of private speech. Diaz (1992) concludes his review by making a number of global 'methodological' suggestions, none of which specifically address the issue of the elicitation of private speech. He does however offer the suggestion that private speech can be reliably elicited by using tasks of medium difficulty and that the presence of another can increase the production of private speech only if that person refrains from taking over the self-regulatory function of language.

One of the major challenges in the study of private speech is that it is not a salient phenomenon and before Diaz's (1992) methodological review few studies attempted to specifically address the methodological difficulties associated with its elicitation. The most notable of studies to date was that conducted by Frauenglass and Diaz (1985) examining the influence of task type on the quantity of private speech. The purpose of that study was to demonstrate that the low level of private speech production seen in past research was an artifact of methodology. These investigators compared the use of visual-spatial tasks (puzzles, block design) and semantic tasks (card classification, story sequencing) with or without explicit instructions encouraging private speech. They concluded that visual-spatial tasks discouragethe
use of private speech as children rely on perceptual strategies to complete the task. In comparison, semantic tasks promote children’s use of language as a tool of thought and thus maximize children’s production of private speech. In addition, they found that instructions that encourage the use of overt language (e.g., “Some children like to talk aloud while they play these games. I would like you to try that. You talk aloud and say whatever you want to say”) (Frauenglass & Diaz, pg. 360, 1985), almost doubled the amount of private speech utterances children produced.

Other investigators have explored the issue of task difficulty. According to Vygotsky’s theory private speech should be produced during times of relative difficulty within a given task. Tasks that are too difficult should therefore inhibit the use of language to guide behavior and tasks that are too easy should employ skills that are automated, again not requiring self-guiding language. All studies concluded that the increased production of private speech was facilitated by tasks that were cognitively demanding, of medium difficulty and where failure was perceived as being self determined (Berk & Garvin, 1984; Goodman, 1981; Deutsch & Stein, 1972; Behrend, Rosengren, & Perlmutter, 1989).

Yet another factor that had been hypothesized to be problematic was that of setting. Berk (1986), for example, reported a significantly higher frequency of private speech emitted in the classroom under naturalistic observation in comparison to studies that investigated private speech in the laboratory. The appropriateness of drawing conclusions regarding the absolute frequency of private speech production in childhood given findings gathered in different settings was therefore questioned (Diaz, 1992).

The purpose of this review was to examine the literature from 1992 to the present to ascertain whether or not investigators have taken into account Diaz’s methodological suggestions
regarding the study of private speech and to determine to what degree this has affected our understanding of the phenomenon. To this end, this review is limited to empirical studies involving children that were published in English peer-reviewed journals. Due to the focus on methodology, each study was rated according to the presence of methodological variables. Unlike a meta-analysis, which relies on similar outcome measures, the ‘rating’ approach facilitates comparison across studies that differ in methodological variables and thus seemed an appropriate choice to help clarify potential difficulties with varying methodologies. This review examined studies with respect to setting, task type, task difficulty, instructions, and the presence of others in the attempt to elicit private speech from children.

METHOD

Literature Review. A systematic search of the literature was conducted from 1992 to the present. Medline and Psychlit were searched using the specific search criteria term “private speech”.

Evaluation of Studies. The following four criteria were considered essential to the validity of a procedure for eliciting private speech in the laboratory. Any criterion had to be explicitly stated to be considered present. The first criterion was use of a known verbally mediated task or a task that within the study had been demonstrated to be verbally mediated. The second criterion was mapping of task difficulty with task performance. To satisfy this criterion, it was required that each subject be individually pre-tested on the experimental task to determine skill level. The third criterion was an explicit statement of the instructions provided to the children before beginning the task. The fourth criterion was the non-regulatory presence of another person during task completion. To satisfy this criterion steps had to be taken to minimize the possibility of the adult functioning as a self-regulatory tool. This included sitting at least two feet from the child, appearing to be pre-occupied with a different task and minimizing conversation between
the child and adult. A rating system was developed to categorize the methodological differences of each study included in our study with equal weighting for each criterion. The rating scale for the methodological differences of the studies is as follows: Level 1, 4 of 4 criteria were satisfied; Level 3, three of four criteria were satisfied; Level 2, two of four criteria were satisfied; and Level 1, one or zero criteria were satisfied. A modified rating was given to each naturalistic study with the exclusion of criteria 4, as one of the main design features is the presence of others.

RESULTS

Literature Review. In total, 51 entries were found. The breakdown was as follows: five dissertations (Bivens, 1993; Winsler, 1995; Chang, 1995; McCarthy, 1999; Mang, 1998), five peer-reviewed theoretical papers (John-Steiner & Panofsky, 1994; Holaday, LaMontagne, & Marail, 1994; McCafferty, 1994; Diaz & Berk, 1995; Girbau, 1996), seven chapters (Ramirez & Smith, 1994; Bivens & Smolka, 1995; Iwao, 1995; Lantolf, 1997; Carlson, 1997; Alexander, White, & Daugherty, 1997; Dillenbourg, 1996), 16 peer-reviewed empirical studies dealing with children (White & Manning, 1994; Daugherty, White & Manning, 1994; Daugherty, 1993; Berk & Landau, 1993: Manning, White, & Daugherty, 1994; Jamieson, 1995; Winsler & Diaz, 1995; Berk & Spuhl, 1995; Winsler, Diaz, & Montero, 1997; Fernyhough & Russell, 1997; Duncan & Pratt, 1997; Daugherty & Logan, 1996; Winsler, Diaz, McCarthy, Atencio, & Chabay, 1999; Sturn & Johnston, 1999; Krafft & Berk, 1998; Winsler, 1998), four peer-reviewed empirical studies addressing private speech in adults (Kronk, 1994; Appel & Lantolf, 1994; Cowan & Hodge, 1996; Duncan & Cheyne, 1999) and 14 reprints of articles published before 1992.

The sixteen peer-reviewed studies examining private speech in children were reviewed further. These studies were divided into two groups based on setting: studies conducted within an experimental paradigm (laboratory or makeshift school laboratory setting) and those that were
naturalistic in design (either conducted in-home or in-classroom). Ten studies were experimental in nature, five naturalistic and one study compared settings (see Table 2.1). None of these studies were rated as Level 4, three studies were rated as Level 3, three studies as Level 2 and 10 studies as Level 1.

Most studies did not label their tasks in terms of requiring the use of verbal mediation. Based on the work of Frauenglass & Diaz (1985) however tasks that could potentially be solved solely through visual strategies was not considered semantic and therefore not verbally mediated. Examples include construction tasks (tangrams, block/Lego building), artwork and free play. Tasks that were interpreted as being verbally mediated included math or language academic seatwork, classification tasks, and story sequencing or selective attention tasks. Three studies used a verbally mediated task, two studies used a verbally mediated task and a visual spatial task, eight studies used only a visual spatial task and three studies did not provide a clear description of the task used.

No studies in this review individually pre-tested children for their ability on the experimental task. All studies relied on global matching, such as age, grade or group pilot testing to determine difficulty level. For example, “The magnet board task was chosen after extensive pilot testing on the basis of it being at an appropriate level of difficulty for this age group” (Winsler, Diaz, McCarthy, Atencio, & Chabay, 1999, pp. 894). Instructions given to the children before beginning the task were explicitly stated in two of the studies (Berk & Spuhl, 1995; Sturn & Johnston, 1999).

The presence of others criterion was reviewed only for studies using an experimental design. Of these ten studies, six reported the presence of the adult experimenter during completion of the task. Adults were located in the same room, either a good distance from the
child or separated by a shield. In all cases, it was implied that the adult told the children that they were busy completing another task and that they should work independently on the task.
### Table 2.1

**Methodological Characteristics of Peer-Reviewed Private Speech Studies**

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Setting</th>
<th>Task Type</th>
<th>Task Difficulty - Individual Pretest</th>
<th>Explicit Instructions</th>
<th>Presence of Others</th>
<th>Results</th>
<th>Rating Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sturm &amp; Johnston, 1999</td>
<td>Laboratory</td>
<td>Fantasy-play construction task</td>
<td>No</td>
<td>Yes</td>
<td>Yes - 2 children 1 adult (NR)</td>
<td>Mean # of PS utterances - 5.3/min SLI &lt; problem solving PS Diff. due to &lt; PS overall NC &gt; PS - cogn eff NC &gt; PS - cogn effic</td>
<td>3</td>
</tr>
<tr>
<td>Winsler, Diaz, McCarthy, Atencio, &amp; Chabay, 1999</td>
<td>Laboratory</td>
<td>Clown construction</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Mean # of PS utterances - 1.2-3.0/min</td>
<td>1</td>
</tr>
<tr>
<td>Krafft &amp; Herc, 1998</td>
<td>Montessori &amp; Traditional classroom</td>
<td>Functional play Constructive play Fantasy play</td>
<td>N/A</td>
<td>N/A</td>
<td>All children</td>
<td>PS 34% of intervals</td>
<td>1</td>
</tr>
<tr>
<td>Winsler, 1998</td>
<td>Laboratory</td>
<td>Lego Construction Selective Attention</td>
<td>No</td>
<td>No</td>
<td>Yes - Mother or Adult</td>
<td>Mean # of PS utterances - 2.7-4.6/min &gt; adult reg’n &lt; PS, &lt; parent lang &lt; PS</td>
<td>1</td>
</tr>
<tr>
<td>Fernyhough &amp; Russell, 1997</td>
<td>Laboratory</td>
<td>Free-play</td>
<td>N/A</td>
<td>No</td>
<td>Yes - 3-4 children 1 adult (NR)</td>
<td>Mean # of PS utterances - 1.1/min Relationship between PS &amp; ability to recog own voice</td>
<td>1</td>
</tr>
<tr>
<td>Duncan &amp; Pratt, 1997</td>
<td>Isolated classroom</td>
<td>Paper folding Story sequencing</td>
<td>No</td>
<td>No</td>
<td>Yes 1 adult (NR)</td>
<td>Mean # of PS utterances - 0.4-1.8 / min PS &gt; on difficult tasks PS &gt; on Story sequencing</td>
<td>3</td>
</tr>
<tr>
<td>Winsler, Diaz, &amp; Montero, 1997</td>
<td>Laboratory classroom</td>
<td>Selective Attention task</td>
<td>No</td>
<td>No</td>
<td>Yes 1 adult</td>
<td>Did not separate SS from PS</td>
<td>2</td>
</tr>
<tr>
<td>Daugherty &amp; Logan, 1996</td>
<td>Laboratory</td>
<td>Classification (sorting) Patterning (blocks)</td>
<td>No</td>
<td>No</td>
<td>Yes (5 feet) 1 adult (NR)</td>
<td>Mean # of PS utterances not reported Task relevant PS predicted creativity</td>
<td>1</td>
</tr>
<tr>
<td>Jamieson, 1995</td>
<td>Home</td>
<td>Construction (blocks)</td>
<td>No</td>
<td>No</td>
<td>Yes - mother Reg func unclear</td>
<td>Mean # of PS utterances - 3.4/min HM-IX &amp; DM-DC used PS to guide behavior &gt;PS by DM-DC</td>
<td>1</td>
</tr>
<tr>
<td>Berke &amp; Spuhl, 1995</td>
<td>Laboratory</td>
<td>Construction (e.g., Matrix task)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes 1 adult (NR)</td>
<td>All children produced PS</td>
<td>3</td>
</tr>
<tr>
<td>Winsler &amp; Diaz, 1995</td>
<td>Classroom</td>
<td>Free Play, SS play SS teacher Teacher direct</td>
<td>No or N/A</td>
<td>No</td>
<td>Yes - All children Adults</td>
<td>26% of observations PS Amount of PS varied according to amount of external regulation</td>
<td>2</td>
</tr>
<tr>
<td>Daugherty, White &amp; Manning, 1994</td>
<td>Laboratory school</td>
<td>Language</td>
<td>No</td>
<td>No</td>
<td>Yes - 1 children 1 adult (NR)</td>
<td>Mean # of PS utterances not reported PS - creativity</td>
<td>1</td>
</tr>
<tr>
<td>White &amp; Manning, 1994</td>
<td>Classroom</td>
<td>Common school tasks</td>
<td>No</td>
<td>No</td>
<td>Yes - All children 1 adult (NR)</td>
<td>20 PS utterances /child collected Treatment group &lt; T1 &amp; Non-Fac 1R &amp; meta cogn</td>
<td>1</td>
</tr>
<tr>
<td>Manning, White &amp; Daugherty, 1994</td>
<td>Classroom</td>
<td>Independent common school tasks</td>
<td>No</td>
<td>No</td>
<td>Yes - All children 1 adult (NR)</td>
<td>20 PS utterances /child collected Autonomous learners &amp; academically advanced learners - T1 PS &amp; - facilitative TR</td>
<td>1</td>
</tr>
<tr>
<td>Study</td>
<td>Setting</td>
<td>Language &amp; task</td>
<td>M.T.</td>
<td>I.T.</td>
<td>Compare</td>
<td>Findings</td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td>-------------</td>
<td>-----------------</td>
<td>------</td>
<td>------</td>
<td>------------</td>
<td>--------------------------------------------------------------------------</td>
<td></td>
</tr>
</tbody>
</table>
| Berk & Landau, 1993 | Classroom Laboratory | Language & math seatwork | No   | No   | Yes - All children 1 adult (NR) | 68% of observations PS  
No diff between tasks in PS production  
LD 2x more than NC TR  
LD = NC TR  
LD/AD/HD 3x more TR than LD & 3x NC |
| Daugherty, 1993   | Laboratory school | Language | No   | No   | Yes - 1 children 1 adult (NR) | Mean # of PS utterances not reported  
PS - creativity  
TR <4-5 yrs >5-6 yrs  
Non-facilitative PS - as age - |

Note: M.T. = hearing mother deaf child, I.T. = deaf mother deaf child, PS = private speech; T = off-task, TR = task-relevant.
DISCUSSION

Studies involving the study of private speech in children more often than not occur in the laboratory under experimental conditions than in naturalistic settings. This is a positive step forward in the study of private speech as the laboratory allows for greater control of extraneous variables and is often more practical. Despite methodological differences in task type, difficulty level and presence of others, the study of private speech in the laboratory continues to be successful.

Variations in task type continue to be an obstacle in the comparison of findings across studies. Research has demonstrated that private speech does not occur during all types of activities. Children use private speech when they are engaged in goal-directed or problem-solving activities (Berk & Garvin, 1984; Dickie, 1973; Rubin, 1979). In two of the studies (Manning, White & Daugherty, 1994; White & Manning, 1994) reviewed task type was not clearly stated. In all but one study, tasks ranged from being known visually based tasks (structure building)(i.e., Jamieson, 1995; Berk & Spuhl, 1995; Winsler, 1988; Sturn & Johnston, 1999) to tasks that are presumed to be semantic in nature (classification, selective attention)(i.e., Daugherty & Logan, 1996; Winsler, Diaz, & Montero, 1998; Winsler, 1998). Only one study (Berk & Landau, 1993) utilized a ‘best-outcome’ task (math computation) despite empirical evidence that tasks other than academic seatwork potentially limit the amount of private speech produced. It remains unclear from this review if the categorization of verbally mediated versus spatially oriented tasks is a useful dichotomy. Perhaps tasks can be both visual spatial in nature and be verbally mediated. For example, construction tasks are visually oriented yet given adequate difficulty successful completion appears to be verbally mediated. This suggests that
perhaps it is not so much the orientation of the tasks but rather difficulty level of the task that determines its ability to elicit private speech.

Only one study individually tested children for their individual competency on the experimental task (Berk & Spuhl, 1995) despite repeated demonstrations that private speech production is optimized under intermediate levels of difficulty (Rosengren & Perlmutter, 1989). It is thus impossible to determine if children were presented with tasks that fell within their individual zone of proximal development, an area of difficulty were the task is challenging but within the child’s ability. Furthermore, the use of tasks that are not individually geared to children’s ability level could result in silence that could reflect both ends of the competence continuum. Vygotsky (1934/1962, 1930-1935/1978) suggested that silence would occur if task difficulty fell within children’s ability level as the cognitive requirements would be automatized and thus self-guiding language would be unnecessary. This would also hold true if the task demands were too great, as children would be unable to rely on language to guide their behavior. Although, it is seemingly possible that task performance could be used to distinguish between these two interpretations unfortunately most studies do not report detailed information on task performance per se. Comparison of incidence rate should therefore occur when methodological variables, particularly task difficulty level and setting, are kept constant.

Two consistent objective findings from this review were that few studies explicitly state their instructions to the child and that the majority of studies take into account the effects of the presence of others on the production of private speech. Naturalistic studies acknowledge and/or appropriately use and report the presence of either children or adults and laboratory-based studies consistently report that experimenters remain an appropriate distance from the child and employ a variety of strategies that discourage social exchange during task completion. The
potential effect of adults' providing scaffolding and thus decreasing the need for self-regulatory language is minimized with this approach.

Based on our rating of methodological differences, the study of private speech in children is difficult. The need for a systematic informed choice approach in the study of private speech in children is needed. Future laboratory based studies should minimally: 1) use semantic based tasks, particularly academic seatwork, 2) test children for their individual zone of proximal development for any task that will be used to elicit private speech, and 3) include explicit statements of instructions. This is not to say that our investigation of private speech should be limited by these recommendations. Diaz (1986) for example, has been explicit about the dangers of limiting experimental variables and thus suppressing the work of science. It is suggested, however, that a level of similarity in reporting of details between studies be achieved so results can be reliably pooled across studies and valid conclusions made.

Preliminary Investigations of Methodology for Eliciting Private Speech in a Laboratory Setting.

In addition to the review of the existing literature, three small pilot studies were conducted to further explore some of the issues raised with respect to task selection. Three tasks were explored with respect to feasibility: block construction, videogames and math computation seatwork. Block construction tasks have been used frequently in an attempt to elicit private speech in young children (see reviews by Diaz, 1992; Fuson, 1979) despite the possibility that they may be solved using perceptual matching strategies and not verbal mediation (Frauenglass & Diaz, 1985). Videogames were chosen due to the discovery of increased talkativeness in children with ADHD during videogame play (Tannock, 1997) and Krafft and Berk’s (1998) finding that the incidence of private speech was more frequent in open-ended activities.
Academic seatwork, in particular math computation was used in the only other study of private speech in clinically diagnosed children with ADHD, on and off medication (Berk & Potts, 1991). Although this study was naturalistic in design it provided supportive evidence that the rate of private speech production can be quite high when children are engaged in academic seatwork. The descriptions of the tasks, procedures, and outcomes are summarized in the Appendices (see Appendix A – C), since this pilot work was not a central component of the current thesis. These pilot studies indicated that a math computation task, in which the task difficulty level was determined for each individual, would provide a viable and optimal method for eliciting private speech in school-aged children in a laboratory-based study.
CHAPTER 3

Math Computation, Error Patterns and Stimulant Effects in Children with Attention Deficit Hyperactivity Disorder
ABSTRACT

This study compared the math performance, error patterns, and concurrent overt behavior of 14 children with Attention Deficit Hyperactivity Disorder (ADHD) and 15 typically developing peers, matched on age, IQ and arithmetic achievement. Subsequently, the group with ADHD participated in a double-blind placebo controlled trial of methylphenidate (MPH) to determine the effects of stimulant medication on academic efficiency, error patterns and overt behavior. In comparison with their non-affected peers, children with ADHD had lower levels of academic efficiency, used more immature computation strategies, made substantially more trading errors in subtraction and exhibited increased levels of inattention and disruptive behavior. MPH exerted a significant positive effect on all measures. The possible interplay between a faulty memory system and poor academic achievement is discussed.

Mathematical performance difficulties in children with ADHD relative to their non-ADHD peers are well documented (e.g., Ackerman, Anhalt, & Dykman, 1986; Hinshaw, 1992). Although the co-occurrences of mathematically based learning disability and ADHD has not been specifically investigated, subgroups of children with ADHD who also have specific difficulties in mathematics have been identified (Ackerman, Anhalt, & Dykman, 1986; Ackerman & Dykman, 1995; Rasanen & Ahonen, 1995; Zentall, 1990, 1993; Zentall & Ferkis, 1993; Zentall, Smith, Yung-bin, and Wieczovek, 1994). Children with attentional deficits without hyperactivity are the most at risk for academic difficulties, particularly in math achievement (Carlson, Lahey & Neeper, 1986; Hynd, Alison, Semrud-Clikeman, Nieves, Huettner, & Lahey, 1991; Marshall, Hynd, Handwerk & Hall, 1997).

One possible explanation for this math vulnerability in ADHD is a failure in automatization. Ackerman, Anhalt & Dykman. (1986) proposed that children with attentional difficulties struggle in mathematics due to a failure to automatize computational skills at an age-appropriate pace. They concluded that the automatization failure results from a major cognitive deficit in memory (Ackerman, Anhalt, & Dykman, 1986; Ackerman, Anhalt, Dykman & Holcomb, 1986). ADHD children’s performance on standard intelligence tests (high ACID factor scores) supports this notion of a limited memory capability (Ackerman, Anhalt, & Dykman, 1986). In addition, it has been suggested that slow and inaccurate computation (speed of retrieval) increases the attentional load on working memory (Gagne, 1983) and thus lends additional credence to the existence of a combined attentional/academic difficulty demonstrated by children with ADHD. Furthermore, failed automatization, which impairs the initial acquisition of number facts, may subsequently restrict the acquisition of more advanced
mathematical procedures, by limiting attentional resources needed for higher level mathematics (Ackerman, Anhalt, Dykman, & Holcomb, 1986; Ackerman, Anhalt, Dykman, Holcomb & Dykman, 1986; Geary, 1993; Geary, Fan, & Bow-Thomas, 1992; Geary & Widaman, 1987). Others have attributed poor automaticity to a lack of repetition in the learning of number facts (Marshall et al., 1997). They proposed that children with attentional problems shun repetitive drills as a learning mechanism due to their limited attentional abilities. Whether impaired math performance in this population results from ADHD-associated problems such as limited memory capacity or attention or whether it is independent of ADHD symptomatology is as of yet unknown.

Although the etiology of math difficulties in ADHD children is unclear, it is hoped that reducing the behavioral symptomatology of ADHD will ameliorate these difficulties. Current practice in treating children with ADHD involves the use of stimulant medication (Safer & Krager, 1988). In contrast to conclusions from the past (Barkley & Cunningham, 1978), evidence now exists that MPH improves the classroom behavior and academic performance of children with attentional deficits (Douglas, Barr, O’Neill, & Britton, 1988; Hechtman, 1985; Pelham, Bender, Caddell, Booth, & Moorer, 1985; Rapport, DuPaul, Stoner, & Jones, 1986). However, some have argued that the only effect of MPH on academics is increased levels of productivity (Pelham, Bender, Caddell, & Booth, 1982; Rapport, Murphy, & Bailey, 1982). In addition, it has been argued that stimulant medication has a limited effect on underlying cognitive abilities (Aman & Werry, 1982) and thus would not be expected to change difficulties in learning (Douglas, Barr, O’Neill, & Britton, 1986).

The confusion regarding stimulant medication effects on mathematics can be attributed to several methodological differences found in the literature. First, children with ADHD and their
non-ADHD peers are typically matched on age and IQ scores with little regard for specific math computation competence. Second, standard achievement tests are typically used as dependent measures despite their known insensitivity to drug effects (Gadow, 1983; Rapport, Stoner, DuPaul, Kelly, Tucker, & Schoeler, 1988). Third, some investigators have assessed performance using informal math computation seatwork assigned by a teacher (Vyse & Rapport, 1989; Rapport et al., 1986; Douglas et al., 1986). Level of difficulty was thus solely determined on present grade level, not individual math ability. Both of these approaches result in several problems. Very high accuracy rates (> than 90%) off medication, for example, leave little room for improvement on medication. Ceiling effects such as this in previous studies meant that children did not receive sufficient numbers of challenging items to ensure optimal performance. In addition, Vygotsky (1978/1987) suggested that it was essential for children to be presented with tasks that fall within what he termed their 'zone of proximal development' if they were to perform optimally on a given task. This means that the task composition must include items with varying difficulty, ranging from easy, to manageable, to above-ability level. The consequence of these design features is that medication effects cannot be unequivocally interpreted.

The present study improved upon previous methodological limitations in order to better evaluate the validity of two prevailing assumptions: 1) that children with ADHD children have weaker math computation skills when compared to peers matched for age, IQ, math achievement, and experimental math task competence and 2) that stimulant medication only affects math computation performance by decreasing disruptive behavior and increasing productivity. A central experimental design issue was addressed. Children with ADHD and non-ADHD children were not only equated on multiple, standard dimensions (age, IQ, grade
level, standardized mathematical achievement), but also on competency on an experimental math task. That is, each child was assessed to determine individual competency level. Moreover, items challenging to the child as well as those within the child's ability level were included. This approach provided each child with tasks that fell within their own zone of proximal development (Vygotsky 1978/1987) and thus optimized their performance, while allowing opportunity for stimulant related improvements.

**Method**

**Participants**

Participants were 30 children ranging in age from 7 to 11 years (Mean = 9.55, SD = 1.01). These children were selected from a larger sample of children who were participating in an ongoing investigation of the language abilities of children with ADHD (Oram, Fine, Okamoto, & Tannock, 1999). Fifteen children (13 male: 2 female) had been referred for possible behavior or attention problems to a psychiatric outpatient clinic at a large metropolitan children's hospital, had received a confirmed diagnosis of ADHD and had participated in an initial baseline assessment. One boy with ADHD withdrew from the study after completion of the initial baseline assessment. Fourteen children with ADHD progressed to a three-day, placebo controlled trial of stimulant medication. The remaining 15 participants (all male) were non-ADHD children recruited from various elementary schools in the same geographic area. Parent and teacher reports confirmed the absence of behavioral or attentional problems. The non-ADHD children participated in the initial assessment only. Exclusionary criteria for both the ADHD and non-ADHD groups included a full-scale IQ score below 80, any evidence of neurological dysfunction, poor physical health, uncorrected sensory impairments, or a history or current presentation of psychosis.
Clinical diagnosis of ADHD, using Diagnostic and Statistical Manual for Mental Disorders-IV (DSM-IV) (American Psychiatric Association, 1987) criteria, was based upon information from semi-structured interviews conducted with parents (Parent Interview for Child Symptoms-IV; PICS-IV; Schachar, Ickowicz & Wachsmuth, 1994) and the child’s classroom teacher (Teacher Telephone Interview-IV; TTI-IV; Schachar & Tannock, 1994). These interviews were not conducted with non-ADHD children. The PICS covered the child’s development and current behavior with a particular focus on the symptoms of ADHD, Oppositional Defiant Disorder (ODD) and Conduct Disorder (CD). It was modeled on the Schedule for Affective Disorders and Schizophrenia for School-Age Children – Epidemiologic version (Orvaschel & Puig Antich, 1987), with the addition of extra probes for the DSM-IV criteria for ADHD. The TTI-IV followed the same basic format as the PICS-IV. It covered symptoms of ADHD, ODD and CD in detail and screened for internalizing disorders. Reliability and validity estimates for the DSM-III-R versions of both interviews are high (Schachar, Tannock, Marriott, & Logan, 1995). Reliability estimates for the DSM-IV versions are in progress. Parents, teachers and children also completed several rating scales and questionnaires to provide supportive information (ADHD Rating Scale, DuPaul, 1991; Revised Ontario Child Health Study Scales, Boyle, Offord, Hoffman, Catlin, Byles, Crawford, Links, Rae-Grant, & Szatmari, 1987; Boyle, Offord, Racine, Fleming, Szatmari, & Sanford, 1993; Revised Children's Manifest Anxiety Scale, Reynolds & Richmond, 1985; Child Depression Inventory, Kovacs, 1992; State-Trait Anxiety Inventory for Children, STAIC, Spielberger, 1973). All measures have been found to have acceptable psychometric properties. The Vocabulary and Block Design subtests of the Weschler Intelligence Scale for Children-III (WISC-III, Weschler, 1949) were administered to provide an estimated IQ score (Sattler, 1988). In the event that a psychologist
had administered these tests within the past year, those results were obtained with consent from parents.

The mean number of positive symptoms on both the PICS-IV and TTI-IV confirmed the diagnosis of ADHD. The mean number of symptoms of inattention and impulsiveness/hyperactivity were 7 and 5, respectively on the parent interview, and 6 and 4 respectively on the teacher interview. Four children (27% of the group with ADHD) were sub-typed as Predominantly Inattentive Only and 11 (73%) as the Combined Subtype, as described in the DSM-IV. A concurrent diagnosis of ODD was made for six (43%) children in the group with ADHD, Anxiety Disorder for three (21%) children and CD for one (7%) child.

None of the participants had a specific mathematically based, learning disability as defined by standard scores of at least 1.5 SD below the mean for their age on the WRAT-3. All children obtained a WRAT-3 (Wilkinson, 1991) arithmetic standard score within normal limits (i.e., standard score > 90). One child with ADHD (7%) exhibited a reading disability and two (14%) children showed evidence of a spelling disability as defined by scores of at least 1.5 standard deviations below the mean for their age on relevant subtests of the Wide Range Achievement Test-Revised (WRAT-3; Wilkinson, 1991). The presence of school identified learning disabilities was determined by special class placement. In the ADHD group 1 child was receiving full-time special education support, 1 child part-time support and all others were in a regular school placement. No children in the non-ADHD group received any form of special education support.

Sample characteristics are shown in Table 1. The groups did not differ significantly in chronological age or grade level, and no significant differences were found between the groups on WISC-III Vocabulary, Block Design, or Full Scale Intelligence Quotient (see Table 1).
Table 3.1

Sample Characteristics

<table>
<thead>
<tr>
<th></th>
<th>ADHD</th>
<th></th>
<th>Non-ADHD</th>
<th></th>
<th>F (1, 28)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td></td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>9.55</td>
<td>1.01</td>
<td>9.02</td>
<td>1.14</td>
<td>1.84</td>
</tr>
<tr>
<td>Grade Level</td>
<td>3.93</td>
<td>1.07</td>
<td>3.29</td>
<td>1.07</td>
<td>0.02</td>
</tr>
<tr>
<td>IQ (WISC-III)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Scale</td>
<td>112.40</td>
<td>14.54</td>
<td>106.87</td>
<td>13.22</td>
<td>1.19</td>
</tr>
<tr>
<td>Vocabulary</td>
<td>12.07</td>
<td>3.41</td>
<td>10.93</td>
<td>2.79</td>
<td>0.99</td>
</tr>
<tr>
<td>Block Design</td>
<td>12.33</td>
<td>3.92</td>
<td>11.40</td>
<td>2.85</td>
<td>0.56</td>
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<tr>
<td>Achievement (WRAT-3)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arithmetic</td>
<td>102.07</td>
<td>5.97</td>
<td>105.73</td>
<td>8.56</td>
<td>1.85</td>
</tr>
<tr>
<td>Reading</td>
<td>105.67</td>
<td>13.23</td>
<td>113.87</td>
<td>9.14</td>
<td>3.90</td>
</tr>
<tr>
<td>Spelling</td>
<td>101.87</td>
<td>3.45</td>
<td>111.73</td>
<td>12.20</td>
<td>4.43 *</td>
</tr>
<tr>
<td>Language (CELF-R)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Score</td>
<td>90.67</td>
<td>12.03</td>
<td>104.08</td>
<td>7.53</td>
<td>10.40 **</td>
</tr>
<tr>
<td>Receptive</td>
<td>95.33</td>
<td>12.16</td>
<td>103.53</td>
<td>9.33</td>
<td>4.29 *</td>
</tr>
<tr>
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<td>100.73</td>
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Parent Measures

OCHS

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<td>SD</td>
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**SNAP**

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<tr>
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**ADHD Scale**

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<td>10.08</td>
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**Teacher**

**OCHS**

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<td>2.69</td>
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<tr>
<td>ODD</td>
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**SNAP**

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<tr>
<td>Hyperactive</td>
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<td>2.0</td>
<td>0.15</td>
<td>0.55</td>
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</table>

**ADHD Scale**

<table>
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<th>Mean</th>
<th>SD</th>
<th>T Value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.44</td>
<td>3.21</td>
<td>0.67</td>
<td>2.31</td>
</tr>
</tbody>
</table>

p < .05 *, p < .01 **, p < .001 ***

Abbreviations: WRAT-3 = Wide Range Achievement Test-3; ZPD = Zone of Proximal Development; OCHS-R = Ontario Child Health Study Scales-Revised. ADHD = Attention Deficit Hyperactivity Disorder. ODD = Oppositional Defiant Disorder. CD = Conduct Disorder. OA = Overanxious Disorder. SA = Separation Anxiety. DEP = Depression. ADHD Scale = ADHD Rating Scale (DuPaul, 1991); Non-ADHD = typically developing children; SNAP = SNAP Rating Scale (Swanson, Nolan, & Pelham, 1980)
groups were matched for arithmetic ability as indexed by both the WRAT-3 and experimental task difficulty level (ZPD). Although children with ADHD performed more poorly than non-ADHD children on the spelling subtest of the WRAT-3, their scores were in the average range. As expected, significant differences were found between groups on parent and teacher ratings of behavior, supporting the diagnostic differentiation. The majority of participants were Caucasian. The ADHD group included one black child and one Asian child. The non-ADHD group included three Asian children. Data on social-economic status was not collected, but data on parents' education level indicate that the majority of parents in both groups had a strong educational background. In the ADHD group, 14% of the parents had some college, 21% had completed college, 21% had some university background and 43% had completed university. In the non-ADHD group, 13% of the parents had some college, 20% had completed college, 13% had some university level education and 53% had completed university.

**Dependent Measures**

Three sets of dependent measures were used to assess ADHD and non-ADHD children's math performance, error patterns, and behavior ratings. All were gathered while the participants performed the experimental math task, which consisted of a math computation worksheet. Worksheets, appropriate for grades 1 to 6, were selected from those developed by Douglas and her colleagues (Douglas, Barr, O'Neill & Britton, 1986). A screening form and four equivalent worksheets were chosen. Administration and scoring of the screening form was modified in order to provide a math computation competence level for each child. Determination of individual difficulty level was based on their demonstrated ability to accurately complete the computation items with the aid of coaching. The set of worksheets used for each child was therefore reflective of the individual demonstrated ability level.
Each level, conceptualized by Douglas et al. (1986) as approximate to grade level, contained addition and subtraction computational items. With increasing level, proportion of addition items decreased from 51% to 32% of the items, and subtraction items decreased from 49% to 32% of the items. Since the higher levels (e.g., five and six) also included multiplication and division items, these latter types of problems were excluded from these analyses, as the purpose was to examine item type to which all children were exposed. In addition to the proportion of addition or subtraction items per level, the difficulty level was increased across grades by expanding the number of digits in each question and/or increasing the procedural demands (i.e., frequent trading). Items were organized in a manner that required the child to shift operations within each row of 5 items. All item types were distributed equally throughout the worksheets.

Math Performance. Similar to Rapport et al. (1986) scores reflecting productivity and accuracy, and an academic efficiency score (AES) were calculated. Productivity was calculated as the number of items attempted (which varied across children) divided by the number of items available. Accuracy was determined by dividing the number of items correct by the total number of items attempted. AES was computed by dividing the number of items correctly completed by the number of items available on the worksheet. AES was considered the primary measure of academic performance as it reflects the proportion of items completed correctly out of the given set and thus allows for comparison between groups. The AES has been found to be associated with both academic productivity and academic achievement (DuPaul et al., 1991, 1993), and to be sensitive to the dose effects of stimulant medication (Rapport et al., 1986, DuPaul et al., 1993).
Error Patterns. Various taxonomies have been proposed to classify arithmetic errors (e.g., Rasanen & Ahonen, 1995; Spiers, 1987). Each classification system differs in number of error types and specificity of error within each category. The classification of errors used in this study was a modification of that used by Rasanen & Ahonen (1995) and is presented in Figure 3.1. We extended previous classifications by providing a separate error classification for errors that were conceptual with respect to the number zero (Zero Errors), whereas errors of the trading type that involved the number zero were included in the trading category.

All addition or subtraction errors were included in the analysis. Multiple types of errors were not permitted for any item, if a particular item contained more than one recognizable error it was scored as uncodable. Due to the small number of uncodable items across subjects (i.e., 3 in ADHD group, 0 in Non-ADHD) the uncodable classification was excluded from further analyses. Similar to Rasanen & Ahonen (1995), errors were calculated separately for operation type. Although subjects were given equal numbers of items to attempt on each ability level, the number of items completed differed across subjects and thus the possibility of errors was not equal. Accordingly, the frequency of each error type was calculated as a proportion of number of items attempted (Engelhardt, 1977; Rasanen & Ahonen, 1995).

Behavior Ratings. Children’s overt behavior during the math task was rated on a 4-point scale, where 1 indicated that the behavior was not noted at all; 2 just a little; 3 pretty much, and 4 very much. Behaviors of interest included: fidgeting, gross body movements, use of task materials, and finger counting. Fidgeting referred to small body movements, such as leg shaking, finger tapping or wiggling in the seat, whereas gross body movements was reserved for times when the child left the seat. Use of task materials was defined as active on-task manipulation of pencil or eraser. ‘Finger counting’, which was conceptualized as a less mature
Figure 3.1.

Math Computation Error Classification

<table>
<thead>
<tr>
<th>Error Type</th>
<th>Example</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Incorrect Operation Error</td>
<td>5 + 2 3</td>
<td>Operation carried out is different from the one requested. Answer could either be correct based on the operation interpretation or other errors may exist.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Basic Fact Error</td>
<td>6 + 5 12</td>
<td>Computational error in basic fact knowledge resulting in incorrect solution (based on child’s interpretation of operation).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Trading Error</td>
<td>5349 + 783 6222</td>
<td>Carried number is added to the incorrect column.</td>
</tr>
<tr>
<td></td>
<td>8478 + 1412 9880</td>
<td></td>
</tr>
<tr>
<td></td>
<td>78688 - 17259 61429</td>
<td></td>
</tr>
<tr>
<td>4. Zero Error</td>
<td>363 - 50 310</td>
<td>Any obvious difficulty with the concept of zero.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Uncodable</td>
<td>81 - 11 62</td>
<td>Incorrect answers that were not possible to classify in one of the above categories.</td>
</tr>
</tbody>
</table>
strategy for computation, was coded only when it was clear that the child was using his/her fingers as a tool for counting. Level of inattentiveness was rated on a 6-point scale (0 = child was able to sustain his/her attention, resisting interference from outside; 5 = child was distracted from the task).

Experimental Design and Procedure

All children were tested individually. Children with ADHD were assessed in a pediatric hospital laboratory classroom; non-ADHD children were assessed either in a designated classroom in their home school or in the hospital laboratory classroom. Children with ADHD completed the acute medication trial on three consecutive days immediately following the initial ADHD/non-ADHD comparison.

Math Pretest. Children were assessed to establish their individual 'zone of proximal development (ZPD) (Vygotsky, 1930-1935/1978) for competence in math computation on this particular task. The first level involved determining the child's upper limit of his/her skill ability without assistance in the areas of addition and subtraction computation. The second level established an upper limit of ability with the aid of coaching (e.g., What sign is this? are you sure 4+2 is 8?). The rational for this methodology was twofold. We wished to ensure that each child was given math problems one step above their demonstrated unaided ability level and to provide each child with an ample number of challenging problems for the time period so as to avoid ceiling and floor effects.

Math Test. Children were instructed to work independently on the math computation worksheet for a total of 10 minutes. The examiner sat approximately 3 feet away from the child at a separate table to encourage independent effort but allowing an opportunity for behavioral observation. Any child claiming to have finished before the 10 minute period had ended (2
ADHD, 1 non-ADHD) was encouraged to continue working, either by attempting more items or by checking the already answered items until the time was complete. Neither of the children with ADHD claiming to have finished early had completed the worksheet, the non-ADHD children had indeed completed the task. During each session the examiner completed the behavioral rating scale based on observation of the child throughout the 10-minute task.

Math computation worksheets were scored for overall productivity, accuracy and academic efficiency. Subsequently these same scores were calculated for addition and subtraction subtypes individually. The examiner then made a separate pass through each worksheet, coding error types for all incorrect items.

**Drug Protocol.** Fourteen children with ADHD participated in a three-day double blind placebo controlled trial of MPH. After baseline measures were obtained, each child received each of three fixed doses (0 mg, 10 mg, and 20 mg). Order was counterbalanced so that approximately equal numbers of children received each of the possible five medication orders. The examiner was blind to medication condition. Since there is no clear evidence that response to medication is dependent on body weight, fixed doses (versus mg/kg) of 10 and 20 mg were utilized (Rapport et al., 1989). Placebo and active medication were prepared by the hospital pharmacist, powdered, and packaged in an opaque gelatin capsule to prevent identification of contents by color, taste or volume. Each child’s medication was placed in an individually named and dated envelope to ensure accurate administration. Each child was provided with a math computation worksheet, pencil and eraser approximately 1.5 hours after receiving medication (i.e., during active phase of medication (Swanson & Cooney, 1978).

**Reliability of behavioral, performance and error data.** Inter-observer agreements for worksheet correction and error type classification were calculated for 20% of the sample. Mean
inter-observer agreement for performance and error data for the group with ADHD was 100% and 90%, respectively. The non-ADHD group inter-observer reliability was calculated to be 100% for performance data and 96% for error data. All disagreements were discussed and resolved before data analysis.

Results

**ADHD and Non-ADHD Comparison**

Productivity, accuracy and AES data were subjected to a univariate analysis of variance (ANOVA) (See Table 2). A significant main effect for group was found in overall productivity, accuracy and AES. Children with ADHD completed significantly fewer items and were more often incorrect in their responses compared to their non-ADHD peers. This resulted in the AES of children in the non-ADHD group being more than triple that of the group with ADHD.

A different pattern of results was found for addition when examined in isolation. Children with ADHD continued to demonstrate a significant weakness in levels of productivity and efficiency but were not significantly different than non-ADHD children when compared on addition accuracy. On average, both groups of children obtained 67% accuracy in addition.

Productivity, accuracy and AES results for subtraction items in isolation showed a similar pattern to that observed for the overall worksheet. The children with ADHD had lower productivity, accuracy and AES compared to the non-ADHD children. Productivity and accuracy scores for subtraction in the non-ADHD group were more than double those of the ADHD group and their AES was approximately five times greater.

Error types were subjected to a multivariate analysis of variance (MANOVA) with repeated measures across error type (See Table 2). This was calculated for the overall worksheet, as well as for addition and subtraction subtypes separately. Significant differences
Table 3.2. ADHD and Non-ADHD Comparisons.

<table>
<thead>
<tr>
<th></th>
<th>ADHD</th>
<th>Non-ADHD</th>
<th>F (1, 28)</th>
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</thead>
<tbody>
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<td></td>
<td>M</td>
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<td>M</td>
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<tr>
<td>Overall</td>
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<tr>
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<tr>
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<tr>
<td>Efficiency</td>
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<td>36.79</td>
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<tr>
<td>Productivity</td>
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<tr>
<td>Accuracy</td>
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<tr>
<td>Productivity</td>
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<td>Accuracy</td>
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### Table 3.2 (Con’t).

**ADHD and Non-ADHD Comparisons**

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<td><strong>M</strong></td>
<td><strong>SD</strong></td>
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<td>5.07</td>
<td>0.15</td>
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<tr>
<td>Basic Fact</td>
<td>15.80</td>
<td>25.32</td>
<td>8.07</td>
<td>7.20</td>
<td>1.29</td>
</tr>
<tr>
<td>Trading</td>
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<td>11.47</td>
<td>14.71</td>
<td>1.64</td>
</tr>
<tr>
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<td>3.60</td>
<td>5.11</td>
<td>1.20</td>
<td>2.57</td>
<td>2.64</td>
</tr>
<tr>
<td><strong>Addition Errors</strong></td>
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<td>4.54</td>
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<td>19.01</td>
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<tr>
<td>Incorrect Operation</td>
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<td>1.0</td>
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<td>0.87</td>
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<tr>
<td>Basic Fact</td>
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<td>3.73</td>
<td>5.22</td>
<td>1.50</td>
</tr>
<tr>
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<td>6.53</td>
<td>8.90</td>
<td>7.70 **</td>
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<td>10.95</td>
<td>1.53</td>
<td>4.09</td>
<td>2.63</td>
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<td>Non-ADHD M</td>
<td>Non-ADHD SD</td>
<td>F</td>
</tr>
<tr>
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<td>---------</td>
<td>---------</td>
<td>------------</td>
<td>-------------</td>
<td>----</td>
</tr>
<tr>
<td>Inattention</td>
<td>2.53</td>
<td>1.51</td>
<td>0.47</td>
<td>0.92</td>
<td>20.64 ***</td>
</tr>
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<td>Fidgeting</td>
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<td>1.06</td>
<td>0.13</td>
<td>0.35</td>
<td>12.02 **</td>
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<td>Gross Body Movement</td>
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<td>1.27</td>
<td>0.40</td>
<td>0.91</td>
<td>7.45  **</td>
</tr>
<tr>
<td>Use of Task Materials</td>
<td>1.80</td>
<td>0.96</td>
<td>2.93</td>
<td>0.26</td>
<td>19.50 ***</td>
</tr>
<tr>
<td>Finger Counting</td>
<td>2.57</td>
<td>1.82</td>
<td>0.33</td>
<td>0.72</td>
<td>19.48 ***</td>
</tr>
</tbody>
</table>

Note 1: Figures for productivity are percentages (they represent the number of items attempted divided by the number of items available). Figures for accuracy are percentages (they represent the number of items correct divided by the number of items attempted). Figures for academic efficiency are percentages (they represent the number of items correct divided by the number of items available).

Note 2: Figures for error patterns represent mean number of errors.

Note 3: Figures for behavior represent total raw scores on the behavior rating scale.
were found only for errors in subtraction (Table 3.2). Children with ADHD had a six-fold
greater number of trading errors than non-ADHD children. The majority of subtraction trading
errors involved a misunderstanding of borrowing. Most resulted from consistently subtracting
the smaller number from the larger number, irrespective of its position in the problem (see Figure
3.1, error type 3).

The behavioral differences of the groups are also shown in Table 3.2. As predicted, the
children with ADHD showed more fidgeting and gross body movements, and were more
inattentive than their peers. Children with ADHD also exhibited less frequent use of task
materials but more frequent use of the immature strategy of finger counting than non-ADHD
children.

**MPH Effects**

MPH effects on the children’s behavior, academic performance and error patterns of the
children with ADHD were analyzed to determine dose level differences (see Table 3). Initially, the statistical significance of MPH effects on all measures was assessed using analysis
of variance (ANOVA) with repeated measures across medication dosages (0 mg, 10 mg, 20 mg).
There was a significant medication effect for overall productivity and AES. Productivity and
AES were significantly improved on 10 and 20 mg of MPH. No significant effect of MPH was
found for overall accuracy. Analysis of addition and subtraction items individually revealed a
significant positive main effect for subtraction efficiency.

No significant effects of MPH on error types were found. Significant main effects of
MPH were found for fidgeting, level of inattention and finger counting, but not for gross body
movements or use of task materials. Tukey post hoc analyses revealed that children’s fidgeting,
### Table 3.3.
**MPH Effects**

<table>
<thead>
<tr>
<th></th>
<th>Placebo Mean</th>
<th>SD</th>
<th>10 mg Mean</th>
<th>SD</th>
<th>20 mg Mean</th>
<th>SD</th>
<th>F (1, 14)</th>
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<tr>
<td><strong>Behavioral Measures</strong></td>
<td></td>
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<tr>
<td>Fidgeting</td>
<td>1.07</td>
<td>1.21</td>
<td>0.21</td>
<td>0.58</td>
<td>0.07</td>
<td>0.27</td>
<td>7.03 **</td>
</tr>
<tr>
<td>Gross Body Movement</td>
<td>1.21</td>
<td>1.31</td>
<td>1.50</td>
<td>1.23</td>
<td>1.21</td>
<td>1.42</td>
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<tr>
<td>Use of Task Material</td>
<td>2.43</td>
<td>0.94</td>
<td>2.93</td>
<td>0.27</td>
<td>2.79</td>
<td>0.80</td>
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<tr>
<td>Finger Counting</td>
<td>1.79</td>
<td>1.76</td>
<td>0.50</td>
<td>0.76</td>
<td>0.21</td>
<td>0.58</td>
<td>9.43 *</td>
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<tr>
<td>Inattention</td>
<td>1.50</td>
<td>1.74</td>
<td>0.29</td>
<td>0.83</td>
<td>0.14</td>
<td>0.36</td>
<td>7.86 **</td>
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<tr>
<td><strong>Performance Measures</strong></td>
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<tr>
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<td></td>
</tr>
<tr>
<td>Productivity</td>
<td>27.04</td>
<td>11.91</td>
<td>35.97</td>
<td>13.12</td>
<td>35.80</td>
<td>12.95</td>
<td>5.30 *</td>
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<tr>
<td>Accuracy</td>
<td>71.91</td>
<td>26.57</td>
<td>71.81</td>
<td>27.116</td>
<td>71.23</td>
<td>25.27</td>
<td>.01</td>
</tr>
<tr>
<td>Efficiency</td>
<td>19.33</td>
<td>10.35</td>
<td>25.79</td>
<td>11.90</td>
<td>25.78</td>
<td>15.35</td>
<td>5.78 **</td>
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<td><strong>Addition</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Productivity</td>
<td>40.17</td>
<td>22.72</td>
<td>40.17</td>
<td>22.72</td>
<td>40.35</td>
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<tr>
<td>Accuracy</td>
<td>77.32</td>
<td>26.20</td>
<td>77.13</td>
<td>26.81</td>
<td>77.39</td>
<td>29.33</td>
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<tr>
<td>Efficiency</td>
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<td>31.72</td>
<td>21.33</td>
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<tr>
<td>Productivity</td>
<td>25.22</td>
<td>25.77</td>
<td>32.04</td>
<td>21.46</td>
<td>31.55</td>
<td>17.19</td>
<td>2.55</td>
</tr>
<tr>
<td>Accuracy</td>
<td>63.55</td>
<td>32.66</td>
<td>69.39</td>
<td>38.06</td>
<td>67.72</td>
<td>34.61</td>
<td>.12</td>
</tr>
<tr>
<td>Efficiency</td>
<td>12.97</td>
<td>12.58</td>
<td>19.95</td>
<td>15.63</td>
<td>20.78</td>
<td>15.24</td>
<td>3.99 *</td>
</tr>
</tbody>
</table>

p<.05*, p<.01**, p<.001***
level of inattention, and finger counting, were significantly decreased on 10 and 20 mg MPH doses when compared to placebo.

**Discussion**

*Math Performance*

This study extends our understanding of math computation competence in children with ADHD. Our data clearly demonstrated a deficit in math computation performance for children with ADHD who do not have specific mathematics disability. This was reflected in productivity, accuracy and AES. These deficits could not be explained by apriori differences in general cognitive functioning (IQ and grade level), traditional measures of academic achievement in arithmetic (WRAT-3) or individual math computation skill (experimental task pre-test).

In agreement with the prevailing view in the literature, a significant deficiency in rate of productivity was fully supported by our data. Non-ADHD children completed more than twice as many computation items as children with ADHD despite individual titration of difficulty level and similar time constraints. This suggested that a determinant other than task difficulty level of the task severely hampered the productivity of ADHD children. Children with ADHD were also compromised in accuracy. This again was at odds with expectations based on the experimental task pre-test titration. As overall efficiency was a composite measure of both productivity and accuracy, poor efficiency of children with ADHD was also revealed. These findings support the prevailing view in the community that children with ADHD are not competent in academics, particularly in math computation (DuPaul & Rapport, 1993; Rapport et al., 1988; Zentall, 1990; Zentall et al., 1994).

To better understand our findings, performance measures were calculated for the addition and subtraction items individually. For addition questions, children with ADHD attempted fewer items but accuracy was equal to that of typically developing children. Thus their lowered
efficacy was a result of low productivity. By contrast, the lowered subtraction efficiency score of children with ADHD resulted from both decreased productivity and significantly impaired accuracy. To examine this seemingly esoteric finding we examined the error patterns of both groups.

Systematic examination of the error patterns of children with ADHD revealed a significant weakness in the procedure of trading (borrowing) in subtraction, but no weakness in the area of carrying in addition. Interestingly, the majority of “borrowing” errors resulted from erroneously subtracting the smaller number from the larger number irrespective of its position in the problem. This error pattern may result from difficulties in both working memory and attention. That is, the process of borrowing places higher demands than carrying on working memory and attention because the child must retain two columns of information in order for correct execution of the item and the child must manipulate number both from left to right and right to left. For example, in order to correctly complete the computation 129 – 9, the child can ignore the tens and hundreds column on the left while executing the computation 9 – 9 on the right. However, for 120 – 9, correct execution requires manipulation of the one and tens columns in a back and forth pattern while changing operations. First, the child must borrow from the tens column (left,), add to the ones column (right) and then proceed with the subtraction question of 10 – 9 (right). This multi-step process clearly requires significant working memory capabilities and attention. Difficulties that have been specifically implicated in the cognitive profile of children with ADHD. Thus it is plausible that the cognitive demands of borrowing ‘tipped the scales’ of working memory, attention or the interplay between the two.

The lack of group differences in addition accuracy supports the working memory/attention hypothesis. Building on the previous example, consider the task of adding
It is possible to compute each column individually \((9 + 0, 2 + 0, 1 + 0)\) and thereby avoid taxing either the working memory or attentional systems. However, if the task is to add \(129 + 9\), the child must add \(9 + 9\), arrive at the answer \(18\) and then carry the 1(from the tens column of \(18\)), a two step process. Thus the additional demand in subtraction of holding in working memory and manipulating on paper the ‘borrowed’ number, coupled with a compromised attentional system, is seen as difficult for the child to overcome. Given that this is the first study to examine computational errors of children with ADHD and that most teachers do not consistently examine each child’s error patterns these hypotheses must be substantiated by further research.

**Behavioral Measures**

Behavioral differences during academic tasks between children with ADHD and non-ADHD peers have been reported frequently in the literature (e.g. DuPaul & Rapport, 1993; Rapport et al., 1988; Zentall, 1990; Zentall et al., 1994). Behavioral indices typically reflect on-task behavior, fine and gross body movements, and ratings of attention. It was not surprising, therefore, in the present study to find that children with ADHD were more physically active, less often on-task and more inattentive than their peers.

Unique to this study was the examination of a task-specific fine motor behavior: finger counting. This variable was thought to provide a window into one strategy used by children when performing math computation. Children with mathematically based learning disability use the same types of problem solving strategies as their non-impaired peers yet make significantly more computation and memory retrieval errors and use less mature strategies, such as counting on fingers (Jordan, 1995) or counting verbally (Siegler & Jenkins, 1989). Our data suggested a similar pattern for children without specific math disabilities but particular difficulties in attention. The children with ADHD relied on finger counting to a greater degree than their
matched typical peers. As children mature they are expected to become increasingly sophisticated in their strategy use (Fuson & Kwon, 1992). Back-up strategies such as finger counting should be replaced with direct retrieval and learning to modify their computation strategy as task demands change (Jordan, 1995). Children with documented learning problems have been shown to be less likely to maximize their performance in these ways (Swanson & Cooney, 1985; Swanson & Rhine, 1985). Our results suggest that the children with ADHD in our sample had not yet replaced the immature finger counting strategy with direct retrieval, despite exhibiting a similar ability in math to that of the non-ADHD group.

**MPH Effects**

The most striking medication effect in this study was the significant decrease in use of finger counting with a concomitant increase in productivity and AES. Medication served to decrease the use of finger counting, a 'back-up' computational strategy, in almost all of the children (93%). By contrast, stimulant medication did not affect accuracy or error patterns. These findings support the notion that MPH enhanced a central, attentional/self-regulatory process (Douglas et al., 1986) in the children with ADHD. Improved retrieval of number facts from memory or increased capacity of working memory could lead to increased productivity and access to more mature computational strategies. By contrast, improved self-regulation or increased memory capacity is unlikely to alter previously learned material and impact on accuracy or error patterns. Thus, findings indicate that MPH improves performance on academic seatwork by increasing productivity and consequently AES (Douglas et al., 1986; Carlson et al., 1991). On the other hand our findings also demonstrate that when task difficulty and ceiling effects are controlled, children with ADHD remain significantly disadvantaged in math computation in productivity, accuracy and AES.
We do not purport that our data provide conclusive evidence for a core academic deficit in children with ADHD, but the findings do allow us to offer some tentative ideas about the underlying mechanism responsible for their math computation difficulties. Generally, we believe that our data provides evidence for a combined functional deficit in the working memory and attention systems of children with ADHD. Our first hypothesis points to a specific deficit in strategy choice and use, whereby ADHD children due to their limited attentional and working memory capacities tend to rely on concrete manipulatives (e.g., finger counting) to successfully carry out basic mathematical computation. This strategy is potentially effective for addition if the child manipulates one column at a time and uses an ‘add on’ approach. For example, for 129 + 9, children could add 9 + 9 with their fingers if they began with the number 9 and continued to 18. However, to compute 120-9 using finger counting would be insufficient, as the child would be hampered by the unavailability of more than 10 fingers for 20-9. The second candidate hypothesis we offer reflects difficulties in attention and memory retrieval. The stimulant-related increase in AES of the children with ADHD coupled with no change in error patterns suggests that their computational knowledge may have been somehow locked in memory and not easily accessed without the aid of medication. They were forced to rely on less mature and less successful strategies to complete manageable computation items. It has been demonstrated that mastery of basic arithmetic can only be achieved once all basic facts can be retrieved from long term memory (Siegler, 1986; Siegler & Jenkins, 1989). Stimulant medication may have allowed our children to rely less on concrete manipulatives and more efficiently access their knowledge base.

The clinical significance of this study is clear. Our findings indicate that cognitive features of the disorder play a role in academic underachievement as well as disruptive behavior.
Thus, it is important that teachers be made aware of the specific difficulties children with ADHD are likely to experience in mathematical computation. Also, notwithstanding the controversial use of stimulant medication per se, clinicians should be aware of its potential beneficial effects on cognitive features of the disorder that contribute to academic difficulties. Our data indicate that a substantial proportion of children with ADHD who struggle daily with the behavioral, attentional, and academic demands of the classroom, might benefit from both cognitive and behavioral effects of stimulant medication.
CHAPTER 4

Private Speech and Stimulant Effects in Children with Attention Deficit Hyperactivity Disorder
ABSTRACT

Objectives: (1) To delineate the quantity, types and function of private speech in children with ADHD and a non-ADHD comparison group (2) to investigate the effects of stimulant medication on private speech.

Method: Private speech data were collected while children completed a math computation worksheet. A comparison between ADHD and non-ADHD children was undertaken in addition to a randomized double blind placebo controlled medication trial for children with ADHD. Private speech data were examined using more refined methodology than has been used in previous research including the following: (1) use of a task calibrated for individual ability level, (2) completion of academic seatwork in a controlled laboratory setting, (3) the use of individual audio-recording sensitive to sub-vocalization, (4) continuous recording of speech throughout the task and (5) verbatim transcription and fine level semantic analysis of private speech data.

Results: Groups differed in the sub-type of private speech used but not in overall amount emitted. Specifically, children with ADHD used more immature forms of private speech as evidenced by more self-talk that was irrelevant to the task or relevant but externalized. Effects of stimulant medication were positive, resulting in increased production of on-task self-talk, decreased finger counting and improvement in both math performance and concurrent overt behavior.

Conclusion: Children with ADHD were not deficient in their production of private speech, but rather exhibited a functional deficit. The argument that deficits in behavioral inhibition are central to the atypical speech-behavior relationship observed in children with ADHD is offered.
Speech addressed to the self or to no particular listener is referred to as 'private speech' (Berk & Potts, 1991). It is evident in the language of normally developing elementary school children 20 to 60% of the time, depending on the situation (Berk, 1986). Children use private speech during cognitively demanding tasks for the purpose of self-direction and self-guidance. Strategic use of language appears to guide behavior and improve performance.

The most comprehensive theory of the development and significance of private speech postulates that children learn to control their own behavior by using language directed to the self (Vygotsky, 1934/1962, 1930-1935/1978, 1960/1981). Initially, children's speech is externalized, first accompanying and then preceding behavior. As children's speech gains control of behavior it becomes internalized as verbal thought. Vygotsky theorized that this union of language, thought and behavior was representative of the transition from other-regulation to self-regulation.

Research in normal development lends support to the Vygotskian model. First, private speech during cognitive tasks follows a developmental path from external self-stimulating forms (off-task), through to external self-guiding speech (on-task external), to internal self-directed language (on-task internal) (Berk, 1985, 1986; Berk & Garvin, 1984; Berk & Potts, 1991; Bivens & Berk, 1990; Fraueglass & Diaz, 1985; Kohlberg, Yaegeper & Hjertholm, 1968; Winsler, 1995). Second, the function of private speech is that of self-guidance. This is evident from the increased use of private speech during cognitively demanding tasks (Beaudichon, 1973; Behrend, Rosengren, & Perlmutter, 1989, 1992; Berk, 1986; Berk & Garvin, 1984; Kohlberg et al., 1968), particularly during difficult points during the task (Goodman, 1981). Third, private speech, behavior and task performance is positively related. On-task private speech is associated with on-task behavior and improved performance (Azmitia, 1992; Beaudichon, 1973; Behrend et al., 1992; Bivens & Berk, 1990; Gaskill & Diaz, 1991).
Current theory of Attention Deficit Hyperactivity Disorder (ADHD) predicts that children with ADHD will exhibit impairments in the use of private speech in comparison to their typically developing peers (Barkley, 1997). According to this model, the central impairment in ADHD is one of behavioral inhibition, which gives rise to secondary impairments in four higher order functions: specifically, internalization of speech (i.e., private speech), working memory, self-regulation of affect-motivation-arousal and reconstitution. A hypothesized consequence of this hierarchical relationship between behavioral inhibition and these four higher order functions is that if inhibitory functioning is improved this should result in improvements in the four areas and furthermore improvement in motor control (Barkley, 1997). Thus private speech is conceptualized as a secondary impairment that contributes to but is not solely responsible for poor self-regulation.

Substantial empirical evidence can be found to support the hypothesized impairment in behavioral inhibition in children with ADHD. Evidence comes from a number of different avenues including parent and teacher ratings of hyperactive and impulsive behavior (i.e., Lahey et al., 1988, 1994), poor performance on motor inhibition tasks (i.e., Schachar & Logan, 1990; Schachar et al., 1993, 1995), errors of commission on continuous performance tasks (i.e., Corkum & Siegel, 1993), and poorer performance during active avoidance paradigms (i.e., Milich et al., 1994) (Barkley, 1997). Yet, despite these repeated findings it remains unclear whether this problem is specific to children with ADHD (Oosterlaan et al, 1996). There is however preliminary evidence of impairment in private speech in children characterized as 'hyperactive' (Copeland, 1979; Dickie, 1973; Goodman, 1977; Zentall, Gobs, & Culatta, 1983; Zivin, 1972) and more recently in children clinically diagnosed with ADHD (Berk & Potts,
1991) that leads one to believe that this too may be supportive of a central deficit in behavioral inhibition in children with ADHD.

Although findings are not always consistent, most studies have found that children with ADHD produce more on-task externalized private speech (Berk & Potts, 1991; Diaz & Lowe, 1987), are less effective in using private speech to guide behavior (Berk & Potts, 1991; Winsler, 1995) and exhibit delays in the internalization of private speech (Berk, 1986, Berk & Garvin, 1984; Bivens & Berk, 1990, Berk & Potts, 1991).

Past research has been useful in enhancing our understanding of private speech. However, a number of methodological problems exist, even in more recent literature, that often precludes integration of findings across studies. Namely: (1) selection of task type and difficulty level in order to optimize private speech production, (2) contextual variables in the collection of private speech (3) sampling methods, and (4) the categorization of private speech data.

The issues of task selection and task difficulty are intrinsic to the study and understanding of private speech. For example, visual spatial tasks such as block design or puzzles yield very little private speech, since these tasks can be solved using perceptual strategies rather than linguistic mediation (Frauenglass & Diaz, 1985). Task difficulty level has also been shown repeatedly to affect private speech production. The use of private speech is increased during cognitively demanding tasks (i.e., Beaudichon, 1973; Berk & Garvin, 1984; Dickie, 1973; Zivin, 1972), yet if the task is too difficult it actually hampers language production (Behrend, Rosengren, & Perlmutter, 1989). Thus it can be concluded that to optimize the production of private speech and to ensure that differences in private speech are not ‘task’ artifacts, two variables, must be considered: (1) completion of the task must require verbal mediation and (2) the task must both challenge and be within reach of the child’s cognitive abilities. Vygotsky
was the first to report a positive relationship between task difficulty and private speech production, suggesting that the relationship facilitated problem solving. He further offered the notion of a Zone of Proximal Development (ZPD): the difference between children's performance when they work alone versus when they are working with a more competent member of society. Recent investigators have interpreted this to mean providing children a set of tasks that the child will be able to complete with assistance (Brown & Ferrara, 1985; Rogoff & Wertsch, 1984). It is therefore expected that children will be likely to produce more private speech during tasks that fall within their ZPD.

Issues regarding the contextual considerations around the collection of private speech are also critical. For example, some studies have shown that the presence of others fosters private speech production (Berner, 1971; Behrend et al, 1989), while others have reported a decrease in production (Berk & Garvin, 1984; Rubin, Hultsch, & Peters, 1971). Diaz (1992) suggested that the presence of an adult is helpful only if the adult does not take over the role of self-regulation for the child. Instructions presented to the child can also alter levels of private speech production (Frauenglass and Diaz, 1985). When children are given an instruction that suggests that private speech is not only permitted but produced by other children in similar situations, the amount of private speech almost doubles. Unfortunately many studies fail to provide explicit details about the instructions given to the child. Furthermore, it has been suggested that attempting to elicit private speech in laboratory settings underestimates the amount of private speech produced when compared to naturalistic settings (Berk, 1986; Berk & Potts, 1991).

Studies also differ in terms of their approach to sampling private speech (e.g., episodic versus continuous) and whether private speech is coded only during periods when children are attentive to the task or also when they are off-task. This is an important issue. Berk & Potts
(1991), for example, recorded children’s speech and conducted behavioral observations only when the children were moderately attentive to the task. They were not recorded when children were off-task and unengaged (e.g., daydreaming) or engaged in social behavior (e.g., talking with peers, asking for assistance from the teacher). This approach of episodic coding versus continuous coding would likely underestimate the production of off-task private speech and may misinform our understanding of private speech.

Differences in the categorization of private speech utterances have also led to difficulties in interpretation. Most often category systems are based on inferences that specific utterances do or do not serve a relevant function in aiding the child through a particular task (Diaz, 1992). For example, Diaz (1986) proposed that an emotional statement like “O.K.” may not appear to be relevant or functional to the task but in reality may serve to aid the child in transitions from one component of the task to the next. Coding of private speech utterances may therefore be more subjective than is desirable. It has also been assumed that nonverbal behavior, such as: lip and tongue movements, are indicative of the internalization of private speech (Berk & Potts, 1991). However, it may be that oral motor movements are not necessarily inherent to private speech, but may also reflect overt motor behavior that accompanies many tasks. Moreover, although most studies share a number of coding similarities, it is also true that different studies incorporate novel categories that are tailored to their particular design. It is also important to note that many studies of private speech in children with learning or behavioral difficulties (Berk & Potts, 1991; Berk & Landau, 1993; Diaz & Lowe, 1987) have coded on-line, without transcribing language verbatim. The use of this technique does not allow for in-depth analysis of the potential subtleties of the internalization of private speech.
Accordingly, one major objective of the present study was to investigate private speech in clinically diagnosed children with ADHD using more refined methodology than used in previous research. Unique features of the present study include the use of a challenging math task that was adjusted for each individual's demonstrated ability, task completion within a structured laboratory setting, individual audio-recording of private speech production that was sensitive to sub-vocalizations, continuous recording of speech production throughout the task, verbatim transcription and fine level semantic analysis of private speech data.

Finally, if children with ADHD exhibit problems in the development and use of private speech then it is imperative that the effects of stimulant medication on private speech be assessed in children with ADHD. As many as 75% of clinically diagnosed children receive this treatment (Barkley, Fischer, Edelbrook, & Smallish, 1990; Copeland, Wolraich, Lindgren, Milich, & Woolson, 1987) with most of these children receiving stimulant medication as the sole treatment modality (Wolraich, Lindgren, Stromquist, Milich, Davis & Watson, 1990). Stimulant medication is known to improve core behavioral symptomatology (e.g., decrease activity level and impulsiveness, increased attention to task), academic productivity, and the quality of social relationships (see review by Schachar, Tannock, & Cunningham, 1997). It is also known to improve cognitive functions such as inhibitory control, sustained attention and behavioral inhibition. Furthermore, current theory regarding behavioral inhibition would predict concomitant improvement in private speech (Barkley, 1997). To date, only one uncontrolled study of the effects of stimulant medication on private speech has been reported (Berk & Potts, 1991). This study concluded that stimulant medication decreased motor behavior, increased attention to task and enhanced the maturity of private speech. It was our second major objective
to conduct the first double blind placebo controlled study of stimulant effects and private speech in children with ADHD.

Method

Subjects

Subjects included 15 children with a confirmed diagnosis of ADHD and 15 typically developing peers, ranging in age from 7 – 11 years (Mean age for ADHD = 9.55, SD=1.01, Non-ADHD = 9.02, SD=1.14. Fourteen of the children with ADHD progressed to a consecutive three-day, placebo controlled trial of methylphenidate (MPH). Exclusionary criteria included an estimated IQ score below 80, any evidence of neurological dysfunction, poor physical health, uncorrected sensory impairments, or a history or current presentation of psychosis.

ADHD Group. The ADHD group was referred for evaluation of possible behavior and/or attention problems and consideration for evaluation of response to treatment with methylphenidate (MPH). A DSM-IV (Diagnostic and Statistical Manual for Mental Disorders – IV) based diagnosis of ADHD was confirmed for all subjects (American Psychiatric Association, 1994) in a clinical diagnostic assessment, comprised of semi-structured clinical interviews with the child’s parents and classroom teacher, standardized behavior rating scales, and screening of the child’s intellectual, academic, and language abilities.

The parent interview (Parent Interview for Child Symptoms-IV (PICS); Schachar & Ickowicz, 1996; unpublished manuscript), which was conducted by a child psychiatrist, covers the child’s developmental history and current behavior with a primary focus on disruptive behavior disorders (ADHD, Oppositional Defiant Disorder, Conduct Disorder), anxiety and clinical depression. The PICS is modeled on the Kiddie SADS-PL (Kaufman, 1979) but does not use skip-out criteria for the disruptive behavior disorders. The teacher interview (Teacher
Telephone Interview-IV (TTI; Tannock & Schachar, 1996, unpublished manuscript) was conducted independently by trained clinicians. It follows the same basic format as the PICS in terms of covering all the DSM-IV criteria for the three disruptive behavior disorders, but only screens for internalizing disorders. Both interviews require the clinician to elicit information from the informant (i.e., parent or teacher) detailed descriptions of the child's behavior in various situations in the specific setting (home or school, respectively). Based on this information, the clinician (rather than the informant) makes a judgement about the presence and severity of symptoms. Reliability and validity for the DSM-III-R version of both interviews are high (e.g., Schachar, Tannock, Marriott, & Logan, 1995: evaluation of the reliability and validity of the DSM-IV versions are in progress).

Supportive information was provided by various rating scales completed by parent, teacher and children (scores did not contribute to diagnosis). Parent and teacher questionnaires included the Revised Ontario Child Study Scales for parents and teachers (OCHS; Boyle et al., 1993), Connors Abbreviated Rating Scales (CPRS, CTRS, Connors, 79), the SNAP-Questionnaire for ADHD (Swanson et al., 1988). Child questionnaires included the Revised Children's Manifest Anxiety Scale (Reynolds et al., 1985) and the Children's Depression Inventory (Kovacs, 1992).

According to the clinical interviews, four children (27%) were sub-typed as Predominantly Inattentive and 11 (73%) as the Combined Subtype. A concurrent diagnosis of Oppositional Defiant Disorder (ODD) was made for six (43%) children, Anxiety Disorder for three (21%) children and Conduct Disorder (CD) for one (7%) child.

The child assessment included the Vocabulary and Block Design subtests of the Weschler Intelligence Scale for Children-III (WISC-III, Wechsler, 1974) to estimate general intellectual
ability (Sattler, 1988), and the Wide Range Achievement Test-3rd Edition (WRAT-3; Wilkinson, 1993) to assess reading, spelling, and arithmetic achievement. In order to assess current receptive and expressive language abilities the Clinical Evaluation of Language Fundamentals-Revised (CELF-R) was administered by a registered Speech/Language pathologist. In the event that any of the mentioned measures had been administered within the past year, results were obtained with consent from parents.

The group estimated IQ score fell within normal limits (M = 112.40, SD = 14.54). Arithmetic standard scores within normal limits (i.e., standard score > 90) were obtained by all children. One child (7%) exhibited a reading disability and two (14%) children showed evidence of a spelling disability as defined by scores of at least 1.5 standard deviations below the mean for their age on relevant subtests of the WRAT-3 (Wilkinson, 1993). Special class placement or withdrawal services determined the presence of school identified learning disabilities for 2 children (one in full-time special education class, the other in part-time special education support).

The overall (M = 90.67, SD = 12.03) and receptive (M = 95.33, SD = 12.16) CELF-R subtest scores fell within normal limits (i.e., standard score > 90) with the expressive subtest score falling slightly below average (M = 87.50, SD = 17.40). Four children with ADHD met the criterion for Expressive Language Impairment.

Non-ADHD Group. Fifteen children were recruited through various elementary schools. They were identified by their teachers as average achieving and were not suspected of having any learning or behavior problems. Diagnostic interviews with parents or teachers were not conducted but parents, teachers and children completed the same questionnaires as the ADHD group. Behavior ratings and questionnaires completed by parents and teachers (e.g., OCHS,
SNAP, CPRS) and child self-ratings confirmed that none of the children had a history or current presentation of problems in behavior, attention or learning.

The estimated IQ score for the non-ADHD group fell within normal limits ($M = 109.40$, $SD = 14.74$). Arithmetic, reading and spelling standard scores for all children fell within normal limits (i.e., standard score > 90) on the WRAT-3 (Wilkinson, 1993). All children attended regular class placements.

Overall, receptive and expressive language scores, as assessed by the CELF-R, all fell within normal limits (Overall language score = 104.50(8.38), Receptive language score = 104.30(10.82), Expressive language score = 100.10(9.72). More detailed sample characteristics are reported elsewhere (Benedetto-Nasho, & Tannock, 1999).

*Group Differences*. The majority of subjects across groups were Caucasian (1-Black, 1-Asian). Although social-economic data were not collected, data on parents’ education level indicated that the majority of parents in both groups had a strong educational background. Groups were roughly equivalent in the percentage of parents who had some college experience (ADHD 14%, non-ADHD 13%), had completed college (ADHD 21%, non-ADHD 20%), had some university experience (ADHD 21%, non-ADHD 13%) and had completed university (ADHD 43%, non-ADHD 53%).

Language ability was the only significant difference found between groups. Scores of both groups fell within normal limits for the overall and receptive subtest score. The expressive subtest score for children with ADHD fell within the Low Average range.

*Context and Procedure for Eliciting and Recording Private Speech*

A math computation task was used to elicit private speech. Pre-testing of math computation competence was assessed at the beginning of the protocol. Children were assessed
to establish their individual 'zone of proximal development (ZPD)' (Vygotsky, 1930-1935/1978) for competence in math computation on this particular task. A systematic approach of determining competency level was developed based on the child's ability to demonstrate understanding of the necessary skills for successful computation in addition and subtraction based on their grade level. The first level involved determining the child's upper limit of his/her skill ability without assistance in the areas of addition and subtraction computation. This was accomplished by allowing the child to complete items independently. The child was stopped after two consecutive failed items and coaching was initiated. The second level established an upper limit of ability with the aid of coaching (e.g., What sign is this? Are you sure 4+2 is 8?). Coaching was terminated after two consecutive failed items. To receive a particular grade level worksheet two criteria had to be met: 1) at least 1 item had to be completed independently and 2) at least 5 items had to be completed with the aid of coaching. The rational for this methodology was twofold: 1) to ensure that each child was given math problems one step above their demonstrated unaided ability level and 2) to provide each child with an ample number of challenging problems for the time period so as to avoid ceiling and floor effects.

A set of worksheets designed by Douglas & colleagues (Douglas et al., 1986) were then selected for use during the study. Each sheet contained items reflective of the child's demonstrated ability level as well as items slightly above the level at which the child could perform accurate computation independently. Thus, for each child, the difficulty level of the math task fell within what Vygotsky termed the individual Zone of Proximal Development (Vygotsky 1935/78).

Private speech samples were recorded with a Sony Professional Walkman WMB-6C Stereo-cassette recorder and multidimensional tabletop microphone positioned approximately two
feet away from the child for the 10-minute period. This procedure is unlike previous research on children's private speech in classrooms, in that all language emitted by the child was likely captured, including language that would otherwise be inaudible. Moreover, speech was coded when the child was off-task and when the child requested assistance from the examiner during the ten minutes. A trained research technician with a background in linguistics transcribed all of the audio-taped language samples using the CHAT transcription and coding format of the Child Language Data Exchange System (CHILDES; MacWhinney, 1995). Each transcript was verified by an independent trained transcriber (EB-N). The basic unit of linguistic analysis was the utterance. This was defined as any one of the following: a string of words that was separate from another for a minimum of 3 seconds, a conversational turn, a complete sentence, or a sentence fragment that was terminated by an intonational marker (Feigenbaum, 1992, Diaz & Lowe, 1987). Samples of coded utterances can be found in Figure 4.2.

Contextual factors (e.g., instructions to child, presence and location of adult) have been demonstrated to affect the amount of private speech produced by children in both laboratory and classroom situations (Berk & Garvin, 1984; Berk & Potts, 1991; Kohlberg et al, 1968). Accordingly, the following contextual controls were used. All children completed testing on an individual basis with only the child and the examiner present. First, children were instructed that they must work independently but that often children talked to themselves during this task and that this was acceptable. Second, the examiner remained in the room, seated at a separate table, at a distance of approximately 3 feet from the child to minimize opportunities for socialization and behavior management. Children were given 10 minutes to complete the worksheet. Third, any comments made to the examiner during the task were ignored unless the questioning was persistent and resulted in the child not being able to re-focus on the task (Child - Do I have to do
the minus’s? (Repeated 2 times), Examiner – Do as many of the questions as you can. Just do your best.) or when the question or comment required cessation of the task (Child – Can I go to the bathroom? Examiner – Please wait until the ten minutes is finished. C – I can’t.). The examiner rated concurrent overt behavior immediately after the child had completed the task.

Dependent Measures

**Math Performance.** An academic efficiency score (AES) was used as the measure of academic performance. It was calculated by dividing the total number of items correct by the total number of items available on the worksheet, expressed as a proportion (Rapport et al., 1986). AES has been found to be associated with both academic productivity and academic achievement (DuPaul et al., 1991, 1993), in addition to being sensitive to the dose effects of stimulant medication (Rapport et al., 1986, DuPaul et al., 1993). Detailed analysis of math performance and error analysis have been reported previously (Benedetto-Nasho & Tannock, 1999).

**Private Speech Categorization.** Language was coded using a multi-tiered hierarchical system that distinguished three mutually exclusive speech types, three private speech levels and nine mutually exclusive sub-types of private speech (See Figure 4.2). This coding system was adapted from the work of Berk & colleagues (i.e., Berk, 1986, Berk & Potts, 1991; Berk & Spuhl, 1994; Berk & Landau, 1993). Modifications reflected methodological differences in data collection (audiotape of individual versus online coding in classroom) and task type (math computation versus reading). At the highest level of the system, language was coded as social, private or uncodable in nature. The second tier reflected global differences in private speech types, specifically off-task, on-task external or on-task internal manifestations of inner speech. The developmental maturity of private speech is embedded at this level of coding. Off-
Figure 4.2.

**Types of Private Speech**

<table>
<thead>
<tr>
<th>Private Speech Category</th>
<th>Definition</th>
<th>Examples from Math Computation Task</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Off-Task</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comments to self/Questions to self</td>
<td>Any utterances that are clearly not related to the task and are directed to the self or no particular listener</td>
<td>Excuse me. Uh, is in Michael and you. Don't try to knock me down. Are you trying to knock me down?</td>
</tr>
<tr>
<td>Word/sound play</td>
<td>Repetition of sounds, words or sentences in a playful manner</td>
<td>Smacking lips Go, go, go...</td>
</tr>
<tr>
<td>Affect expression</td>
<td>Emotional expression that is not directly related to the task</td>
<td>Laughing This sucks</td>
</tr>
<tr>
<td><strong>On-Task External</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-guiding comments/ Questions or answers to self</td>
<td>Reference, questions or answers regarding math functions or counting containing reference to math functions that are clearly audible</td>
<td>Five take away two. Six plus five equals eleven. Eight take away four equals eight. What is two plus three?</td>
</tr>
<tr>
<td>* Counting</td>
<td>Counting that contains only reference to number and is clearly audible</td>
<td>Eleven six. Four eight. Two three four five.</td>
</tr>
<tr>
<td>Affect Expression</td>
<td>Emotional expression that is related to task activity and clearly audible</td>
<td>It’s so hard! I just can’t do it! There’s so much!</td>
</tr>
<tr>
<td><strong>On-Task Internal</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Audible muttering</td>
<td>Incomplete sentences or words that are clearly on task, and audible but in a whispered voice</td>
<td>That’s eighteen. (whispers) Thirteen fourteen fifteen. (whispers)</td>
</tr>
<tr>
<td>* Partial muttering</td>
<td>Incomplete sentences or words that are clearly on task but not clearly audible</td>
<td>Three take away… and that ...(whispers)</td>
</tr>
<tr>
<td>* Phonological fragments</td>
<td>Sounds that are clearly a component of an inaudible word</td>
<td>&amp; ti.</td>
</tr>
</tbody>
</table>

Note 1: Adapted and modified from “Development of Private Speech Among Low Income Appalachian Children.” Laura Berk and Ruth Garvin in *Developmental Psychology*, 20(2), 271-286.
Note 2: * refers to novel categories
Note 3: Off-task = Task-Irrelevant. On-task External = Task-Relevant External. On-task Internal = Task-Relevant Internal
On-task private speech is conceptualized as the least mature, with on-task external following and on-task internal private speech hypothesized to be the most mature form of private speech - internalized language. Lastly, each of the global private speech levels was divided into finer categories in an attempt to further describe the characteristics of private speech utterances. Level 1, or Off-task fine categories were identical to those used in Berk, 1986. On-task external fine categories were altered to reflect task demands (reading aloud versus counting aloud). The fine categories of on-task internal utterances were modified from the original classification by Berk and colleagues. Specifically, the use of audio-recording and linguistic transcription permitted the addition of 2 unique categories: partial muttering and phonological fragments. Both of these sub-categories are reflective of a better ability to detect sub-vocalizations of private speech. When contextual information was captured using this type of linguistic transcription (i.e., prosody, affective information) it was used to clarify categorization of utterances. Children’s language was not coded on line and thus lip and tongue movements were not codable. Category definitions and examples of both ADHD and non-ADHD children’s private speech utterances are available in Figure 4.1.
Figure 4.1.

Speech Categorization System

- Utterance
  - Private Speech
  - Social Speech
  - Uncodable
    - Task-Irrelevant
      - Comments/Questions
      - Words/Sound play
      - Affect expression
    - Task-Relevant External
      - Self-guiding comments/questions
      - Counting
      - Affect Expression
    - Task-Relevant Internal
      - Inaudible muttering
      - Partial muttering
      - Phonological fragments
**Behavior Ratings.** Level of inattentiveness was rated on a 6-point likert scale, where 0 indicated that the child was attentive to the task for the majority of the 10 minutes and 6 indicated that the child was typically inattentive. Finger counting was rated on a 4-point likert scale (1 = no finger counting, 4 = substantial amounts of finger counting).

Detailed findings of overt behavior, including activity level have been reported previously (Benedetto-Nasho & Tannock, 1999). Data for visual attention to task and finger counting are included here to determine the relationship between private speech and task behavior.

**Medication Protocol.** A randomized double blind, placebo controlled, crossover trial of methylphenidate was conducted for 3 consecutive days. After baseline measures were obtained, each child received each of 3 fixed doses (placebo, 10 mg, and 20 mg) in randomized order. Placebo and active medication was prepared by the hospital pharmacy, powdered, and packaged in an opaque gelatin capsule to prevent identification of contents by color, taste or volume. Each child's medication was placed in an individually named and dated envelope to ensure accurate administration. Testing was conducted blind to medication condition, approximately 2 hours after ingestion of the capsule (i.e., during active phase of medication (Swanson & Cooney, 1978). Fixed doses rather than dosing based on gross body weight were utilized as there is no clear evidence that response to medication is dependent on body weight (Rapport et al., 1989).

**Inter-rater Reliability**

Inter-rater reliability was calculated for behavioral observation and private speech categorization for 20 % of the sample. Reliability, averaged across observers, for the ADHD and non-ADHD groups respectively were as follows for both the broad and finer categories of private
speech: a) private speech versus social speech, 1.0, .98, b) private speech off-task (TI) .96, 1.0, on-task external .96, .89, on-task internal, .89, .94. Reliability for the broader behavioral observation were .87, 1.0. The mean inter-observer reliability for the finer behavioral categories was .98, .99 with a range of .71 to 1.0 and .92, .95 with a range of .65 to 1.0 for private speech categories. Reliability was consistent with that previously reported in the literature (e.g., Berk & Landau, 1993; Berk & Potts, 1991).

Results

ADHD/Non-ADHD Comparison

Math Performance. Assigned math worksheet levels for this study are representative of children's individual Zone of Proximal Development. Past research, using these worksheets conceptualized these levels to be indicative of grade level (Douglas et al., 1986). For most children however, ZPD level was not consistent with actual grade level. The proportion of children assigned to math worksheets at their grade level were 13% (2/15) and 20% (2/10), in the ADHD and non-ADHD groups, respectively. The remaining children in the ADHD group were divided amongst levels 4-6 (grade 3 – 2 children at level 6, 1 child at level 4; grade 4 – 4 children level 5, 2 children level 6; grade 5 – all children (4) level 6). The balance of the non-ADHD group fell within level 6 (grade 3 – 5 children level 6; grade 4 1 child level 6). Thus, the conceptualization that these particular math worksheets are representative of grade level, and thus individual math computation ability, is incorrect. The underestimation of children's actual math computation ability level may therefore affect the amount of private speech produced during task completion. It was therefore imperative that individual testing of actual math computation ability be undertaken.

AES data were subjected to a univariate analysis of variance (ANOVA). A significant main effect was found (F (1,24) = 27.69, p<.001), with children with ADHD being
approximately 1/3 less efficient (AES) on the math task than their non-ADHD peers, despite being matched on math computation as measured by the WRAT. For further details of math performance and error analysis see Benedetto-Nasho & Tannock, 1999.

*Private Speech.* The majority of children (83% of the total sample) produced some form of private speech utterance during the math task. All children with ADHD produced some form of private speech and so were included in the subsequent analysis of types of private speech in ADHD and comparison children. By contrast, one third (n = 5) of the non-ADHD sample produced no audible language during the task and were therefore excluded from subsequent analysis of private speech. These five children did not differ from the 10 remaining children on any other independent variables.

A t-test of the significance of the difference between two proportions was calculated for each speech type (See Table 4.1) (Bruning & Kintz, 1987). More children with ADHD produced social and private speech in comparison to the non-ADHD sample. The proportion of children who produced uncodable utterances did not differ significantly between groups. Proportion of children in the non-ADHD group who produced task irrelevant or task relevant external utterances was too small to permit examination of the finer categories of private speech.
Table 4.1.

Incidence of Speech Type in ADHD and Non-Children with ADHD

<table>
<thead>
<tr>
<th>Speech Type</th>
<th>ADHD (n=15)</th>
<th>Non-ADHD (n=15)</th>
<th>Z Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td># of children</td>
<td>% of children</td>
<td># of children</td>
</tr>
<tr>
<td>Private</td>
<td>15/15</td>
<td>100 %</td>
<td>10/15</td>
</tr>
<tr>
<td>Social</td>
<td>10/15</td>
<td>67 %</td>
<td>4/15</td>
</tr>
<tr>
<td>Uncodable</td>
<td>4/15</td>
<td>27 %</td>
<td>2/15</td>
</tr>
<tr>
<td>Private Speech</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Off-task</td>
<td>13/15</td>
<td>87 %</td>
<td>4/10</td>
</tr>
<tr>
<td>On-task External</td>
<td>13/15</td>
<td>87 %</td>
<td>3/10</td>
</tr>
<tr>
<td>On-task Internal</td>
<td>15/15</td>
<td>100 %</td>
<td>10/10</td>
</tr>
<tr>
<td>On-task Internal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inaudible muttering</td>
<td>14/15</td>
<td>93 %</td>
<td>7/10</td>
</tr>
<tr>
<td>Partial muttering</td>
<td>15/15</td>
<td>100 %</td>
<td>7/10</td>
</tr>
<tr>
<td>Phonological fragments</td>
<td>7/15</td>
<td>47 %</td>
<td>4/10</td>
</tr>
</tbody>
</table>

Note: ADHD = Attention Deficit Hyperactivity Disorder, non-ADHD = typically developing children
* p< .05
Analysis of task relevant internal utterances revealed that significantly more children in the ADHD group exhibited partial muttering than the non-ADHD group (See Table 4.1).

The overall incidence of private speech was 81.6%. The mean number of private and social speech utterances for the ADHD group were 31 and 4, and for the non-ADHD group 15 and 1 respectively. The mean number of uncodable utterances was comparable across groups, with both producing on average 1 uncodable utterance. As base rates of private speech production differed across children, the amount of private speech produced in the global categories is expressed as a proportion of total private speech, and the number of utterances in the finer categories are expressed as a proportion of each global category. Arcsine transformations were conducted to normalize the distributions, but since the results were unchanged, the un-transformed proportions are presented in Table 4.2 for ease of interpretation.

The proportions of private speech utterances, as well as sub-types of private speech were subjected to a univariate analysis of variance (ANOVA). The two groups did not differ in the overall amount of private speech as indicated by the percentages of utterances that reflected private speech (F(1,23)=2.40, ns). With respect to the sub-types of private speech, children with ADHD produced more off-task utterances, more on-task external utterances and fewer on-task internal manifestations of internal private speech compared to the non-ADHD sample (see Table 2). Analysis of finer categories within each of the three subtypes of private speech revealed no difference between ADHD and non-ADHD groups.

Behavior Ratings. Children with ADHD were less attentive (F(1,24) = 20.64, p<.001) compared to non-ADHD children. Also children in the ADHD group used finger counting significantly more often than the non-ADHD group (F(1,24) = 19.48, p<.001).
Table 4.2.

Percentages of Private Speech in Each Category for ADHD and Non-Children

<table>
<thead>
<tr>
<th></th>
<th>ADHD M</th>
<th>ADHD SD</th>
<th>Non-ADHD M</th>
<th>Non-ADHD SD</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Social Speech</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Private Speech</td>
<td>89.5</td>
<td>11.6</td>
<td>73.6</td>
<td>37.8</td>
<td>2.4</td>
</tr>
<tr>
<td><em>Off-Task</em></td>
<td>18.7</td>
<td>16.8</td>
<td>5.3</td>
<td>8.5</td>
<td>5.3*</td>
</tr>
<tr>
<td>Word play</td>
<td>75.1</td>
<td>32.6</td>
<td>96.4</td>
<td>7.1</td>
<td>1.1</td>
</tr>
<tr>
<td>Affect</td>
<td>0.4</td>
<td>1.4</td>
<td>0.0</td>
<td>0.0</td>
<td>0.3</td>
</tr>
<tr>
<td>Comments/questions to self</td>
<td>24.5</td>
<td>32.7</td>
<td>3.6</td>
<td>7.1</td>
<td>1.6</td>
</tr>
<tr>
<td><strong>On-Task</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self guiding</td>
<td>40.0</td>
<td>34.2</td>
<td>53.1</td>
<td>50.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Comments/questions to self</td>
<td>1.5</td>
<td>4.6</td>
<td>0.0</td>
<td>0.0</td>
<td>0.3</td>
</tr>
<tr>
<td><em>Counting</em></td>
<td>26.6</td>
<td>33.3</td>
<td>11.1</td>
<td>19.3</td>
<td>0.6</td>
</tr>
<tr>
<td>Affect</td>
<td>31.3</td>
<td>30.6</td>
<td>35.8</td>
<td>55.7</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>On-task Internal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inaudible muttering</td>
<td>30.7</td>
<td>23.5</td>
<td>38.7</td>
<td>41.0</td>
<td>0.4</td>
</tr>
<tr>
<td>*Partial muttering</td>
<td>59.7</td>
<td>19.3</td>
<td>48.5</td>
<td>39.6</td>
<td>0.9</td>
</tr>
<tr>
<td><em>Phonological fragments</em></td>
<td>9.6</td>
<td>17.3</td>
<td>12.8</td>
<td>31.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Uncodable</td>
<td>1.0</td>
<td>2.5</td>
<td>16.7</td>
<td>38.9</td>
<td>2.4</td>
</tr>
</tbody>
</table>

Note 1: all data are expressed as a percentage
Note 2: (*) Amount of private speech, social speech and uncodable utterances expressed as a proportion of total speech
(†) Expressed as proportion of total private speech utterances
(‡) Expressed as proportion of utterances within each global category
ADHD = Attention Deficit Hyperactivity Disorder. Non-ADHD = typically developing children.
* Codes unique to the present study
Note 3: Developmental progression of private speech: off-task, on-task external, on-task internal p>0.05*, p>0.01**
Relationship of Math Performance, Private Speech and Behavior.

Pearson-product correlation coefficients of the relationship between private speech, overt behavior and math performance is presented in Table 4.3. On-task external utterances were positively correlated with level of inattention, whereas on-task internal manifestations of inner speech were negatively correlated with inattention level. The correlation of private speech and math performance revealed a negative relationship between overall efficiency and on-task external speech. More utterances of the on-task internal subtype were also related to increased task efficiency.

Effects of Stimulant Medication

The statistical significance of MPH effects on all measures was assessed using an analysis of variance (ANOVA) with repeated measures across medication dosages.

Math Performance. A significant effect for AES was found ($F(1,14) = 5.78$, $p<.01$), with medication increasing academic efficiency from 19.33% during the placebo condition to 25.79% during medication conditions.

Private Speech. All children produced some form of private speech during the placebo condition. One child produced no audible language during either dose condition (10mg, 20 mg). Medication had no effect on overall amount of private, social or uncodable utterances. Within the two global subtypes of private speech, a decrease in off-task speech ($F(1,14) = 3.87$, $p<.05$) was observed with a concomitant increase in on-task internal utterances ($F(1,14) = 4.24$, $p<.05$) (see Table 4.4). No differences in the fine categories of private speech were observed.

Behavior. Level of inattention and reliance on finger counting were decreased on medication ($F(1,14) = 7.86$, $p<.01$; $F(1,14) = 9.43$, $p<.05$).

Relationship of Math Performance, Private Speech and Behavior. The most striking
# Table 4.3

## Correlation of Private Speech Categories with Behavioral and Math Performance Indices

<table>
<thead>
<tr>
<th>Behavioral Measures</th>
<th>Math Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Behavioral</td>
</tr>
<tr>
<td></td>
<td>Measures</td>
</tr>
<tr>
<td></td>
<td>Fidget</td>
</tr>
<tr>
<td></td>
<td>Gross Body</td>
</tr>
<tr>
<td></td>
<td>Movement</td>
</tr>
<tr>
<td></td>
<td>Use of Task</td>
</tr>
<tr>
<td></td>
<td>Materials</td>
</tr>
<tr>
<td></td>
<td>Finger Counting</td>
</tr>
<tr>
<td></td>
<td>Inattention</td>
</tr>
<tr>
<td></td>
<td>Productivity</td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
</tr>
<tr>
<td></td>
<td>Efficiency</td>
</tr>
</tbody>
</table>

*Note: Correlation’s of the proportion of private speech is reported

* p < .05,  p < .01 **
Table 4.4.

Private Speech Production of Children with ADHD during MPH Trial

<table>
<thead>
<tr>
<th></th>
<th>Placebo</th>
<th>10 mg</th>
<th>20 mg</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Social Speech (n=14)</td>
<td>13.2 (20.8)</td>
<td>15.4 (21.8)</td>
<td>13.2 (23.2)</td>
<td>0.06</td>
</tr>
<tr>
<td>Private Speech (n=14)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Private Speech</td>
<td>84.9 (21.9)</td>
<td>84.0 (22.4)</td>
<td>86.0 (23.0)</td>
<td>0.05</td>
</tr>
<tr>
<td>Off-Task</td>
<td>21.1 (27.8)</td>
<td>5.9 (9.9)</td>
<td>6.0 (12.3)</td>
<td>3.9 *</td>
</tr>
<tr>
<td>On-Task external</td>
<td>14.3 (19.8)</td>
<td>13.7 (27.1)</td>
<td>4.8 (12.7)</td>
<td>0.8</td>
</tr>
<tr>
<td>On-Task internal</td>
<td>64.6 (33.0)</td>
<td>80.4 (26.4)</td>
<td>89.2 (16.0)</td>
<td>4.2 *</td>
</tr>
<tr>
<td>Uncodable (n=14)</td>
<td>0.5 (1.9)</td>
<td>0.6 (1.4)</td>
<td>1.9 (2.6)</td>
<td>1.9</td>
</tr>
</tbody>
</table>

*p < .05, p < .01**
relationship found between variables was that between private speech and finger counting. Finger counting was positively associated with off-task utterances ($r(23) = .84, p < .01$) during the placebo condition as well as being positively related to on-task external utterances ($r(23) = 0.75, p < .01$) at 10 mg of MPH. A negative correlation was found between finger counting and on-task internal utterances ($r(23) = -0.77, p < .01$) during the placebo condition. No other relationships were found to be significant.

Discussion

The goals of the present study were to compare private speech in children with ADHD with their typically developing peers using more refined methodology than used in previous research and to examine the effects of stimulant medication on private speech in children with ADHD during a controlled medication trial. The finding that one third of the non-ADHD children did not display any overt private speech was puzzling. According to Vygotsky (1935), lack of overt private speech signifies the internalization of private speech and thus it could be hypothesized that our non-speaking non-ADHD children had completely internalized private speech at this point in their development. Conversely if the difficulty in subtraction experienced by the children with ADHD inadvertently made particular items more difficult, then it is possible that the amount of private speech produced was deceiving. If despite individual testing of children, ADHD children were provided a more challenging task then non-ADHD children then overall amounts of private speech may have been underestimated for children with ADHD. These findings reinforce the suggested need of task difficulty to be carefully tailored to the abilities of individual children. Gross matching of ability level and task difficulty could produce more private speech or just as likely produce less private speech, and thus in order for an accurate account of the quantity and quality of private speech to be determined in children,
individual matching is essential.

Results of the ADHD/non-ADHD comparison are consistent with findings from previous studies: children with ADHD produced more external off-task, more external on-task and less internalized private speech than their unimpaired peers. It was also apparent that an increase in on-task but external private speech was related to higher levels of inattention and poorer task performance. This was in direct contrast to an increased usage of internal on-task private speech that was related to lower levels of inattention and better task performance. These findings clearly indicate that children with ADHD are impaired in their production of specific types of private speech. It remains unclear however whether or not children with ADHD are impaired in the function of private speech or whether the significant differences in the amount of various types of private speech, make its proper use unattainable. The medication trial findings of the present study are provocative. The amount of total private speech was unaffected by medication. However, external off-task private speech was decreased and on-task internal private speech was increased.

Another interesting finding was that expressive language ability outside of private speech did not appear to affect amounts of private speech produced (F(1.22) = 0.978, ns). Children in the ADHD group had significantly lower expressive language scores on the CELF-R. It could have been argued therefore that deficits in expressive language would lead directly to deficits in private speech production. Two findings contradict this hypothesis. First, children with ADHD produced more private speech than non-ADHD children. Second, when the Expressive Language Score of the CELF-R was used as a covariate the findings remained. A theoretical question remains: is private speech (thought) separate from language. Certainly this study does purport to address this issue. However, it does raise the question about the possible relationship
between private speech and expressive language abilities.

The results of the present study confirm that the study of private speech is highly sensitive to experimental manipulation. Various unique design variables were employed in this study: 1) the use of an academic task within a laboratory setting, 2) individualized selection of task difficulty level, 3) audio-recording of private speech that was sensitive to sub-vocalizations, 4) continuous recording of private speech throughout the duration of the task, and 5) linguistic transcription of all language.

First, the results suggest that the collection of private speech in the laboratory is not inherently detrimental to the production of private speech nor does it necessarily underestimate the amount produced in comparison to naturalistic settings. In the naturalistic setting of the classroom Berk & Potts (1991) found that in 80% of the observation intervals children (both ADHD and non-ADHD) produced some form of private speech. The results of this study are strikingly similar, with 82% of utterances being classified as private. This confirms the validity of using an academic task in the laboratory, where greater experimental control can be exercised, in order to elicit private speech at similar rates to that found in naturalistic settings.

Second, previous research has typically determined task difficulty level by the child's grade placement. This procedure is questionable if optimization of private speech production is the goal. In the present study task difficulty was determined by individual testing on the experimental measure. This resulted in only 2 out of 15 children in the ADHD group achieving a worksheet level at their grade level. Nine of the remaining children in the ADHD group were assigned a worksheet 1 level above their grade level, 2 children 2 above grade level and 2 children 3 above grade level. This inconsistency was also found to be true for the non-ADHD group. Two of the ten non-ADHD children were assigned a worksheet commensurate with their
grade level. Five children received a worksheet 3 above grade level, 4 children 2 above grade level and 2 children 1 above grade level. It is possible that the grade level assigned to the math worksheets was incorrect however it is also possible that assumed grade level abilities can not be shared across differing curriculums or provinces (Douglas study – Montreal, Quebec; present study – Toronto, Ontario). Once again, the emphasis appears to be the need for very specific individualized tasks for children in order to optimize private speech production

If it is true that the production of private speech is increased during cognitively demanding tasks, it is possible that previous research has underestimated the amount of private speech produced for both ADHD and non-ADHD children. Our results provide preliminary support for this hypothesis. For example, in the ADHD group, 90% of utterances were classified as private and 74% were classified as private in the non-ADHD group. Compared to these same incidences in the Berk & Potts (1991) study, 80% and 78% respectively, our data suggests that ADHD children can produce more private speech given certain conditions. It also highlights the need to ensure that children be given a task that will not result in ceiling effects. This may artificially curtail the quantity and perhaps the quality of private speech produced.

The results also support the use of audio recording as a means of potentially capturing private speech that would otherwise be left unheard. Both Berk & Potts (1991) and Berk & Landau (1993) report lower amounts of on-task internal private speech in ADHD/LD and in non-ADHD children compared to the present study. Thus, it might be that previous research has underestimated the abilities of atypical populations, namely ADHD and LD, to produce private speech. It is also possible that coding across studies differs despite similar coding schemes. Few studies provide private speech language samples and how they would be coded based on the coding system. This may for example have made the already existing problem of lack of clarity
and objectivity in coding more severe. This study provides explicit information not only on the coding system itself but also what type of language was placed within each category. The implication of providing language sample exemplars and relevant coding is substantial. It allows investigators to determine even if at a superficial level the possible discrepancies across studies using similar coding systems.

Fourth, many studies have chosen to refrain from coding private speech when children have not been engaged with the task, particularly at times when children seek out assistance from the adult. The assumption is that teacher assistance typically lessens the need for self-guiding private speech (Berk & Garvin, 1984; Diaz, 1992). Unfortunately, although the quantity of self-guiding private speech may be affected, it is also possible that other types of private speech are being utilized during this time or that ADHD children have a propensity to seek assistance or go off-task at the precise time that self-guiding speech would be employed. Our data do not directly provide support for the hypothesis that children seek out more assistance from an adult during this time, as levels of social speech were not increased. However, the hypothesis that children with ADHD may gravitate towards other types of private speech was suggested by our higher percentage of on-task external and internal utterances compared to previous studies.

Lastly, an advantage of this study, was the use of verbatim transcription of the language data in comparison to on-line coding. This provided what we believe to be valuable information with respect to the actual internalization of private speech. We have begun to disentangle the notion of internal manifestations of private speech by dividing this larger category into 3 subtypes based upon the linguistic transcription. For example, inaudible muttering reflected on-task whispering whereas the other two categories within this grouping reflected first sentences or words that had just begun to be internalized and then sounds that were clearly a component of a
word. In addition, verbatim coding allowed us to rethink the 'language' of private speech and explore a new categorization system. In this system on-task external and internal private speech utterances were coded with respect to their hypothesized function. This novel categorization of private speech utterances highlighted the tendency for typically developing children to rely heavily on directional words, such as, 'put the one here' in their external private speech. Children with ADHD did not appear to rely on this strategy as frequently. In addition, children with ADHD tended to use more one word counting utterances (i.e., one – two – seven versus one, two, three, four, five) in an attempt to complete the math computation. As private speech becomes internalized both ADHD and non-ADHD children appear to produce similar amounts of utterances described as directional, expansive, and sequence counting. What appears to be different is non-ADHD children's increase use of one word counting. This could be hypothesized to be reflective of speech being fragmented as private speech is internalized. This data must be interpreted with caution, as number of utterances within each category was minimal. It does however suggest that further investigation of private speech at a functional level is warranted.

The positive results of the present study suggest that the investigation of private speech in children with ADHD is essential in advancing our understanding of the function of private speech both in atypical and typical development. However, despite the improved methodology used in this study a number of limitations remain that should be improved upon in future research. First, sample size was small. Small sample size did not allow for differentiation between subtypes of ADHD, or differentiate groups based on difficulties in language or learning. Second, although experimental control was maximized it will also be important to examine the use of private speech and medication effects in the natural learning environments of children.
with ADHD in order to determine the effects of teachers, peers and natural distractors. Noisy 'private speech' and overt finger counting for example may be viewed as disruptive in the group setting and may be discouraged, despite their necessity in the developmental path of the internalization of private speech. Lastly, the ample use of finger counting by children with ADHD led to the hypothesis that finger counting may represent a non-verbal private speech strategy. Perhaps finger counting accompanied by counting aloud is a form of on-task external private speech whereas finger counting and silence represents on-task internal private speech. The fact that MPH decreased finger counting further suggests that there is a relationship between a child's use of finger counting and the internalization of private speech. The use of verbatim transcription coupled with videotape and computation performance may explain this relationship.

Clinically, these findings highlight the need for children with ADHD to be exposed to learning environments that allow them to use on-task private speech whether it is external or internal. Teachers and parents need to understand that private speech follows a developmental progression from external to internalized language and that children need the opportunity to progress freely through these stages. It will also be important for teachers supporting children with ADHD to realize that there is a functional component to talking. Not all superfluous language that children with ADHD produce is inappropriate or dysfunctional. On-task private speech has been shown to guide behavior and facilitate children's academic performance.

The results of the present study also suggest that there are potentially positive effects of stimulant medication on the use of private speech, the ability to control behavior, and academic performance. The internalization of private speech is increased, permitting a higher private speech developmental level to be achieved while concomitantly decreasing potentially intrusive overt behavior such as finger counting and increasing academic performance. It would thus be
an injustice to children with ADHD if their treatment regime did not explore the possible positive effects of stimulant medication.

Finally, the findings from the current study have important theoretical implications. If behavioral inhibition is a component of the effective use of private speech as a tool for self-regulation, then Vygotsky's proposed unidirectional relationship between private speech and self-regulation must be expanded. Berk's (1991) expansion of the speech-behavior relationship included a bi-directional component whereby private speech and the self-regulation of behavior were interdependent. Should the results of this investigation be sustained in future research it suggests that children with ADHD may have difficulty with a higher order function that affects a number of behavioral responses, including but not necessarily exclusive to external private speech. This conclusion underscores the potential inappropriateness of describing children with ADHD as solely having a deficient private speech system. In contrast, it is possible that these children have an intact private speech system that falls prey to a deficient higher order function, namely behavioral inhibition.
CHAPTER 5

Conclusions
Private speech is speech that is directed toward the self for the purpose of self-guidance. Despite a lack of definitive evidence of a cause and effect association between private speech and self-regulation there is ample evidence that can be interpreted to be supportive of such a relationship (Kraft & Berk, 1998). Private speech has also been characterized as a phenomenon that is highly sensitive to experimental manipulation (Diaz, 1992). It tends to be low in frequency (Fuson, 1979), barely audible as it is internalized (Berk, 1986), facilitated or constrained by social variables (Berk & Garvin, 1984; Berk & Spuhl, 1995; Berner, 1971; Diaz, Neal, & Vacchio, 1991; Goudena, 1987; Rubin, Hultsch, & Peters, 1971), highly dependent on setting, task type (Berk & Garvin, 1984) and task instruction (Frauenglass & Diaz, 1985), and associated with both current and future task performance (Gaskill & Diaz, 1991; Goodman, 1981; Montero & Diaz, 1992).

A clinically diagnosed group of children with ADHD was used to investigate the relationship between private speech and children’s self-regulation. Children with ADHD have been characterized, by many, as having significant difficulties in self-controlled behavior. The study of private speech in these children thus has implications for both theory and clinical practice. Only one other study has investigated the private speech of clinically diagnosed children with ADHD on and off stimulant medication (Berk & Potts, 1991). The present study, with its emphasis on methodological variables, replicates and extends previous work in this area.

The present thesis included three approaches taken in an attempt to study private speech in children with ADHD. The first approach (Chapter 2) was a critical review of the literature reviewing methodological differences. The second approach was a detailed analysis of task performance and error patterns on a math computation task used to elicit private speech. Lastly, an empirical investigation of private speech in children with ADHD in comparison to their non-
affected peers and during a double blind placebo controlled medication trial of MPH was conducted.

The review of the literature resulted in the conclusion that a systematic informed choice approach was needed in the study of private speech. Clearly, children’s use of private speech is task, difficulty level and setting specific. In the majority of studies reviewed, little emphasis was placed on variables known to affect children’s production of private speech. It was apparent that the hypothesized impact of a number of methodological variables needed to be clarified. First, the laboratory setting does not appear to be inherently detrimental to the study of private speech and often allows for the tighter control of experimental design features. It may be that too much emphasis has been placed on the issue of setting when it is the variables within the settings that actually determine children’s use of private speech.

The second issue that arose was that of the relationship between task type and task difficulty level. To what degree do task type and task difficulty levels alter children’s production and use of private speech? It has been repeatedly demonstrated that visual spatial tasks elicit less private speech than semantically based tasks and that private speech production increases during goal directed or problem solving activities (Berk & Garvin, 1984; Dickie, 1973; Rubin, 1979). It has also been demonstrated that private speech use is optimized during intermediate levels of task difficulty (Rosengren & Perlmutter, 1989). Given that all these statements have been shown to have some validity the choice of the ‘best’ task to elicit private speech is daunting.

From a task type perspective, it was clear that block construction and videogames were not appropriate tasks to study private speech. This however was not determined by the quantity of private speech produced but rather by the lack of ability to control difficulty level. Perhaps we have been misguided to believe that task type is a paramount variable when in fact the ability
to control task difficulty that may determine children’s need for problems solving and thus ultimately children’s need to use private speech.

In this thesis (Chapter 3), children with ADHD demonstrated a deficit in math computation, both in overall productivity and in subtraction accuracy, despite global matching on academic math achievement, a lack of specific math disability and individual pre-testing on the experimental task. This highlights a second issue related to task difficulty level. Is there a relationship between task difficulty level, the resulting quantity of private speech produced and the type/quality of that private speech? Researchers have only begun to explore the possibility that specific item difficulty level may change the type or quality of private speech produced. If indeed subtraction posed a specific difficulty for children with ADHD then it is possible that the types of private speech produced were different than if only addition items were presented. This may or may not have had an effect on overall production of private speech. Thus, matching on global task difficulty may blur skill competency and thus task difficulty level on any given item. This is of particular concern for research involving children from special populations where difficulty may be imbedded in specific task items but hidden in global scores of performance. Only with detailed analysis of addition and subtraction items and error analysis was it apparent that children with ADHD had a specific difficulty with subtraction computation items.

If less cognitive challenge results in less use of private speech, it may be that less overall private speech results in more self-stimulatory, self-guiding or internalized language. Preliminary support for this hypothesis was found in our data of on-task internal manifestations of private speech. Previous studies (Berk & Potts, 1991; Berk & Landau, 1993) have reported lower amounts of this type of private speech than found in the present study. This may be a direct result of our use of close proximity audio recording or it could represent evidence that the
sub-types of private speech are altered when task difficulty is individualized. Consequently, it seems appropriate to suggest that the examination of task performance and item error analysis when appropriate are important design features in the study of private speech.

One of this theses' major contributions is that it highlights the need for future research to consider task difficulty level and its effect on the quantity and quality of private speech produced as crucial components of investigation. A number of methodological options for choosing tasks and determining difficulty level are proposed. First, tasks that have proven in the past to elicit optimal levels of private speech can be used (i.e., academic work) if children are individually tested for competency. Second, novel tasks can be explored if preliminary within study data supports the production of optimal levels of private speech (i.e., selective attention tasks) and individual competency. Lastly, the relationship between private speech and task performance can be investigated using a speech-item match, thus an item-level not subject-level analyses (Winsler, Diaz, & Montero, 1997). In the study of private speech in this dissertation this would have been achieved by examining private speech in conjunction with performance on each math computation item. This within task approach would lessen the likelihood that overall private speech production is hampered by variability of skill within a given task.

One empirical study was conducted as the main body of this thesis. The study reported in Chapter 4 represents one of a few studies in the literature to examine private speech in children with ADHD with an emphasis on methodology. It is also the only study to date using a placebo controlled double blind design to study the effects of stimulant medication on private speech. Our findings lend support to the belief that children with ADHD are not deficient in their production of private speech. The differences seen between children with ADHD and non-ADHD children appear to be found within the types of private speech used rather than quantity
per se. In this study children with ADHD produced more external off-task, more external on-task and less internalized private speech than their non-impaired peers. It was also apparent that an increase in on-task external private speech was related to higher levels of inattention and poorer task performance. This was in direct contrast to an increased usage of internal on-task private speech that was related to lower levels of inattention and better task performance. These findings clearly indicate that children with ADHD are impaired in their production and use of specific types of private speech.

In this thesis, all children were given a standardized test of language ability (CELF-R). Although overall language skill did not differ between children with ADHD and non-ADHD children in this sample, Expressive Language scores for the children with ADHD were significantly lower (ADHD=87.40, non-ADHD = 100.10). This led to the question of the effects of expressive language difficulties on the production of private speech. Would, for example, expressive language difficulties cause children to produce less private speech because private speech is expressive language internalized or would expressive language skills have no bearing on private speech because private speech (thought) is different from expressive language (language). The finding that the exclusion of the effects of expressive language had no effect on the production of private speech suggests that the ability to use language (private speech) to guide behavior may be less reliant on the quality of the overt language and more reliant on the ability to use what language one has. It remains a question whether or not children with poor syntax for example carry this deficit into their private speech or whether these abilities are unrelated.

Also unique to this study was the exploration of finger counting: a task-specific fine motor behavior. Finger counting was thought to provide a window into one strategy used by
children when completing math computation. It has been reported that children with mathematically based learning disabilities employ the same types of problem solving strategies as non-disabled youngsters when completing math computation but rely more heavily on counting on their fingers (Jordan, 1995) and verbally counting (Siegler & Jenkins, 1989). This was found to be true of our sample despite a lack of evidence of specific math disability.

It seems to us that finger counting may represent "overt behavioral" private speech. If one considers both movement and verbalizations as behavior then it is possible that children with ADHD during math computation are dually functionally deficient. Two interpretations are possible. One can take externalized private speech to mean an inability to use higher forms of private speech, namely internalized private speech to guide behavior and finger counting to simply mean an inability to control bodily movements. Or these two behaviors can be interpreted to be representative of the same deficit, namely behavioral inhibition. Perhaps finger counting accompanied by counting aloud is a form of on-task external private speech whereas finger counting and silence represents an intermediate step towards on-task internal private speech. The fact that stimulant medication decreased finger counting and increased higher level private speech further suggests that there is a relationship between children's motor control and the internalization of private speech. If it can be replicated that children with ADHD display deficits in private speech function and behavioral control then some of the proposed components of behavioral inhibition may be supported. The deficits seen in these executive functions would therefore give rise to deficits in what we call self-regulation.

Another notable contribution of the present thesis was the investigation of the effects of stimulant medication on private speech production (Chapter 4). This study represents the first double blind placebo controlled medication trial in children with ADHD addressing the issue of
private speech. Stimulant medication was found to increase children's production of the maturest form of private speech (on-task internal), increase attention to task, decrease potentially intrusive behaviors such as finger counting and increase academic performance. These medication findings lead credence to Barkley's hypothesized model that children with ADHD have difficulty with a higher order function, namely behavioral inhibition, which affects a number of behavioral responses, including but not necessarily limited to external private speech.

Many studies have found evidence supporting a deficit in behavioral inhibition in children with ADHD (Barkley, 1997). In addition to studies documenting specific difficulties with motor-inhibition tasks (i.e., go-no-go paradigm, change paradigm, stop-signal task) Barkley (1997) has inferred that the evidence that children with ADHD are more hyperactive and impulsive in their motor behavior and that they talk more both to themselves and others as supportive of a behavioral inhibition deficit. In keeping with this interpretation, several of our findings suggest that children with ADHD are unable to inhibit responses that would have been appropriate at an earlier developmental stage. This includes both verbal behavior (on-task external private speech) and motor behavior (finger counting). Given the opportunity to improve their attentional control and thus theoretically improve their behavioral inhibition private speech gains control of behavior (i.e., finger counting and motor calmness) and allows movement towards the internalization of private speech.

As previously noted, the strength of the findings contained in this thesis lies in the level of methodological quality. Children were rigorously diagnosed and individual skill level was mapped to task difficulty. In addition, careful attention was given to contextual variables such as instructions and the presence of others. The specific limitations to each study are discussed in the related chapters. Globally, the results of this thesis are limited by a number of sample
variables. Overall, sample size was small, and the lack of production of private speech in 1/3 of the non-ADHD group reduced sample size even further. The exclusion of part of the control group due to lack of private speech production also represents a problem from a conceptual point of view. I have argued within this chapter that private speech production is a potential ‘marker’ for the appropriateness of task type and difficulty level. Unfortunately it is impossible for us to determine why some children would use private speech while others would not. This potentially natural variability in children’s reliance on private speech challenges our present understanding of the phenomenon of private speech and its empirical study. Another sample limitation was our lack of ability to propose that our findings are solely characteristic of children with only ADHD. Children with ADHD and non-ADHD children differed on a number of variables, for example, anxiety, Oppositional Defiant Disorder and Conduct Disorder. It is unclear what the effects of these comorbid conditions have on the production and function of private speech.

The results of the current research have direct implications for clinical practice. Teachers must be made aware of two findings. Children with ADHD are likely to experience difficulties in math computation despite perhaps a lack of a specific comorbid condition of math disability and secondly children with ADHD must be exposed to learning environments that allow them to use on-task private speech whether it is verbal or motoric. It is essential that teachers supporting children with ADHD realize that there is at times a functional developmental component to talking. On-task private speech has consistently been shown to guide behavior and facilitate children’s academic performance. Lastly, potential positive effects of stimulant medication were observed on private speech, the ability to control behavior, and academic performance. Further study of the potential benefits of medication intervention for both short term and long-term learning must be undertaken.
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APPENDIX A

Task Selection: Pilot Study 1 – Videogames
This pilot study was conducted to determine the feasibility of using videogames to elicit private speech in children with ADHD. This was prompted by the discovery of increased talkativeness by children with ADHD during videogame play (Tannock, ADHD Report) and Krafft and Berk's (1998) finding that the incidence of private speech was much more frequent in open-ended activities. Twenty boys participated in the study, 10 boys with a diagnosis of ADHD and 10 typically developing peers matched on age, IQ, regular videogame utilization and years of Nintendo experience. Each boy played two videogames (Pacman and SuperMario) at two levels of difficulty (easy, hard). These videogames were conceptualized to be different in their inherent appeal to children of this age range. Pacman involved negotiating one character through a maze, eating pellets to gain points while being chased by one other character. SuperMario again involved maneuvering one character however the ability level of the character was dependent on child's ability to gain special powers and to overcome obstacles varying in content and difficulty. Difficulty level was calibrated based on the speed of the stimuli for Pacman and in terms of speed, obstacles and number of distracters for SuperMario. Subject's speech was transcribed and coded for: 1) quantity of social versus private speech, 2) task relevance or irrelevance of private speech utterances, and 3) mean length of utterance of private speech utterances.

The central finding was that videogames elicited private speech in 95% of our sample. More importantly, approximately 66% of all speech utterances during videogame play were classified as private. The second finding demonstrated that the ADHD group consistently used more private speech during both tasks compared to their typically developing peers, particularly during the difficult level of each task. In comparison to popular belief this language was not off-task but rather reflected the ADHD groups attempt to maneuver their characters through the videogame. Our third finding referred to the mean length of private speech utterance. This was
found to vary based on game and difficulty level. Utterances elicited by Pacman were on average 2 words in length. For example, ‘that’s it, oops, whoa’. SuperMario elicited utterances were somewhat longer, approximately 3-4 words in length (this is really hard, take that fish, ooh walking men).

From a methodological perspective, on first glance our findings appeared to suggest that videogames were a viable tool for eliciting private speech. Closer analysis questioned their feasibility. Several findings contributed to this conclusion. First, the categorization of utterances as social or private was not always clear. Diaz (1992) suggested that the private-social distinction be made solely on observable characteristics to decrease the possibility of inference bias. He proposed the following guidelines in determining if an utterance is social in nature: 1) the utterance contains an explicit reference to another person (Hey, Yoshie, I need your help); 2) the utterance represents a response to a question or comment from another; or 3) the utterance is accompanied by a gaze or longer look at another person. Due to the social nature of this particular videogame, the fact that it contained characters, that the children ‘engaged’ with in order to complete the task, resulted in highly inference based coding.

Second, language was coded for all conditions for a continuous stream of 15 minutes commencing one minute after play began. The average number of utterances across conditions was 10. Furthermore, mean length of utterance indicated that length of utterance typically ranged from 2 to 4 words depending on task condition. It was felt that this amount and quality of private speech data were not sufficiently rich to warrant further in-depth analysis.

Lastly, as has been suggested in previous research (i.e., Beaudichon, 1973; Behrend, Rosengren, & Perlmutter, 1989; Berk & Garvin, 1984) task difficulty plays a significant role in the quantity and quality of private speech production. Although varying difficulty levels were
provided it was felt that stricter control of individual task difficulty and closer maintenance of a constant difficulty level throughout the task would be more appropriate for the study of private speech.
Table A.1

Sample Characteristics

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<td>Estimated Full Scale IQ</td>
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<td>Videogame Utilization Session/week</td>
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<td>Nintendo Experience (Years)</td>
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</table>
Figure A.1

Percentage of Private Speech Utterances

Easy Ha rd
SuperMario
Hard

■ ADHD  □ Non-ADHD
Figure A.2

Types of Private Speech Utterances
Figure A.3

Mean Length of Private Speech Utterances
APPENDIX B

Task Selection: Pilot Study 2 – Block Construction
Block construction tasks have been used frequently in an attempt to elicit private speech in young children (see reviews by Diaz, 1992; Fuson, 1979) despite the possibility that they may be solved using perceptual matching strategies and not verbal mediation (Frauenglass & Diaz, 1985). A small study with adults was conducted using a set of graded construction tasks in order to determine if a visual spatial task could be effectively used to elicit private speech so that children with known difficulties on standardized language measures (i.e., CELF-R) would not be explicitly disadvantaged by the task itself. It was further hypothesized that having the target construction picture in view at all times would provide immediate feedback to the children on their performance on a piece by piece approach thus allowing them to fluctuate within their individual zones of proximal development calling upon private speech as it was needed within the task itself. The use of this microgenetic approach, examining the dynamic relationship between private speech and performance has been substantiated by the work of Winsler, Diaz and Montero (1997).

Five adults participated in the initial step of determining difficulty levels of block construction. A set of commercial blocks was used that contained attached groupings of blocks of 2 or more. Level 1 constructions were arranged solely in a linear fashion, level 2, 3 and 4 were hypothesized to increase in difficulty systematically based on embedding one more horizontal row for each level (See Figure 1).

The first step in grading difficulty was to determine if each level represented a coherent difficulty level across subjects (See Figure 2, 3, 4, 5). This was determined by recording completion time for each card in each of the four levels for each subject. The two ends of the hypothesized continuum demonstrated the most consistent findings. The data from levels two
and three was not interpretable. The verification of reliable levels of difficulty was not possible and thus the use of this task was abandoned.
Figure B.1

Block Construction Targets

Level 1

Level 2

Level 3

Level 4
Figure B.2
Block Validation Study Data - Level 1

Time (secs)

Cards

subj #1  subj #2  subj #3  subj #4  subj #5

N = 5
Figure B.3

Block Construction Validation Study Data – Level 2
Figure B.4

Block Construction Validation Study Data – Level 3
Figure B.5

Block Construction Validation Study Data – Level 4
APPENDIX C

Task Selection: Pilot Study 3 – Math Computation
Academic seatwork, in particular math computation was used in the only other study of private speech in clinically diagnosed children with ADHD, on and off medication (Berk & Potts, 1991). Although this study was naturalistic in design it provided supportive evidence that the rate of private speech production can be quite high when children are engaged in academic seatwork. This was in direct contrast to all previous studies addressing private speech in children labeled hyperactive and/or impulsive which used a variety of non-verbally mediated tasks such as puzzles, block design, free play or coloring. One major methodological weakness in the Berk & Potts study, and in fact in all studies that use academic seatwork as a means of eliciting private speech, was the lack of mapping of individual math ability with task difficulty. It was assumed that because the two schools from which ADHD and non-ADHD children were recruited adhered to similar curriculum that groups would be matched on math exposure and thus ability level. Furthermore, it was assumed that having children work at a difficulty level commensurate with achievement/grade level would “eliminate the possibility that ADHD subjects’ math assignments were overly challenging in comparison to those of their control counterparts” (Berk & Potts, 1991, p. 363).

A pilot study was conducted with three children with ADHD to determine if indeed grade level or achievement level were sufficient in determining difficulty level. Furthermore, the use of a pretest to establish children’s individual ‘zone of proximal development (ZPD) (Vygotsky, 1930-1935/1978) for competence in math computation on this particular task was investigated.

Worksheets, hypothesized by Douglas and her colleagues to be appropriate for grades 1 to 6, were selected (Douglas, Barr, O’Neill & Britton, 1986). Each level, conceptualized by Douglas et al. (1986) as approximate to grade level, contained addition and subtraction computational items. With increasing level, proportion of addition items decreased from 51% to
32% of the items, and subtraction items decreased from 49% to 32% of the items. Since the higher levels (e.g., five and six) also included multiplication and division items, these latter types of problems were excluded from these analyses, as the purpose was to examine item type to which all children were exposed. In addition to the proportion of addition or subtraction items per level, the difficulty level was increased across grades by expanding the number of digits in each question and/or increasing the procedural demands (i.e., frequent trading). Items were organized in a manner that required the child to shift operations within each row of 5 items. All item types were distributed equally throughout the worksheets.

A screening form and four equivalent worksheets were chosen. Administration and scoring of the screening form was modified in order to provide a math computation competence level for each child. The first step involved determining the child's upper limit of his/her skill ability without assistance in the areas of addition and subtraction computation. The second level established an upper limit of ability with the aid of coaching (e.g., What sign is this? are you sure 4+2 is 8?). Determination of individual difficulty level was based on children's demonstrated ability to accurately complete the computation items with the aid of coaching. The set of worksheets used for each child was therefore reflective of the individual demonstrated ability level. The rational for this methodology was twofold. We wished to ensure that each child was given math problems one step above their demonstrated unaided ability level and to provide each child with an ample number of challenging problems for the time period so as to avoid ceiling and floor effects.

By using the approach of mapping hypothesized task difficulty to demonstrated ability level on this particular task it was quickly realized that the hypothesized link between grade level and task difficulty was not supported. All three of the children who participated in this pilot
study demonstrated math computation ability on the task at two levels above grade level (actual grade level = 3, pre-tested ability level = 6). This suggests that had grade level been used as the criteria for task difficulty selection these children would have been provided with math worksheets greatly below their competence level. This type of error in judgement would therefore result in the production of decreased amounts of private speech, as the cognitive requirements of the task would potentially be automatized.

Based on our preliminary findings this task and approach to determination of difficulty level were used in the larger investigation of private speech in children with ADHD.
### Math Worksheet – ADHD Baseline – Level 2

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>35</td>
<td>54</td>
<td></td>
<td>219</td>
<td>39</td>
<td>112</td>
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<tr>
<td>+</td>
<td></td>
<td></td>
<td>-370</td>
<td>-27</td>
<td>+540</td>
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<tr>
<td>64</td>
<td>18</td>
<td>111</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>57</td>
<td>27</td>
<td></td>
<td>795</td>
<td>217</td>
<td>99</td>
</tr>
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<tr>
<td>647</td>
<td>33</td>
<td></td>
<td>88</td>
<td>268</td>
<td>32</td>
</tr>
<tr>
<td>+131</td>
<td>+32</td>
<td></td>
<td>-58</td>
<td>-147</td>
<td>+44</td>
</tr>
<tr>
<td>78</td>
<td>65</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>937</td>
<td>694</td>
<td></td>
<td>40</td>
<td>14</td>
<td>398</td>
</tr>
<tr>
<td>-220</td>
<td>-572</td>
<td></td>
<td>+21</td>
<td>+14</td>
<td>-203</td>
</tr>
<tr>
<td>20</td>
<td>371</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+75</td>
<td>+125</td>
<td></td>
<td>431</td>
<td>41</td>
<td>82</td>
</tr>
<tr>
<td>95</td>
<td>45</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>215</td>
<td>66</td>
<td></td>
<td>421</td>
<td>548</td>
<td>62</td>
</tr>
<tr>
<td>+361</td>
<td>-14</td>
<td></td>
<td>+112</td>
<td>-418</td>
<td>+20</td>
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<td>56</td>
<td>55</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>58</td>
<td>46</td>
<td></td>
<td>968</td>
<td>60</td>
<td>52</td>
</tr>
<tr>
<td>-185</td>
<td>-10</td>
<td></td>
<td>-118</td>
<td>+19</td>
<td>+36</td>
</tr>
</tbody>
</table>
Figure C.2

Math Worksheet – Non-ADHD Baseline – Level 3

\[
\begin{array}{ccccccc}
95 & 21 & 263 & 163 & 143 \\
-82 & -10 & -147 & +774 & +73 \\
\hline
13 & 11 & 131 & 611 & 130 \\
\hline
596 & 87 & 292 & 627 & 89 \\
+82 & -74 & -52 & +239 & -39 \\
\hline
514 & 13 & 240 & 412 & 50 \\
\hline
937 & 40 & 733 & 81 & 26 \\
-221 & +33 & -74 & -11 & +18 \\
\hline
716 & 04 & 747 & 70 & 58 \\
\hline
860 & 590 & 886 & 398 & 62 \\
+96 & +37 & -65 & -233 & -52 \\
\hline
848 & 567 & 831 & 165 & 10 \\
\hline
78 & 858 & 462 & 22 & 43 \\
-10 & -55 & +57 & +24 & +32 \\
\hline
68 & 803 & 445 & 68 & 811 \\
\hline
749 & 282 & 548 & 556 & 788 \\
-36 & +94 & -418 & +73 & -11 \\
\hline
713 & 217 & 130 & 589 & 777 \\
\hline
567 & 199 & 588 & 694 & 750 \\
+50 & -61 & +81 & -572 & +55 \\
\hline
517 & 118 & 515 & 12 & 705 \\
\end{array}
\]
Figure C.4

Math Worksheet – ADHD 10 mg MPH – Level 2
APPENDIX D

Private Speech Coding System
### Private Speech Coding System

<table>
<thead>
<tr>
<th>Private Speech Category</th>
<th>Definition</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Off-task</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Comments to self/Questions to self | Any utterances that are clearly not related to the task and are directed to the self or no particular listener | Excuse me.  
Uh, is in Michael and you.  
Don't try to knock me down.  
Are you trying to knock me down? |
| Word/sound play                 | Repetition of sounds, words or sentences in a playful manner                | Smacking lips  
Go, go, go...                                                                                             |
| Affect expression               | Emotional expression that is not directly related to the task              | Laughing  
This sucks                                                                                               |
| **On-task external**            |                                                                            |                                                                                           |
| Self-guiding comments/Questions or answers to self | Reference, questions or answers regarding math functions or counting containing reference to math functions that are clearly audible | Five take away two.  
Six plus five equals eleven.  
Eight take away four equals eight.  
What is two plus three? |
| * Counting                      | Counting that contains only reference to number and is clearly audible      | Eleven six.  
Four eight.  
Two three four five.                                                                                       |
| Affect Expression               | Emotional expression that is related to task activity and clearly audible  | It's so hard!  
I just can't do it!  
There's so much!                                                                                          |
| **On-task internal**            |                                                                            |                                                                                           |
| Audible muttering               | Incomplete sentences or words that are clearly on task, and audible but in a whispered voice | That's eighteen. (whispers)  
Thirteen fourteen fifteen. (whispers)                                                                         |
| * Partial muttering             | Incomplete sentences or words that are clearly on task but not clearly audible | Three take away... and that ...(whispers)                                                                 |
| * Phonological fragments        | Sounds that are clearly a component of an inaudible word                  | & ti.                                                                                      |

Note 1: Adapted and modified from "Development of Private Speech Among Low Income Appalachian Children." Laura Berk and Ruth Garvin in Developmental Psychology, 20(2), 271-286.

Note 2: * refers to novel categories.
APPENDIX E

Language Transcript Exemplars
Pacman Transcript – Difficult Level

- This is hard
- They go fast
- That’s it
- Whoo
- Ok that’s it
- Oops
- That’s it
SuperMario World Transcript – Easy Level

- Walking time bomb
- Mr Yoshi
- Yoshi eats the green bombs
- Oh come on I want a turtle here
- Oops
- Whamo
- Yoshi can't make big jumps very well
- Take that fish
- Oh
- Ooh walking men
- Bye
SuperMario World Transcript – Difficult Level

- Can I fall down here
- Do I want to
- Oh no
- Come on pick it up
- You’re here
- So I can get up
- Ya their all done and then they all fall off
- Somewhere to fall
- No I want to
- Yikes
- I need these guys to …
- Yikes
- Oh oh
- Oh oh
- Ooh they stole all my Yoshi points
## Symbol Summary

All remaining language samples were transcribed using the CHILDES system. The following is a modified glossary of symbols used.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>xxx</td>
<td>unintelligible speech, not treated as a word</td>
</tr>
<tr>
<td>xx</td>
<td>unintelligible speech, treated as a word</td>
</tr>
<tr>
<td>www</td>
<td>untranscribed material</td>
</tr>
<tr>
<td>0</td>
<td>actions without speech</td>
</tr>
<tr>
<td>&amp;</td>
<td>phonological fragment</td>
</tr>
<tr>
<td>[?]</td>
<td>best guess</td>
</tr>
<tr>
<td>()</td>
<td>non-completion of a word</td>
</tr>
<tr>
<td>0*</td>
<td>omitted word</td>
</tr>
<tr>
<td>0*word</td>
<td>ungrammatical omission</td>
</tr>
<tr>
<td>00word</td>
<td>(grammatical)ellipsis</td>
</tr>
<tr>
<td>?</td>
<td>question</td>
</tr>
<tr>
<td>!</td>
<td>exclamation</td>
</tr>
<tr>
<td>-*?</td>
<td>rising final contour</td>
</tr>
<tr>
<td>-*!</td>
<td>final exclamation contour</td>
</tr>
<tr>
<td>-.</td>
<td>falling final contour</td>
</tr>
<tr>
<td>-.!</td>
<td>fall-rise final contour</td>
</tr>
<tr>
<td>-:</td>
<td>level nonfinal contour</td>
</tr>
<tr>
<td>-:!</td>
<td>falling nonfinal contour</td>
</tr>
<tr>
<td>-:</td>
<td>low level contour</td>
</tr>
<tr>
<td>:</td>
<td>rising nonfinal contour</td>
</tr>
<tr>
<td>:</td>
<td>syntactic juncture</td>
</tr>
<tr>
<td>::</td>
<td>tag question</td>
</tr>
<tr>
<td>#:</td>
<td>pause between words</td>
</tr>
<tr>
<td>:-</td>
<td>previous word lengthened</td>
</tr>
<tr>
<td>/</td>
<td>stress</td>
</tr>
<tr>
<td>//</td>
<td>accented nucleus</td>
</tr>
<tr>
<td>///</td>
<td>contrastive stress</td>
</tr>
<tr>
<td>::</td>
<td>lengthened syllable</td>
</tr>
<tr>
<td>::</td>
<td>pause between syllables</td>
</tr>
<tr>
<td>^</td>
<td>blocking</td>
</tr>
<tr>
<td>+...</td>
<td>trailing off</td>
</tr>
<tr>
<td>+..?</td>
<td>trailing off of a question</td>
</tr>
<tr>
<td>+!?</td>
<td>question with exclamation</td>
</tr>
<tr>
<td>+!</td>
<td>interruption</td>
</tr>
<tr>
<td>+/?</td>
<td>interruption of a question</td>
</tr>
<tr>
<td>+!/</td>
<td>self-interruption</td>
</tr>
<tr>
<td>+!/?</td>
<td>self-interruption of a question</td>
</tr>
<tr>
<td>+&quot;/</td>
<td>quotation follows on next line</td>
</tr>
<tr>
<td>+&quot;</td>
<td>quotation precedes</td>
</tr>
<tr>
<td>+&quot;</td>
<td>quoted utterance follows</td>
</tr>
</tbody>
</table>
quick uptake
"lazy" overlap marking
self-completion
other-completion
clause delimiter
paralinguistics, prosodics
stressing
contrastive stressing
quotation marks
explanation
replacement
omission
translation
alternative transcription
best guess
overlap follows
overlap precedes
overlap follows and precedes
overlap enumeration
retracing without correction
retracing with correction
retracing with reformulation
false start without retracing
unclear retrace type
error marking
postcode
excluded utterance
included utterance
addressee
general purpose coding
comments by investigator
ADHD Baseline Transcript

*EXP: go!

*CHI: ## no -: # I hate you # Kenneth.


*CHI: ## &fI # sixteen -: !

*CHI: # <sixteen -: # plus one -: # equals> [% sounds like an

    auctioner]# seventeen [=! sings].

*CHI: ## where's <all that> [=? Nona] ? [+ bch]

%add: EXP

*CHI: ## where's my grandmother? [+ bch]

%add: EXP

*EXP: keep going.

*CHI: # but where is she? [+ bch]

%add: EXP

*CHI: # 0.

%com: vigorously scratches pencil on paper

*CHI: # fifty is xxx.

*CHI: <seven eight nine ten eleven> [=! whispers].

*CHI: ## <two [?] > [=! whispers] .

*CHI: # <two [?] > [=! whispers] .

*CHI: ## four.

*CHI: four plus two.

%com: bangs pencil while saying last two words
*CHI:  ## six.
*CHI:  six plus two.
*CHI:  ## eight.
*CHI:  eight plus +..
*CHI:  # 0 [% coughs once].
*CHI:  &sEv [% sounds like he is choking] +..
*CHI:  # 0 [% coughs again].
*CHI:  +, seven.
*CHI:  # <nine ten eleven twelve eleven thirteen fourteen # fifteen>
     [=! whispers].
*CHI:  # I've done number one. [+ bch]
%add:  EXP
*CHI:  ## 0 [=! sings for several seconds].
*CHI:  # 0 [% clears throat].
*CHI:  # is this a new pencil? [+ bch]
%add:  EXP
*CHI:  ## <mm> [>] ? [+ bch]
%add:  EXP
*EXP:  <yes [% voice sounds faint]> [<].
*CHI:  ## &ti -: # seven seven [=! whispers].
*CHI:  # &s.
*CHI:  # <eleven> [=! whispers].
*CHI:  # <eleven :-> [=! whispers].
*CHI: ## &s.
*CHI:  # done! [+ bch]
%add:  EXP
*CHI:  # I'm just joking.  [+ bch]
%add:  EXP
*CHI:  ## <joking [=! whispers] > [% pronounces "j" sound as "d"].
*CHI:  # <<joking joking joking> [=! whispers] > [% pronounces "j" sound as "d"].
*CHI:  0 [% sings].
*CHI:  ## 0 [% shuffles papers].
*CHI:  <don't touch> [?].
%com:  rolling pencil on table
*CHI:  # <four - : [=! whispers] .
*CHI:  # <two # three> [=! whispers] .
*CHI:  # &s &s eight [=! whispers].
*CHI:  ## eight!
*CHI:  ## <one two three four> [=! whispers].
*CHI:  ## <six times> [?] three. [=! whispers].
*CHI:  <one two three four five six> [=! whispers].
*CHI:  # six [=! whispers] .
*CHI:  # twenty [=! whispers] .
*CHI:  # <&e - : # &e &e &e # eight> [=! whispers] .
*CHI:  <seventeen # eighteen> [=! whispers].
*CHI:  # <<nine -: > [?] > [=! whispers].

*CHI:    # twenty+four.

*CHI:    ## <&s -: # xxx xxx xxx xxx> [=! whispers].

%com:    words are almost inaudible, sound of eraser being used

*CHI:    four [=! whispers].

*CHI:    # eight.

*CHI:    <two three four five six seven eight nine ten> [=! whispers].

*CHI:    # it is # twenty+one.

*CHI:    # <forty equals [?] > [=! whispers].

*CHI:    # eight [=! whispers].

*CHI:    <forty -: > [=! whispers].

*CHI:    eight -: !

*CHI:    0 [% noises with mouth].

*CHI:    ## <two three four five six seven eight nine ten> [=! whispers].

*CHI:    # <xxx twenty> [=! whispers].

*CHI:    # <<twenty+six twenty+seven twenty+eight twenty+nine> [?] > [=! whispers].

*CHI:    # <one two three four five six -: > [=! whispers].

*CHI:    # I'm done the [/] this one. [+ bch]

%add:    EXP

*CHI:    # this was hard for me. [+ bch]

%add:    EXP

*CHI:    when I did it. [+ bch]
%add: EXP

*EXP: ## xxx.

*CHI: ## 0 [% sighs].

*CHI: # six times six.

*CHI: # <xxx six> [=! whispers].

*CHI: # twelve # thirteen # fourteen fifteen sixteen seventeen
    eighteen.

*CHI: xxx.

*CHI: ## <twenty+one twenty+four> [?] twenty+nine thirty> [=! whispers].

*CHI: ## <one &$> [=! whispers].

*CHI: ## three times $four.

%com: drops something

*CHI: # <one two three four five six # eight ## nine -: <ten eleven
twelve> [?] > [=! whispers].

*CHI: ### I don't get this. [+ bch]

%add: EXP

*CHI: ## three times # four plus three. [+ bch]

%add: EXP

*CHI: I don't get this. [+ bch]

%add: EXP

*EXP: ## sit down.

*EXP: keep quiet.
*CHI: I'll skip? [+ bch]

%add: EXP

*EXP: yeah.

*CHI: (be)cause I don't know <that> [>] one. [+ bch]

%add: EXP

%com: pushes the microphone over

*EXP: <ahh> [<] !

*CHI: oopsy!

*CHI: that was an accident. [+ bch]

%add: EXP

*CHI: (o)kay? [+ bch]

%add: EXP

*EXP: okay.

*CHI: xxx xxx xxx.

%com: microphone moves again

*EXP: okay sit down on your bum.

*CHI: # my bum? [+ bch]

%add: EXP

*EXP: all the way.

*CHI: # all the way?

*EXP: okay continue.

*CHI: I don't know how -: !

*CHI: ## uh # <I -: [>] # I don't know how to do the # times. [+
bch]
%
%add: EXP
*CHI: ## 0 [% sings].
*CHI: 0 [% whines].
*CHI: ### mm # dinosaurs.
*CHI: # okay.
%com: feet banging
*CHI: <what's that girl that> [/]
*CHI: # an(d) there's a girl :: that used this.
%com: shuffles papers
*CHI: okay ::.
*CHI: # xxx xxx.
%com: rolling pencil back and forth across the table
*CHI: ## <mm it equals> [?] three.
%com: banging on table
*CHI: one take away two.
%com: banging on table
*CHI: # can't really do.
%com: banging on table
*CHI: ### 0 [% groans quietly].
%com: starts banging on table again
*CHI: 0 [% makes raspberry with mouth].
*CHI: equals nine.
*CHI:  ## 0 [% makes noise with mouth].

*CHI:  ## one.

*CHI:  ## <equals six> [=! whispers].

*CHI:  <take away four five six> [=! whispers].

*CHI:  0 [% bangs on table].

*CHI:  ### uh -: ## <I'm done> [?].

*CHI:  ## I don't know [!] this one. [+ bch]

%add:  EXP

*CHI:  0 [% bangs on table].

*CHI:  ## 0 [% sighs].

*CHI:  ## three plus one equals four.

*CHI:  ## three plus five # equals eight.

*CHI:  ## seven plus four # equals # eleven.

*CHI:  # five.

*CHI:  0 [% makes a series of choking noises for several seconds].

*CHI:  0 [% rolls pencil on paper].

*CHI:  ## two times five.

*CHI:  0 [% banging noises].

*CHI:  # <xxx xxx> [=! whispers].

*CHI:  xxx xxx four.

*CHI:  ## <xxx xxx xxx xxx> [=! whispers].

%com:  words are almost inaudible

*CHI:  # two plus seven.
*EXP:  okay time's up.

%tim:  10:00

@End
Non-ADHD Baseline Transcript

*EXP: go!

*CHI: okay.

*CHI: nine and # <eight [?] > [=! whispers].

*CHI: ## 0 [% breathes out].

*CHI: nine [=! whispers].

*CHI: nine [=! whispers].

*CHI: #### <okay [?] > [=! whispers].

*CHI: 0 [% audible breathing through mouth].

*CHI: #### 0 [% sighs].

*CHI: 0 [% audible breathing through mouth].

%com: sound of plane passing

*CHI: #### <three [?] > [=! whispers].

*CHI: ## may I go to the other side? [+ bch]

%add: EXP

%cod: SS

*EXP: mmhm.

*CHI: okay.

%com: turns page

*CHI: #### 0 [% breathes heavily through mouth for a few seconds].

*CHI: 0 [% soft bang].

*CHI: 0 [% sound of erasing].

*CHI: 0 [% loud breathing through mouth for a few minutes].
%com: background shuffling noises, then sound of plane passing

*CHI: #### &s.

*CHI: 0 [% turns page, otherwise silent].

*CHI: ## 0 [% sighs].

*CHI: 0 [% audible breathing, otherwise silent for a minute].

*CHI: 0 [% sighs, then silent for a couple of minutes].

*CHI: #### 0.

%com: sound of plane passing by

*CHI: #### 0 [% sighs, followed by silence for a couple of minutes].

*CHI: #### 0 [% audible exhalation].

*CHI: ## 0 [% soft whistling, barely audible].

%com: sound of plane

*CHI: ### 0 [% audible breathing].

*CHI: ## 0 [% sighs, followed by beeper a few seconds later].

@End
**ADHD Medication Trial Transcript (20 mg MPH)**

*CHI: # <six plus nine> [=! whispers] .

*CHI: plus one> [=! whispers] .

*CHI: <times six seven equals # eight> [=! whispers] .

*CHI: <eight nine # ten eleven twelve thirteen fourteen fifteen sixteen> [=! whispers] .

*CHI: # <um # ten> [=! whispers] .

*CHI: ## <ten plus ten equals xxx> [=! whispers] .


*CHI: <thirteen plus five> [=! whispers] .

*CHI: # <fourteen fifteen sixteen seventeen eighteen> [=! whispers] .

*CHI: <eighteen plus four - : > [=! whispers] .

*CHI: <eighteen nineteen twenty twenty+one twenty+two> [=! whispers] .

*CHI: ## 0 [% yawns] .

*CHI: # <three - : plus two equals five> [=! whispers] .

*CHI: <five # plus one equals six> [=! whispers] .

*CHI: <six # plus two equals seven> [=! whispers] .

*CHI: ### 0 [% hums] .

*CHI: 0 [% groans for a couple of seconds] .

*CHI: # (o)kay.

*CHI: seven plus three equals ten.

*CHI: # ten plus four equals fourteen.

*CHI: # five plus one equals six.

*CHI: # one plus zero equals one.
*CHI:  ### oh I hate the times [= multiplication].
*CHI:  # uh I like adding.
*CHI:  but I hate the times.
*CHI:  <and the> [/] <and the # &sAbtr & ### multiplication [% mAltIklImplaiSAN@u]> [/] and multiplication [% mAltIklImplaiSAN@u] and subtract # and divideds are too hard right? [+ bch]
*CHI:  # right? [+ bch]
*CHI:  # huh? [+ bch]
*CHI:  right? [+ bch]
*CHI:  am I right? [+ bch]
*CHI:  ## four # times six.
*CHI:  <one two three four five six seven :- nine ten eleven twelve thirteen fourteen fifteen sixteen seventeen eighteen nineteen twenty twenty-one twenty-two twenty-three twenty-four> [=! whispers].
*CHI:  0 [% sighs].
*CHI:  ### &ls <you know> [?] <I don’t> [/] I don’t get it if [/] if it’s three in a row of # times # huh? [+ bch]
*CHI:  so what should I do? [+ bch]
*CHI:  # huh? [+ bch]
*EXP:  ## just do your best.
*CHI:  I don’t know um # two times eight times five. [+ bch]
*CHI:  huh? [+ bch]
%EXP: # you can skip something if it’s too hard.
and go on to the next one.

*(CHI): *(o)kay. [+ bch]

*(CHI): three times two.

*(CHI): # <one two three four five six> [=! whispers] .

*(CHI): six.

*(CHI): # one times six # equals six.

*(CHI): sixty+six.

*(CHI): one # subtraction [% spoken slowly and with difficulty] .

*(CHI): <three # take away three> [=! whispers] .

*(CHI): can’t do.

*(CHI): cross out the four.

*(CHI): put up # three in the # top.

*(CHI): eleven <take away three> [=! whispers] .

*(CHI): ### 0 [% blows out] .

*(CHI): ## <two take away seven> [=! whispers] .

*(CHI): ### <<take away three> [?] > [=! whispers] .

*(CHI): ### 0 [% taps table] .

*(CHI): # 0 [% sighs] .

*(CHI): ## <one two three four five six seven> [=! whispers] .


*(CHI): ## <eight take away one equals five # xxx # seven> [=! whispers] .


*(CHI): ## <six # plus five equals # eleven> [=! whispers] .
*CHI: # <nine plus four> [=! whispers] .

*CHI: <one two three four> [=! whispers] .

*CHI: # <one # two> [=! whispers] .

*CHI: # 0 [% coughs] .

*CHI: ## <one two> [=! whispers] .

*CHI: <one two three four five six seven eight> [=! whispers] .

*CHI: ## <three # five> [=! whispers] .

*CHI: <one two three four five six seven eight nine ten eleven twelve thirteen fourteen fifteen sixteen seventeen eighteen # nineteen #: twenty #: # twenty+one twenty+two twenty+three twenty+four twenty+five #: > [=! whispers] .

*CHI: #### I don’t get this again. [+ bch]

*CHI: oh #: I love this.

*CHI: # oh I love this.

*CHI: #### one plus //.

*CHI: oh # whatever!

*CHI: <four plus one two three four five nine> [=! whispers] .

*CHI: <nine plus one equals ten> [=! whispers] .

*CHI: <ten plus five> [=! whispers] .

*CHI: ## <eleven twelve thirteen fourteen fifteen> [=! whispers] .

*CHI: 0 [% makes quiet non-verbal noise] .

*CHI: (e)xcuse me.

*CHI: 0 [% coughs] .

*CHI: <five [/] # five plus four equals nine> [=! whispers] .
*CHI: <nine equals # four [?] > [=! whispers].

*CHI: <ten eleven twelve thirteen fourteen equals six> [=! whispers].

*CHI: xxx [=! whispers].

*CHI: # <ten plus nine equals nineteen> [=! whispers].

*CHI: # <nineteen plus nine> [=! whispers].

*CHI: 0 [% erases].

*CHI: <ten plus nine equals nineteen> [=! whispers].

*CHI: # <xxx plus nine> [=! whispers].

*CHI: # <nineteen -: # twenty twenty+one twenty+two twenty+three twenty+four twenty+four twenty+five twenty+six twenty+seven twenty+eight twenty+nine> [=! whispers].

*CHI: <eight -: plus> [=! whispers] +...

*CHI: <<twenty+seven twenty+eight> [?] twenty+nine thirty thirty+one thirty+two thirty+three thirty+four thirty+five thirty+six thirty+seven> [=! whispers].

*CHI: ## <seven -: > [=! whispers].

*CHI: ## there.

*CHI: # five plus one equal xxx [% makes funny non-verbal noises].

*CHI: <one equals -: # & f four> [=! whispers].

*CHI: # <& s two> [=! whispers].

*CHI: <<five one> [?] equals zero> [=! whispers].

*CHI: <five -: > [=! whispers].

*CHI: ## 0 [% coughs].

*CHI: ## <one two three four five six seven eight nine ten> [=! whispers].
*CHI: ### <four five six seven eight # nine ten eleven twelve thirteen fourteen fifteen sixteen> [=! whispers].

*CHI: # sixteen [=! whispers].

*CHI: # seven [=! whispers].

*CHI: # eight [=! whispers].

*CHI: #### <two [?]> [=! whispers].

*CHI: # am I right here? [+ bch]

*CHI: # oh # never mind. [+ bch]

*CHI: # three <times three> [=! whispers].

*CHI: <one two three four five six seven eight nine> [=! whispers].

*CHI: ## <three times two> [=! whispers].

*CHI: <one two three four five six> [=! whispers].

*CHI: ## <six [/] & plA & tAI # six times two> [=! whispers].

*CHI: ### <three four five six seven eight nine ten eleven twelve> [=! whispers].

*CHI: ## <one plus seven equals eight> [=! whispers].

*CHI: # <xxx plus seven> [=! whispers].

*CHI: ## <one two> [=! whispers].

*CHI: # <<plus seven is> [?] seven times three> [=! whispers].

*CHI: # one two three four five six seven eight nine ten eleven twelve thirteen fourteen fifteen sixteen seventeen eighteen nineteen twenty twenty+one> [=! whispers].

*CHI: ## <two plus> [=! whispers] +///.

*CHI: <&t I mean xxx one two three four xxx> [=! whispers].

*CHI: <eighteen [?] > [=! whispers].
*CHI: ## oh <I know> [/] I [/] I now go in the wrong spots <I don't know now> [/](be)cause I know now.

*CHI: # see &dugat &lublt &d&buS &S&mi &d&dEg &e &d&du.
%com: child appears to be counting in another language

*CHI: 0 [% groans] .

*CHI: # 0 [% audible exhalation] .

*CHI: # <four times six> [=! whispers] .

*CHI: # <one two three four five six seven eight nine ten eleven twelve thirteen fourteen fifteen sixteen seventeen eighteen # nineteen twenty+one twenty+two twenty+three twenty+four> [=! whispers] .

*CHI: ## <twenty+four times eight> [=! whispers] .

*CHI: ## <eight times eight equals sixty [/] sixty+four> [=! whispers] .

*CHI: # <times five> [=! whispers] .

*CHI: # <sixteen times five> [=! whispers] .

*CHI: ## <two three four five # six seven eight nine> [=! whispers] .

*CHI: <six seven # eight nine ten # eleven> [=! whispers] .

*CHI: # <thirteen [?] fourteen fifteen sixteen seventeen eighteen nineteen # twenty twenty+one twenty+two twenty+three twenty+four twenty+five twenty+six twenty+seven twenty+eight twenty+nine # thirty thirty+one thirty+two thirty+three thirty+four # thirty+five # thirty+six thirty+seven thirty+eight thirty+nine ## forty forty+one forty+two forty+three forty+four forty+five forty+six forty+seven forty+eight # forty+nine ## fifty fifty+one fifty+two fifty+three> [=! whispers] .

*CHI: # mmm I didn’t get this one too. [+ bch]
*CHI: 0

%com: makes tapping noises

*CHI: ## <equals zero> [=! whispers].

*CHI: ### <equals nine [?] xxx> [=! whispers].

*CHI: ## <xxx xxx> [=! whispers].

*CHI: # <one two three four five six seven # eight nine> [=! whispers].

*CHI: #### xxx [=! whispers].

*CHI: #### <<four plus four> [?] [=! whispers].

*CHI: <eight plus one equals nine> [=! whispers].

*CHI: # <<four plus one equals # five [=! whispers].

*CHI: +^ <five plus five equals ten> [=! whispers].

*CHI: ## <eight plus nine> [=! whispers].

*CHI: ## <seventeen [?] [=! whispers].

*CHI: # <seventeen -: plus one equals # eighteen> [=! whispers].

*CHI: ## 0 [% sighs].

*CHI: # uh # time up? [+ bch]

*CHI: ## <ten xxx> [=! whispers].

*EXP: okay.

*EXP: time up now.

%tim: 10:00

@end