CHILDREN’S STRATEGIC BEHAVIOR ON A MEASURE OF EXECUTIVE
FUNCTIONING: DEVELOPMENTAL TRENDS AND RELATIONS TO AEROBIC
EXERCISE

by

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(Under the Direction of Patricia H. Miller)

ABSTRACT

There is growing support for the notion that aerobic exercise selectively benefits executive functions (EF). Although several physiological mechanisms have been proposed, the hypothesis that aerobic exercise benefits children’s executive functioning via changes in strategic behavior has not been tested. The focus of this study was to reexamine for possible mediation by strategy use data (Davis et al., 2007; under review) that demonstrated that aerobic exercise selectively benefited EF. The results revealed differences in strategy use across the treatment levels but provided no evidence that strategy use mediated the relation between aerobic exercise and improved EF. However, the results did provide valuable information regarding developmental trends in strategic behavior on a standardized measure of EF. Also, strategy use was related to greater accuracy but not to decreased completion time on all EF tasks.

INDEX WORDS: Executive Functioning, Aerobic Exercise, Strategy Use, Cognition
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CHAPTER 1: INTRODUCTION

The notion that there exists a link between physical activity and psychological well-being—part of the greater mind-body connection—is not a new one. As a matter of philosophic discussion, the relation between physical activity and mental health surfaced in Grecian civilization some 2500 years ago (Tomporowski, 2006). Systematic investigation of this facet of the mind-body connection, however, is nascent in comparison, and has suggested that the relation is complex. It depends in part on the characteristics of the physical activity as well as the aspect of psychological well-being in question. Further, the form and strength of the association between physical activity and psychological well-being appears to change across the lifespan (Hillman, Motl, Pontifex, et al., 2006). The intricacies of this complex relation remain unknown.

A meta-analysis by Colcombe and Kramer (2003) on studies designed to measure the relation between aerobic exercise and older adults’ cognitive functioning has yielded an intriguing finding: While aerobic training was generally related to enhanced cognitive functioning on a general level, the greatest gains were typically found in cognitive tasks involving coordination, inhibition, planning, and working memory. Such tasks embody the higher-order domain of cognition often referred to as executive function (EF) or executive control. The executive function hypothesis (also known as the executive-control hypothesis) accounts for this intriguing finding by suggesting that aerobic exercise has both broad and specific effects. The broad effects are that aerobic exercise leads to general improvements in cognition compared to a control group; the specific effects are that the largest cognitive improvements occur within the EF domain (Colcombe & Kramer, 2003; Kramer, Hahn, Cohen,
et al., 1999). Although EF is not generally considered to be a unitary process (Miyake et al., 2000), the various EF domains are bound together by the fact that they all are needed in goal-oriented behavior and are associated with neural activity in the prefrontal cortex (PFC; Hughes, 1998).

The EF hypothesis\(^1\) gained initial support from studies examining the impact of physical activity in older adults (Colcombe & Kramer, 2003; Hillman et al., 2006), but it recently has received support in young adult populations (Harada, Okagawa, & Kubota, 2004). In fact, recent experimental findings indicate that the impact of aerobic exercise may be specific to the EF domain, with no significant benefit in other cognitive domains when compared to a non-aerobically trained control group (e.g., Colcombe et al., 2004; Davis et al., 2007; Harada, Okagawa, & Kubota, 2004; Kramer, Hahn, & Gopher, 1999). These experimental findings indicate a revision of the EF hypothesis, such that now it narrowly focuses on the specific impact of aerobic exercise on EF. And recently, researchers have tested its validity in child populations (Tomporowski, Davis, Miller, & Naglieri, 2007).

The introduction to this thesis is organized as follows: First, those studies that have examined the EF hypothesis in children will be discussed. This will be followed by a discussion of potential mechanisms underlying the aerobic exercise—EF connection, one mechanism being changes in strategic behavior. In turn, studies examining the development of strategy use will be outlined, including those that investigate strategy use on measures of EF. Finally, the aims of the current investigation will be described.

\(^1\) In this paper the term *executive function* (EF) will be used, but the term *executive control* could be substituted without an alteration in meaning.
The Link between Aerobic Exercise and EF in Children

In a meta-analysis of 59 studies pertaining to the association between physical activity and cognition or academic performance in children (ages 4 – 18 years), Sibley and Etnier (2003) found an overall effect size of 0.32, suggesting a significant positive connection between physical activity and cognition. Of particular interest, the type of cognitive assessment moderated the association, with measures of perceptual skills, IQ and academic achievement being most sensitive to the benefits of physical activity. On the other hand, there was no beneficial effect on measures of memory. Moreover, the physical activity–cognition connection was strongest among 4- to 7-year-olds and 11- to 13-year-olds. As there was no specific category pertaining to EF, Sibley and Etnier (2003) did not provide direct support for the EF hypothesis in children; however, it is likely that EF is critical to school performance (e.g., St. Clair-Thompson & Gathercole, 2006), and thus, the beneficial effect on academic achievement may provide indirect support for the EF hypothesis.

The bulk of evidence in favor of the EF hypothesis comes from correlational studies. Castelli, Hillman, Buck, and Erwin (2007) provided indirect support of the EF hypothesis in a study associating aerobic capacity with mathematics and reading achievement in 3rd and 5th grade children. For both math and reading standardized test performance, there was a significant positive correlation with aerobic fitness. Neither muscle strength nor flexibility was significantly associated with standardized test performance. This finding is important to the integrity of the EF hypothesis, which specifies that aerobic exercise, as opposed to anaerobic exercise (that may benefit muscle strength or flexibility) selectively benefits EF.

Campbell, Eaton, and McKeen (2002) utilized an interesting correlational design with 4- to 6-year-olds. They investigated the association between these children’s typical levels of daily
activity and their ability to inhibit a prepotent response in favor of a less typical response. Inhibition of a prepotent response is the inhibition of a predominant or primed response and is widely considered a foundational aspect of EF in both childhood (e.g., Huizinga, Dolan, & Van der Molen, 2006; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003) and adulthood (Miyake et al., 2000). It was assessed using a battery of neuropsychological measures forcing the child to perform a contra-habitual action. Daily activity levels were measured with actometers, which measured the frequency of motor movement of the non-dominant wrist and ankle. It was found that greater frequency of movement correlated positively with inhibition task performance. The researchers speculate that increased movement affords children of this age more opportunities to practice and hone inhibitory skills. Although this study does not provide direct support for the EF hypothesis, it does suggest that increased physical movement (that may come in the form of aerobic exercise) may provide experiences that benefit EF.

The studies by Castelli et al. and Campbell et al. promote the EF hypothesis, but both also have certain limitations. For one, both employ a correlational design, which disallows causal inferences. Second, the Castelli et al. study examined achievement scores, not performance on a theoretically-based measure of EF. Third, the Campbell et al. study did not measure aerobic activity specifically. To best assess the EF hypothesis, research designs ought to employ true-experimental designs as opposed to correlational designs that examine the association between aerobic fitness and EF. With random assignment of participants to either an aerobic exercise intervention or control condition, true-experimental designs control for confounds associated with fitness level (e.g., nutrition, participation in organized sports) that may also be related to EF.

Hinkle, Tuckman, and Sampson (1993) did just that in assigning children in the 8th grade to either a 5-day/week aerobic running program or to a 5-day/week non-aerobic physical
education program (control). The intervention lasted eight weeks. Children assigned to the aerobic running program made fitness gains, as measured by 800 meter run time, and gains in measures of creativity, including creative fluency, creative flexibility, and creative originality, compared to the control group. A previous experimental study by Tuckman and Hinkle (1986) also yielded improvements in measures of creativity but not in perceptual-motor skills for children (ages 9 – 12) assigned to aerobic running. Although creativity measures have not traditionally been considered to be direct measures of EF, it has been suggested that creativity is an integral part of EF (Delis, Lansing, Houston, et al., 2007). Given that creativity relies on EF processes, enhancements in creativity also suggest enhancements in EF. In this way, Hinkle et al.’s (1993) experimental research supports the EF hypothesis by demonstrating that aerobic exercise improves creativity.

Clear support for the EF hypothesis in children has also come recently from a randomized controlled experiment conducted by Davis et al. (2007; under review). The study examined the impact of an aerobic exercise intervention (10 to 15 weeks) on the cognitive functioning of 181 overweight children (BMI ≥ 85th percentile), ages 7 to 11 (M = 9.3 yrs, SD = 1.04 yrs). With the rise of pediatric obesity to near epidemic proportions in recent years (Strauss & Pollack, 2001), this investigation of an aerobic exercise intervention in overweight children was particularly apt. Further, childhood overweight’s association to poor academic achievement (Dwyer, Sallis, Blizzard, Lazarus, & Dean, 2001; Taras & Potts-Datema, 2005) and poor IQ test performance (Li, 1995) led the investigators to believe that this population would be particularly likely to incur cognitive benefits from the exercise intervention. Children were randomly assigned to one of three treatment conditions: no exercise control, 20-minute exercise dose or 40-minute exercise dose. The children participated in vigorous after school aerobic activities that required the
children to maintain an average heart rate of above 150 bpm. The after school aerobic activities occurred five days per week with an overall duration of between 10 and 15 weeks, depending on the particular cohort of children. To examine potential changes in cognitive functioning, the Cognitive Assessment System (CAS; Naglieri & Das, 1997) was administered prior to and immediately following the intervention period. The CAS consists of four scales, each measuring a distinct component of cognitive functioning. The Planning scale assesses the child’s ability to create and apply a plan, verify that subsequent behavior aligns with that plan and modify a plan if necessary; the Attention scale assesses focused, selective cognitive activity and resistance to distraction; the Simultaneous scale assesses spatial and logical processing of verbal and nonverbal material; and the Successive scale assesses processing of sequential information. It is the Planning scale that measures EF and corresponds most closely to activity in the frontal lobes (Naglieri & Rojahn, 2001). After controlling for pretest score, gender, cohort, and race, a significant linear contrast was revealed in the posttest Planning scores, indicating a dose-response effect between exercise and Planning performance \((p = .015)\). Further, contrasts to the control group demonstrated that both the 20-min and 40-min exercise groups had higher posttest Planning scores \((p = .046)\). No other differences were observed in the remaining three scales, highlighting the selective benefits of aerobic exercise on EF.

*The Potential Mechanisms Underlying the Aerobic Exercise—EF Connection*

This finding that an aerobic exercise intervention selectively influenced the performance of overweight children on the Planning scale supports the EF hypothesis, but it leaves to further investigation the mechanism(s) by which chronic exercise results in improved EF. Several lines of research have attempted to uncover these mechanisms.
In a recent meta-analysis, Etnier, Nowell, Landers, and Sibley (2006) examined specifically the cardiovascular fitness hypothesis, which posits that the association between physical activity and cognition is mediated by cardiovascular (aerobic) fitness level. The researchers examined 37 studies of varying age ranges (overall age range of 11 to 88 years) and found a significant positive correlation between physical activity and general cognitive performance (not limited to EF) as the previous meta-analysis (Sibley & Etnier, 2003) had found within child samples. They did not find a significant relation between aerobic fitness and cognitive performance when age was ignored; however, when age was included as a moderator, they did find a significant association between aerobic fitness and cognitive performance for certain age groups. Perplexingly, aerobic fitness was negatively related to cognitive performance in children and young adults, positively related in adults, and unrelated in older adults. Overall, Etnier et al. conclude that this meta-analysis does not provide support for the cardiovascular fitness hypothesis. Since this meta-analysis looked only at general cognitive performance, the possibility that aerobic fitness mediates the relation between physical activity and EF should not necessarily excluded. In fact, Buck, Hillman, and Castelli (2008) have recently found a link between fitness in preadolescent children and performance on a Stroop task, a classic measure of EF. Though the notion that aerobic exercise transmits its influence to EF via increased aerobic fitness should not be discarded, it still leaves the question: What is it about aerobic fitness and exercise that would benefit EF?

More fine-grain analyses investigate the possible anatomical and chemical changes that might explain the association between aerobic exercise and EF in particular. In older adults, Churchill, Galvez, Colcombe, et al. (2002) have suggested that physical activity works in a preventative manner to thwart cognitive decline, which is most pernicious in the prefrontal and
hippocampal regions—regions critical for EF and memory processes. In particular, Churchill and his colleagues describe several physiological mechanisms evident in animal studies by which physical activity may prevent prefrontal and hippocampal decline in late adulthood. The two most prominent mechanisms are synaptogenesis, the process by which synaptic connections are increased and altered, and neurogenesis, the process by which new neurons develop. Indeed, exercise-induced cell proliferation has been observed in the hippocampus of young adult mice (van Praag, Christie, Sejnowski, & Gage, 1999) and older mice (van Praag, Shubert, Zhao, & Gage, 2005). Kramer and Erickson (2007) add that exercise increases mRNA and protein levels of brain-derived neurotrophic factor (BDNF), an important neuroprotective substance that promotes cell survival and synaptic plasticity. BDNF appears to be crucial to the behavioral improvements associated with exercise. In support of the EF hypothesis, these increases in BDNF occur in the hippocampus, cerebellum and frontal cortex, which as noted previously is considered to be the seat of EF.

Direct research with older adult participants using event-related brain potential (ERP) measures suggests that high-fit older adults produce smaller magnitude error-related negativity (ERN) during conflict tasks than their low-fit counterparts without a sacrifice in task performance (Themanson, Hillman, & Curtin, 2006). The authors interpret this finding to indicate that top-down EF processes are working in lieu of the action-monitoring processes measured by the ERN in physically fit older adults. Further, the authors note that this finding is consistent with previous observations that physical activity is related to increased EF performance. In other work, randomized clinical trials with aging adults suggest that exercise promotes increases in gray matter volume in the frontal and temporal cortex, and increases in
anterior white matter volume, areas recruited in tasks measuring EF (see Kramer & Erickson, 2007 for a brief review).

Similar research with children is sparse, and it is incumbent upon future research to discover whether similar neurophysiological differences are evident in children as a result of exercise training. Only one study (Hillman, Castelli, & Buck, 2005) was obtained for this review that examined ERP measures in high-fit and low-fit preadolescent children. In this study high-fit children had greater P3 amplitude, which theoretically indexes attention and working memory processes, compared to low-fit children or adults (either low- or high-fit) on a visual discrimination task. Importantly, this visual discrimination task requires the child to inhibit response to a frequently presented non-target and to respond to the infrequently presented target stimulus. Because of this requirement of inhibition and working memory processes, it is reasonable to assume the task taps EF processes. In addition, high-fit children had shorter P3 latencies, indicating faster neurocognitive processing, and faster response times compared to low-fit children. In light of these findings, the researchers reason that in childhood greater cortical activation (indicated by larger P3 amplitude) is beneficial to performance, but that in adulthood greater cortical efficiency (indicated by smaller P3 amplitude) is favorable to performance. Though this study is insightful, it does not provide direct evidence for the mechanisms underlying the aerobic exercise—EF connection as it did not manipulate aerobic fitness via an exercise intervention. With experimental studies including neurophysiological measures (e.g., fMRI, EEG) researchers will be better equipped to examine those potential physiological mechanisms underlying the EF hypothesis.

Another interesting avenue to explore with regard to why exercise selectively facilitates performance on EF tasks is the potential differences in how aerobically trained and untrained
children complete the particular tasks. In their review of exercise and cognition studies involving children, Tomporowski et al. (2007) suggest that the learning components of exercise interventions may influence the child’s cognitive functioning. Games or other structured activities that require cooperation and learning may lead the child to adapt differently than physical activity that requires relatively little cognitive effort and/or is done in isolation (e.g., running alone). One possibility is that physically-demanding group games such as soccer or basketball that require a certain degree of learning encourage the development and use of various strategies in order to enhance performance. Perhaps children who participate in such activities conducive to strategy use experience a carryover effect such that they also use more strategies in other situations, including on cognitive tasks.

In particular, EF tasks present the child with novel situations in which a plan of action facilitates task performance. Such tasks do not rely on automatic processes but require mediation by top-down EF and the constant monitoring of performance (Colcombe & Kramer, 2003). Based on the nature of EF tasks, it is reasonable to hypothesize that EF task performance would benefit from strategy use. Stated otherwise, perhaps aerobic exercise trains not only the body but the mind as well. The work of Posner and his colleagues (see Posner, Sheese, Odludaş, & Tang, 2006 for a brief review) indicates that EF is malleable such that it can be improved through training. In a series of studies, Posner and his colleagues found that the use of computerized EF exercises over a five-day period improved EF efficiency as measured by EEG in 4- to 7-year-olds. Also, children with the most initial difficulty on the EF tasks gained the most from the training. The added benefit of training EF via aerobic exercise over using computerized tasks is that it would promote physical improvements as well.
General Conceptualizations of Children’s Strategy Use

Our understanding of the development of strategic behavior comes primarily from research on memory development and strategic memory recall. Contrary to early notions that strategy use in children is rather uniform and that the development and use of more advanced strategies (i.e., those strategies that are both efficient and facilitate task performance) occurs in a predictable manner, strategy development and use is now viewed as highly variable across children, across different tasks, across different trials of the same task, and even within a single trial of a task (Siegler, 1996; Siegler, 2007; Winsler, Naglieri, & Manfra, 2006). Siegler’s overlapping waves model (Siegler, 1996; Siegler & Alibali, 2005) illustrates the variability in strategy use within a child. As children develop, more advanced strategies develop gradually and compete with extant strategies for use. Through competition, less advanced strategies are gradually employed less and less frequently by the child while more advanced strategies become more prevalent. Accordingly, there are no sudden developmental jumps or shifts in strategy use; on the contrary, a child may display both sophisticated, effective strategies and inferior, ineffective strategies within a short period of time, perhaps even within solving one problem.

Though the conceptualization of strategy use as highly variable has led to a more accurate understanding of its development, strategy variability is still an imprecise term. Coyle (2001) refined its conceptualization by decomposing strategy variability into two components—strategy diversity and strategy change—and examined the relation between these components and task performance as a function of age. Strategy diversity refers to the overall number of strategies used during a period of time while strategy change refers to the number of changes in the particular strategies used over a set of trials. Coyle found that for performance on a sort-recall task, the two components of strategy variability were differentially associated with task
performance depending on age. Strategy diversity correlated positively with sort-recall performance for elementary-aged children but was unrelated to performance for young adults. Strategy change, on the other hand, correlated negatively with sort-recall performance for young adults, but was unrelated to performance for the elementary-aged children. Coyle reasoned that early in life it is important for the child to acquire, and experiment with, numerous strategies. Thus, the greater number of strategies used was related to better performance in children. Through strategy competition, the most advanced strategies—those that are most efficient and lead to the best task performance—will remain in one’s strategy repertoire while lesser strategies will fade away. By young adulthood, it is thought that the natural selection of the best strategies has occurred and thus it is more important to use strategies consistently. For this reason, strategy change (i.e., strategy inconsistency) was negatively related to task performance in young adults.

Just as strategy use does not follow a neat, linear path from simple to sophisticated, the use of ostensibly effective and sophisticated strategies does not necessarily translate into improved task performance. Miller (Miller, 1990; Miller & Seier, 1994) identified what she coined a utilization deficiency when a child spontaneously produces a certain strategy without accruing any benefit of using that strategy. Typically, a younger child will display a utilization deficiency for a strategy while an older child will use the strategy effectively and with benefit to task performance. One plausible reason for the existence of utilization deficiencies in young children is that strategy use is effortful and taxes a young child’s cognitive capacity (Flavell, Miller, & Miller, 2002). This leaves few cognitive resources for the actually completion of the task at hand. In older children, the strategy may become more automatic through practice, require fewer cognitive resources, and thus leave sufficient cognitive resources for task completion. The use of varied strategies in childhood may then be important because a particular
strategy may not initially be effective, but as the child persists and gains more experience in using it (along with various other strategies), it may increase in its degree of effectiveness.

Development of Memory Strategies

As stated earlier, the study of strategy development has its roots in memory research, and much of its research involves children’s observed strategy use on sort-recall tasks. A sort-recall task presents the child with a list of items that she should memorize for latter recall. Typically the list-to-be-remembered contains items that are categorizable but may vary in the conspicuousness of the underlying category. Coyle and Bjorklund (1997) examined the presence of four possible sort-recall strategies in 2nd, 3rd and 4th grade children: sorting (arranging the words into groups); rehearsing (verbalizing the list items); category naming (identifying and verbalizing the category name for a group of items); and clustering (recalling the words by category). Unlike previous research that included protocols that simply credited the child for using a strategy or not, Coyle and Bjorklund recorded which of the four potential strategies the child used during a sort-recall trial. Thus, the researchers measured multiple strategy use per trial. In general, all children used more than one strategy per trial, although older children used more strategies per trial than younger children. In addition, children of all ages showed substantial variability in the strategies used from one trial to the next. Borrowing from Coyle’s (2001) later publication, these children showed both strategy diversity and change. For the older children, there was clear benefit to recall across trials from using multiple strategies. For younger children, the positive correlation between number of strategies used and recall performance was only realized on the latter sort-recall trials. Finally, children who used a “stable mixture of strategies” demonstrated better recall than those children showing greater strategy change. These
results reaffirm the finding that children use multiple strategies on sort-recall tasks and that this strategy diversity promotes memory performance.

Recent research (Lehmann & Hasselhorn, 2007; Shin, Bjorklund, & Beck, 2007; Schwenck, Bjorklund, & Schneider, 2007) has also investigated strategy use in the sort-recall paradigm. Lehmann and Hasselhorn (2007) note that with few exceptions (e.g., Coyle & Bjorklund, 1997) past research studies only look at the presence or absence of strategic behavior instead of identifying the number and types of strategies used within a single trial. Using 2nd, 3rd and 4th grade children, the researchers found that there was a gradual shift from the simple strategy of *labeling*, saying each item aloud only once, to the more advanced strategy of *cumulative rehearsal*, rehearsing two or more items at a time. Additionally, digit span, a measure of working memory capacity, correlated positively with the size of the rehearsal set.

Schwenck et al. (2007) examined utilization deficiencies of both item sorting and clustering. They inferred a utilization deficiency when strategy use (either sorting or clustering) increased from one trial to the next without a corresponding increase in recall. The researchers found that utilizations deficiencies were fairly infrequent, but more frequent when the child was prompted to sort or cluster the to-be-recalled items. Moreover, the incidence of utilization deficiencies did not vary as a function of the strategy measure (i.e., sorting or clustering the items). These results draw attention to the fact the effectiveness of a strategy may be importantly related to whether the strategy was spontaneously produced by the child or prompted by the experimenter. Miller’s (Miller, 1990; Miller & Seier, 1994) original definition limited the utilization deficiency phenomena to spontaneously produced strategies, but more recent work (Bjorklund, Miller, Coyle, & Slawinski, 1997) has extended its conceptualization to trained or
prompted strategies as long as there is some element of strategic self-regulation; that is, the child may be shown a particular strategy and on subsequent trials produces the strategy on her own.

Shin et al. (2007) studied the relations among metamemory, strategy use and memory performance. The researchers were interested in how overestimation of recall performance, an ostensible indicator of limited metacognition, relates to strategy use and actual recall in young, school age children. Pertinent to this study, Shin et al. found that kindergarten age and 1st grade children who highly overestimated their recall ability were more likely to persist in using the same strategies of early trials on later recall trials, though the statistical analysis was not significant. However, there was no strong indication that increased strategy use improved recall performance. These studies of memory strategy use suggest in general that children use multiple strategies to facilitate memory performance and that over development these strategies become more sophisticated.

Development of Arithmetic Strategies

The development of strategy use has also been widely examined in the context of solving arithmetic problems. Siegler (1996) outlines the development of addition. During the preschool years, the child transitions from mere guessing with low accuracy to using counting strategies, such as counting on one’s fingers and using the sum strategy (counting up from 1). As she enters school, the child begins using more advanced strategies, such as the min strategy (counting from the larger addend) and decomposition (dividing the problem into simpler ones). Between kindergarten and 2nd grade counting and guessing decrease rapidly while use of the min strategy and decomposition steadily increase. By 2nd grade the child begins to retrieve the correct answer from memory for simple addition problems. All along, the child makes improvements in the speed, accuracy, and automaticity of completing arithmetic problems.
Bjorklund and Rosenblum (2001) investigated addition strategy use in a real-world context, that is, in the board game ‘Chutes and Ladders’ to ascertain if our understanding of arithmetic strategy use generalizes beyond classroom-type addition problems. The participants were children in preschool, kindergarten, and 1st grade. In accordance with Siegler’s (1996) overlapping waves model, all children used a mixture of strategies including what would be considered sophisticated and unsophisticated strategies. Though all children used multiple strategies, older children relied more on sophisticated strategies, namely the min strategy and retrieval, while relying less on less sophisticated strategies, such as the sum strategy. These findings extend previous research outlined by Siegler (1996) using classroom-type addition problems to real-world uses of addition strategies.

Imbo and Vandierendonck (2007) recently looked at strategy use and arithmetic performance with two distinct manipulations in children ages 10 to 12. First, using a dual-task method, the researchers manipulated working memory load with the assumption that working memory is involved in strategy selection and efficiency. Second, they included both a choice condition (no restraints on type of strategy used) and no-choice condition (only one strategy allowed) to tease apart strategy selection processes and strategy efficiency processes. The researchers found that with age the retrieval and counting strategies became more efficient such that the negative impact of simultaneously loading working memory diminished from age 10 to 12. The results of the choice/no-choice conditions pinpointed the differential impact of working memory load across age on strategy efficiency processes and not on strategy selection processes. Since there were no age-related differences in the impact loading working memory had on the speed of naming a completed addition problem (a measure of processing speed), Imbo and Vandierendonck argued that greater executive efficiency, but not general improvements in
processing speed, underlies the improved strategy efficiency. Stated simply, it appears that EF processes are critical to efficient and effective strategy use on arithmetic tasks.

*Strategy Use on EF Tasks*

Much less strategy development research has utilized neuropsychological measures of EF. Hughes and Bryan (2002) examined age-related differences in strategy use on verbal fluency tasks among younger and older adults. Fluency tasks have been included in neuropsychological batteries of EF (e.g., Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001; Brocki & Bohlin, 2004; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003; Welsh, Pennington, & Groisser, 1991), and performance on fluency tasks is associated with frontal and temporal lobe activity, with phonemic fluency tasks (e.g., naming words beginning with C) and excluded word fluency tasks (e.g., naming words that do not begin with C) being more closely linked to frontal lobe functioning (Hughes & Bryan, 2002). In this study, there were no differences in the number or type of strategy used to recall words but younger adults produced more words on the excluded fluency task, perhaps suggesting that strategy use in the younger adult group was more effective.

In another study involving younger and older adults, Gilhooly, Phillips, Wynn, Logie, and Dell Sala (1999) inspected strategy use on a five-disc version of the Tower of London (TOL). This version of the TOL presents the participant with five colored disks that need to be moved between three pegs in order to create a target pattern in a set number of moves. The participant can move only one disc at a time and cannot move a disc if it is located underneath another disc (i.e., it is in a blocked position). Thus, to achieve the minimum number of moves to complete the pattern, the participant needs to plan ahead, creating a strategy prior to moving the first peg, and evaluate his or her progress after each move in order to plan the next move.

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2 There are several versions of the Tower of London (ToL) and the related Tower of Hanoi (ToH) with differing rule systems. See Berg & Byrd (2002) for a thorough review and description of many of these test versions.
investigate what strategy the participant used, the participants verbalized their thoughts both in the planning and move phases of the task. Regardless of age, a goal selection strategy was preferred, in which the participant chose a goal from among the many needing achievement (e.g., move all the disks from a particular peg) and then decided upon a move or sequence of moves based on that immediate goal. The participant selected the goal that was easiest to meet (i.e., had the fewest obstacles in the way). Further, there were no differences in the number of moves to achieve the target pattern based on age, but analysis of the participant reports during the planning phase revealed that older adults made less complete plans (e.g., planned ahead fewer moves) and were more error prone in their planning (e.g., could not maintain an accurate representation of the disc positions and thus planned moves inconsistent with previously planned moves). The authors suggest that working memory is heavily loaded during the planning phase, but not during the move phase where there are external cues, and that the natural decrement in working memory with age explains the age-related differences in planning phase strategy quality.

Though these studies suggest age-related differences in the types and effectiveness of strategies used on EF tasks, these differences relate to adult aging rather than childhood development. Very few studies encountered for this review used traditional neuropsychological EF tasks (e.g., TOL, Wisconsin Card Sorting Task) to examine strategy use and development in non-clinical populations of children or adolescents. For example, Berg and his colleagues (Berg & Byrd, 2002; Berg, Byrd, McNamara, & MacDonald, 2006; McNamara, DeLucca, & Berg, 2007) have performed detailed examinations of the TOL task. In this version of the TOL, the

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3 Several studies examine strategy use in solving complex problems, including a study by Crowley and Siegler (1993) that examined children’s adaptive strategy use in a game of tic-tac-toe and a study by Gardner and Rogoff (1990) that investigated children’s degree of planning in response to mazes of varying complexity. Though these complex tasks surely place demands of EF, they are not considered neuropsychological measures of EF and thus were excluded from this review.
child is presented with three differently colored balls arranged on three pegs on a game board. Berg argues that there are two phases in reaching the TOL solution, a pre-goal phase and a goal-path phase that can be identified by close examination of each move. The first is marked by exploratory moves while the second is characterized by goal-oriented and strategic behavior. In their review of previous research involving preschool age children, Berg and his colleagues note that young children tend to spend most of their time in the pre-goal phase, executing non-planful moves (Berg et al., 2006).

Berg et al. (2006) also carried out a study of specific strategy use by investigating TOL problems in which it is necessary to first move a ball to a position inconsistent with the goal (i.e., the configuration to be replicated). This strategy is necessary in situations in which a ball is blocking another ball sitting lower on a particular peg. The child must first move the blocking ball to a free peg and then move the desired ball to the proper location; that is, the child must make a goal-inconsistent move prior to executing a goal-consistent move. The researchers argue that such a move requires inhibitory processes since the tendency to move the ball only in a goal-consistent manner must be overridden. Four-year-olds executed this strategy more often than 3-year-olds, who instead attempted moves in violation of the rules (e.g., moving both the blocking and blocked balls simultaneously). This finding is consistent with the development of sophisticated strategy use with increasing age.

More recently, McNamara, DeLucca, and Berg (2007) tracked detailed change in the type of strategy used and EF performance with increased experience on the ToL task by using a microgenetic design. Using this design, it is possible to examine change over brief periods of time (hours or days) by giving multiple trials of the same task or of similar tasks. McNamara et al. noted subtle trial-by-trial changes in the number of strategies used (strategy change) as well as
in the types of strategies used (strategy diversity). These changes were complimented by reliable increases in several speed and accuracy measures of performance.

Overall, Berg and his colleagues recommend that EF researchers develop a standardized version of the TOL and that any analysis include multiple measures of performance. They note that strategy use should be one of these performance measures, and that historically, strategy use has been largely ignored by researchers in the study of EF. In addition to examining strategy use, they advise that the researcher include at least one accuracy measure and one speed measure. (Berg & Byrd, 2002; Berg et al., 2006). Without multiple measures of performance, it is not possible to examine the convergence of the results for each performance measure, e.g., to determine whether speed, accuracy, and strategy use show similar developmental trends. Without standardization, it is difficult to make comparisons across studies.

Although Berg’s recommendations apply specifically to the TOL, it would be prudent that these same recommendations be met by any EF measure. The Planning scale of the CAS meets these recommendations. First, the CAS has very good psychometric properties as it was validated and standardized on a large representative sample (N = 2,200) of U.S. children ages 5 to 17 (Naglieri & Rojahn, 2004). Such good psychometric properties indicate stability of measurement over time and the validity of the cognitive processes being measured. It also indicates that cross-study comparisons can be made. Second, the performance score is a ratio of time to completion and number correct for most tasks. Thus, it is possible to not only look at the connection of strategy use to the ratio score, but also to the accuracy and time to completion scores separately. Additionally, the Planning scale is particularly amenable to examination of strategy use. The three Planning tasks require the child to develop and apply a plan of action (i.e., a strategy) (Das, Naglieri, & Kirby, 1994), and the use of a strategy benefits performance...
compared to a condition in which the child is prohibited from being strategic (Haddad, 2004). Moreover, the CAS Record Form for test administrators contains a section to record the use of pre-selected strategies on each of the subtests of the Planning scale. As part of the standard protocol, the test administrator records both those strategies observed and those reported by the child. Thus, the Planning scale provides time to completion, accuracy, and strategy measures.

Finally, the CAS is unique in that it is based on a theoretical model of EF derived from research in neuro- and cognitive psychology (Luria, 1966, 1973, 1980). The CAS has been found to correlate highly (r = .70 - .72) with the revised Woodcock-Johnson (WJ-R), a measure of academic performance (Naglieri & Rojahn, 2004), and its processing approach to intelligence may be superior to traditional intelligence tests to describe cognitive differences and non-differences based on gender (Naglieri & Rojahn, 2001) and race (Naglieri, Rojahn, Matto, & Aquilino, 2003).

Two studies (Winsler & Naglieri, 2003; Winsler, Naglieri, & Manfra, 2006) have examined strategy use on the CAS by analyzing the data from the nationally representative sample involved in the standardization process. In the first Winsler and Naglieri (2003) examined age-related changes in use, self-report, and awareness of strategic verbalization on Planned Connections (one of the three Planning tasks). Planned Connections requires the child to first string together numbers scattered on the page in sequential order. Next, it requires the child to connect both numbers and letters scattered on a page, alternating between numbers and letters (e.g., 1-A-2-B-3-C…). Approximately 60% of children and adolescents displayed or reported some sort of verbal strategy, whether it be clear outward speech, soft mutters or completely internalized speech—with increasing age the form of this strategic verbalization transitioned from overt self-talk to covert inner speech. The number of children who used some sort of verbal
strategy, including semi-covert ones such as whispering or muttering, was significantly greater than the number who actually reported using a verbal strategy, suggesting that “conscious awareness of strategy use is not a prerequisite for strategy selection” (p. 673). Finally, for children of all ages, overt and covert verbal strategy use was unrelated to task performance.

In the second study (Winsler, Naglieri, & Manfra, 2006), Winsler and colleagues investigated search strategy use on Matching Numbers (the first of the three Planning tasks), looking specifically at children’s self-report of such strategies. On this task, the child is required to match the two identical numbers in a row of six numbers. The number of digits in each number varies from two to seven digits. Here, there were age-related increases in search strategy use, with the largest gains occurring between ages 5 and 9 and leveling off thereafter. Despite the increase in search strategy use with age, a full one-third of adolescents did not report any search strategy use. Indeed the use of multiple search strategies was rare with less than 10% of children ages 5 to 9 and less than 20% of children ages 9 to 17 using more than one search strategy. The researchers further discovered that the link between search strategy use and task performance was moderated by age: the use of search strategies was effective for the youngest children ages 5 – 7, irrelevant for children ages 8 – 12, and actually related to poorer performance in adolescents (ages 13 – 17). The results of these two studies combined indicate that the relation between strategy use and performance on the CAS Planning scale is far from clear.

The work by Winsler and his colleagues has been highly informative for at least a couple of reasons. First, it provides much needed information about the use of strategies by children and adolescents on executive-mediated tasks. Second, their use of a large, nationally representative sample makes the results very generalizable. That stated, a few questions remain concerning strategy use and the CAS: How can strategy use be described on Planned Codes (the one
Planning task not examined by Winsler and his colleagues)? How is strategy use on one particular Planning task related to the other two tasks? Does strategy use relate differently to time to complete task and number correct on the task, the two components that comprise the performance score? Finally, does exercise influence the types or number of strategies used on the CAS and does strategy use in some way mediate the relationship between exercise and CAS Planning performance found by Davis et al. (2007; under review)?

**Current Aims**

The purpose of this thesis investigation is to examine these questions using the strategy and performance data collected for the Davis et al. (2007; under review) study. Though the child participants of this study were overweight, this fact does not necessarily make the results irrelevant to children in general. As of 2002, overweight children comprise nearly one-third of all children in the U.S. (Hedley, Ogden, Johnson, Carroll, Curtin, & Flegal, 2004). The prevalence of childhood overweight in the area from which this sample came—Augusta, GA, USA—is 40% or more (Davis, Flickinger, Moore, Bassali, Domel, & Yin, 2005). Thus, the selection of overweight children is neither unrepresentative of the region nor of the U.S. in general. In this way, a description of strategy use and development in this population would be valuable in understanding current child development in the United States. Further, overweight children may be particularly responsive to the cognitive benefits associated with the exercise intervention because they more likely are inactive (Davis et al., 2007; Must, Bandini, & Tybor, 2007; Must & Tybor, 2005).

Considering the findings of Coyle (2001) that strategy diversity (i.e., the number of strategies used) is related to improved task performance in children, it was hypothesized that task performance would be positively related to the number of strategies used on that Planning task.
Expanding on this hypothesis to include the influence of exercise, it was hypothesized that the strategy-conducive nature of group aerobic games would lead those children in the exercise intervention to become more strategic in the face of challenging and novel situations such as the tasks included in the Planning scale. It is expected, then, that after controlling for pretest strategy use, there would be a linear trend in the number of strategies used, with children in the control condition using the fewest strategies and children in the high-dose group using the most. In turn, this increased strategy use will lead to better performance.

In addition to these primary hypotheses concerning the impact of the intervention on the posttest, another interest was to explore the developmental pattern of strategy use on the CAS pretest; that is, to examine age-related changes in particular strategy use and the number of strategies used irrespective of the influence of the exercise intervention. Prior to testing this hypothesis, all the possible strategies included in the CAS examiner’s booklet were considered for their perceived degree of effectiveness. For each strategy a decision was made regarding whether it should be considered effective or not. This decision process is described in detail in the Methods section. Therefore, another aim of the current study was to determine whether the decision to consider a particular strategy as effective or not was empirically supported by the data. This included examining interactions between age and specific strategies as they related to performance since it is possible that some strategies may be more effective for children of different ages.

Assuming age-related differences in strategy use and strategy effectiveness, an exploration of working memory differences was conducted as well. Several researchers (e.g., Lehmann & Hasselhorn, 2007; Miller, 1990; Miller & Seier, 1994) have theorized and found differences in strategy use and effectiveness based on differences in cognitive capacity (i.e.,
working memory). For example, Lehmann and Hasselhorn (2007) found that children with larger working memory capacities (as measured by backward digit span) were more likely to use a cumulative rehearsal strategy, were less likely to use simple labeling, and rehearsed larger item sets. Working memory generally improves with age throughout middle childhood (e.g., Gathercole, Pickering, Ambridge, & Wearing, 2004) and is considered a fundamental component of EF (e.g., Miyake et al., 2000). Based on these findings, it is believed that children with larger working memory capacity will use different types of strategic behaviors than those with limited working memory capacities. Specifically, performance on the first subtest, Matching Numbers, benefits from systematic searching. Children with large working memory capacities may be able to successfully scan the numbers without the need of any other strategy. For this reason, it is believed that children with larger working memory capacities may use a scanning strategy more frequently and also more effectively than children with more limited working capacities. To explore the relations among working memory, age, specific strategy use, and strategy effectiveness, two measures of working memory, the Word Series and Sentence Repetition subtests, both belonging to the CAS Successive scale, were analyzed with an interest in potential differences based on age or the particular strategy selected to facilitate task completion.
CHAPTER 2: METHOD

Participants

This investigation was part of a larger study conducted by Davis et al. (2007; under review). In total, 181 children ranging from 7 to 11 years of age ($M = 9.3$ years, $SD = 1.04$) participated in the study. Cohorts of 30 to 40 children were recruited from local elementary schools in the Augusta, Georgia area. Children were eligible if they were overweight ($\geq 85^{th}$ percentile body mass index, BMI, for age and sex; Ogden et al., 2002), inactive (i.e., did not participate in a regular physical activity program more than one hour per week), had no medical condition that would affect study results or limit physical activity, and were not taking medication that would affect study results (e.g., antipsychotics). Of the original sample, 146 were included in this investigation. Any children with missing data points were excluded (n = 16) as well as 7-year-olds (n = 19), who completed a different version of the CAS than the older children. Of this subsample, 85 were girls and 61 were boys (62% African American and 38% Caucasian). The mean age at pretest of the subsample was 9.51 years of age ($SD = 0.88$).

Procedure

Children in each cohort were assigned randomly to either a low-dose exercise treatment, consisting of 20 minutes of aerobic exercise per session, a high-dose exercise treatment, consisting of 40 minutes of exercise, or a no-exercise control condition. The exercise treatments were equivalent in intensity and differed only in duration of daily exercise. The exercise sessions met 5 days per week for 15 weeks and were conducted after school during a school semester. The exercise intervention was modeled on a program previously shown to decrease adiposity (fatty tissue) and to enhance children’s aerobic fitness (Gutin et al., 1999). The ratio of students
to teachers was 9:1. The emphasis was on intensity (i.e., the ability to elicit a heart rate greater than 150 beats per minute), enjoyment and safety. Activities included running games, tag games, jump rope, and basketball and soccer. A 5 minute daily warm-up included moderate cardiovascular activity (e.g., brisk walking, jumping jacks) and static and dynamic stretching (toe touches, lunges). Sessions ended with a water break, light cool-down cardiovascular activity (slow walking), and static stretching. Children assigned to the 40-minute, high-dose exercise condition completed two 20-minute exercise bouts each day. Children who participated in the low-dose exercise condition completed one 20-minute bout in the gymnasium and a 20-minute period in an adjoining room where they were permitted to do homework or other quiet activities. No tutoring was provided during this period. Children assigned to the control condition were not provided any after-school program but were asked to continue their usual activities. For a complete description of the intervention and the measures, see Davis et al. (2007).

**Cognitive Measure.** Children’s cognitive performance was assessed prior to and following the exercise intervention via the CAS, a measure standardized on a large representative sample of children aged 5 to 17 (see Davis et al., 2007 for a more complete description of its psychometric properties). The CAS is based on the Planning, Attention, Simultaneous and Successive (PASS) theory of cognitive function (Das, Naglieri, & Kirby, 1994). The PASS theory, in turn, is based on the work of Luria, whose work linking brain anatomy and function informed much of neuropsychology (Luria, 1976). The CAS is a standardized test that measures children’s mental abilities defined on the basis of the PASS cognitive processes. Since the overall study by Davis et al. found that exercise influenced Planning performance, the focus of this description is on the Planning scale (for a description of the other CAS scales, see Davis et al.). The three subtests of the Planning scale assess executive function processes, requiring the
child to create a plan of action, apply that plan, and monitor the plan’s effectiveness as it relates to efficient and accurate task completion. The Planning subtests are not meant to be overly challenging but rather to present the child with novel tasks that encourage strategic behavior. Samples of the three Planning subtests are presented in the Appendices.

The first subtest, Matching Numbers, contains four pages, each with eight rows of numbers and six numbers per row. Numbers increase in digit length every four rows from one digit to seven digits. Children are asked to underline the two numbers in each row that are the same. Each page is timed, with pages 1 through 3 having a 150-second time limit, and page 4 having a 180-second time limit. Children ages 8 – 17 completed pages 2 through 4. Scores reflect the ratio of the time to complete the item to the number correct.

The second subtest, Planned Codes, contains two items, each with a matrix of 7 rows and 8 columns of letters with empty boxes. The legend at the top of the page shows a correspondence of letters to specific codes (A to OX, B to XX, C to OO and D to XO). Children are asked to fill in the corresponding codes in the empty boxes just beneath each letter. In the first item, the letters are arranged vertically such that all A’s are in the first column, B’s in the second column, etc. In the second item, the letters are arranged diagonally such that all A’s are on a diagonal, B’s on a diagonal, etc. Children ages 8 – 17 are given 60 seconds per item. A ratio score is formed based on time to complete each item and number correct.

The third and final subtest, Planned Connections, contains 8 items. The first six items require the child to connect numbers in sequential order, with an increasing length of numbers to connect with each item. The last two items require the child to connect both numbers and letters in alternating sequential order (i.e., 1-A-2-B-3-C, etc.), again with the total sequence increasing in length from Item 7 to Item 8. If the child makes a mistake, the examiner directs the child back
to the previous correct position. Children ages 8 – 17 complete Items 4 through 8. The item score is the total time required to complete that item and the total test score is the time to complete all items.

Two measures from the Successive scale were included in a few analyses. The Word Series and Sentence Completion tasks ostensibly measure working memory. In the Word Series subtest, the child must reproduce a string of one-syllable words. The word string varies between 2 and 9 words and is presented orally by the test administrator. In the Sentence Repetition subtest, the child must repeat nonsense sentences presented by the test administrator. The sentences contain mainly color words (e.g., “The blue is yellowing.”) so that each sentence has little meaning. Performance is calculated based on the number of correctly repeated word strings or nonsense sentences, respectively.

Task performance. In accordance with the CAS testing manual, task performance on Matching Numbers and Planned Codes is calculated by taking the ratio score for each page (which is [number of items correct plus 10] squared, divided by the number of seconds it took the child to complete the page), and then summing these ratio scores to make an overall scale score. This sum was then converted to a standard score ($M = 10$, S.D. = 3) for each age year. Task performance on Planned Connections consisted only of the time it took to complete the page summed across all the pages of that subtest. This summed time was then converted to a standard score in a manner equivalent to that of Matching Numbers and Planned Codes. Thus, task performance can be examined as a standardized ratio score, an un-standardized ratio score, and as un-standardized time and accuracy scores.

Strategy use and reporting. On the CAS Record Form there is a list of potential behaviors (based on pilot testing of the CAS; Naglieri & Das, 1997) that may facilitate performance for
each subtest and a place to record the presence of each behavior. These behaviors are specific and distinct so as to minimize confusion and overlap. During the CAS administration, the examiner observed and recorded the behavior that the child displayed while completing each test. The examiner also solicited the child’s self-report of these behaviors. After the child completed all of the pages of a subtest and while the test booklet was still in front of the child, the examiner asked about the child’s strategy use by saying the following: “Tell me how you did these” (while the examiner pointed to several items in front of the child, referring to the entire test rather than one specific aspect of the test). If the child did not respond, the examiner posed specific questions as to how he or she completed the task (e.g., “How did you find the numbers that were the same?”). The examiner could continue to prod the child if no response was given but was specifically instructed not to give any examples of strategies or other behaviors listed on the Record Form. As with observed behaviors, the examiner marked the presence of self-reported behaviors by the child on the Record Form. If the child did not report any particular behavior that aligned with a listed behavior or if the child made a vague reply (“I just looked at the numbers”), then the child was coded as not reporting a strategy. For each potential behavior, an *a priori* decision was made as to whether or not it should be considered strategic. A discussion of this decision process follows:

The Matching Numbers subtest, in essence, is a number searching/matching task. For searching behavior to be considered an effective strategy on such a task, it must be systematic (i.e., follows a plan or pattern, and/or contains structure) and/or is selective (i.e., only relevant locations are searched) (Winsler, Naglieri, & Manfra, 2006). Thus, those strategies that were considered effective are as follows: (1) *First, Last, Middle Numbers* (systematically looking at the first, then last, then an interior/middle digit of all of the numbers in the row), (2) *First, Then
Last Digit (systematically matching the first and then the last digit in all of the numbers in the row), (3) First Two Digits of Number (systematically matching the first two digits as a group in all the numbers in the row), (4) Last, Then First Number (systematically matching the last and then the first digits in all of the numbers in the row), (5) First Digit of Each Number (systematically matching the first digit of each number in the row), (6) First, Second, Third (systematically matching the first, then second, then third . . . numbers in the row until match is found), and (7) Last Digits of Number (systematically matching the last digits of each number in the row). In addition to these systematic search strategies, the following non-strategic behaviors were recorded as well: (1) Put Finger on Numbers (pointing at the numbers or using one’s fingers as place-holders during the task), (2) Verbalize Numbers (saying one or more of the numbers out loud while searching), and (3) Scan Row (scanning the row in either direction to match the numbers). The reader should note that these behaviors may be intentional, but did not have the pattern or selectivity required by the definition of effective strategy used here.

Since the arrangement of the letters differs across the two items of Planned Codes (vertical versus diagonal arrangement), the strategies differed slightly for the two items. Those types of behavior that took advantage of the pattern of the letters and/or appeared to expedite completion were considered effective strategies. For Item 1, the effective strategies were as follows: (1) Column by Column (coded A’s in first column, B’s in second column, etc.), (2) Right to Left (coded from right to left or from bottom to top), (3) All A Columns, etc. (coded both A columns, then both B columns, etc.), and (4) Looked at Completed Codes (looked at codes already completed rather than the key at top of page). In addition, other non-strategic behavior could be recorded as well: (1) Coded Left to Right (coded entire row, ABCDABCD, left to right, top to bottom in a non-selective manner), (2) Verbalized Codes (said codes to self out loud), (3)
Coded Half a Row (coded half a row, ABCD, left to right, top to bottom), and (4) Coded Neatly and Slowly.

For Item 2, the effective strategies included: (1) **ABCD Diagonally** (coded ABCD diagonally from left to right, top to bottom), (2) **A’s on Diagonal** (coded A’s on diagonal, then B’s, etc.), (3) **All A’s on Diagonal** (coded all A’s on diagonal, then all B’s, etc.), and (4) **Diagonally in Pairs** (coded diagonally in pairs—AB, CD—from left to right, top to bottom. The non-strategic behaviors that could also be recorded were: (1) **Coded Left to Right** (coded entire row, ABCDABCD, left to right, top to bottom), (2) **Verbalized Codes** (said codes to self out loud), (3) **Right to Left** (coded from right to left or from bottom to top), (4) **Coded Neatly and Slowly**, and (5) **Perseverate** (began coding as though pattern was the same as Item 1).

On the final Planning subtest, Planned Connections, the goal was to connect the proper sequence of numbers and letters as quickly as possible. Only one behavior was perceived to facilitate this goal: **Looked Back at Last** (looked back at last number or letter). Other behaviors could be recorded; however, these behaviors were not considered to be systematic or to substantially facilitate performance. They included: (1) **Scanned page for next number or letter**, (2) **Remembered last number or letter**, (3) **Lifted hand off the page to see better**, (4) **Repeated alphabet/number series out loud**, and (5) **Repeated alphabet/number series to self**.

**Statistical Analyses**

To examine the number of strategies used by the children, a composite variable was created for each subtest (and in the case of Planned Codes, for Item 1 and for Item 2) representing the sum of strategies used, either reported by the child or observed by the examiner. Thus, if a child both reported using a particular strategy and was observed using that same strategy, she was only counted as using that strategy once. Then the number of unique strategies
used was summed to create this composite variable. Throughout this paper “effective strategy use” refers to the sum of only those strategies considered effective as indicated above; “strategy use” refers to the sum of all possible strategies as determined by the CAS Record Form (e.g., all 8 strategies listed under Planned Codes Item 1). This variable was calculated for both pretest and posttest strategy use. In addition, a variable summing strategy use across all three subtests was calculated to examine overall Planning strategy use as it related to Planning performance and the influence of the exercise intervention.

All statistics were analyzed using the Statistical Package for the Social Sciences (SPSS), version 15.0. First, strategy use on the pretest was examined. In particular, to investigate age-related changes (or changes related to other historical variables) in specific strategy use, logistic regression was used with relevant strategy use entered as the dependent variable (a dichotomous response, either used or not used) and historical variables (e.g., age, gender, and cohort) and exercise (dummy-coded as a dichotomous variable) entered as predictor variables. In each logistic regression analysis test administrator was entered as a categorical covariate to control for differences in strategy observation based on the test administrator (initial analysis showed differences in strategy use on the pretest based on test administrator, $F(2, 142) = 16.607, p = .000$). Effect size estimates are typically expressed in terms of odds ratios. To explore age-related changes in the number of strategies used, multiple regression was conducted with age as the predictor variable of interest. In addition, multiple regression was conducted to examine the relation between strategy use and performance and whether that relation held constant across the age range. Here, age (continuous in years), strategy use, and the product (age x strategy use) were entered as predictor variables.
Various aspects of performance, the dependent variable, were examined. First, the overall standardized performance score was examined. In follow-up analyses both time to complete task and number correct were examined separately. Analysis of variance (ANOVA) was used to examine the relationship between the number of strategies used (the independent variable) and pretest performance (the dependent variable), accounting for differences due to test administrator by entering it as a blocking variable.

To examine the relations of strategy selection and age to working memory, two types of analyses were performed. First, analysis of variance was performed, one analysis with word series pretest score as the dependent variable and one with sentence repetition as the dependent variable. Scanning behavior (scanners vs. non-scanners) and age (younger half vs. older half) were entered as the independent variables. Second, multiple regression was conducted with the working memory measure (either Word Series or Sentence Repetition) entered as the dependent variable. Specific strategy (e.g., scanning), age (continuous in years), and the cross-product was entered as predictors.

The influence of the intervention on posttest strategy use was also explored. Analysis of covariance (ANCOVA) was used to examine differences in the number of strategies used on the posttest among the treatment levels (control, low- and high-dose exercise) controlling for the number of strategies used at pretest, pretest age and test administrator. The interaction of strategy use and treatment was also considered in these analyses. An estimate of the effect size, partial eta squared ($\eta^2_p$), was calculated for each dependent variable. Post hoc trend analysis was used to examine the form of the difference between groups’ posttest adjusted means.
CHAPTER 3: RESULTS

Preliminary logistic regression analyses indicated no gender or race differences in specific strategy use or in the number of strategies used on any of the Planning subtests, $p > .10$.

Girls (standard score $M = 10.01$, S.D. = 2.28) did outperform boys (standard score $M = 9.28$, S.D. = 1.93) slightly on the Planned Codes subtest, $F(1, 143) = 4.146$, $p = .044$. This finding is consistent with previous research (Naglieri & Rojahn, 2001) that suggests that girls outperform boys on the Planning scale of the CAS. The mean number of effective strategies used, both reported and observed, and standard deviations are presented in Table 1 for all three subtests and for both pretest and posttest. The correlations among strategy use, age, time to completion, and number correct for each task are presented in Table 2, which will be described in detail along with the main results and are organized as follows: First, the tendency to be strategic across the three pretest subtests is described briefly. The pretest provides an assessment of strategy use, without contamination of the exercise intervention, and therefore, allows for an examination of developmental trends. Next, pretest strategic behavior within each subtest of the Planning scale is described in detail. This includes age-related changes in strategic behavior and the relationship between strategy use and performance. Finally, posttest strategy use is described in detail with regard to the exercise intervention and its hypothesized role as a mediator.

Pretest

Overall Strategy Use

The first global question concerned children’s tendency to use strategies across the tasks, each with different task demands, and thus, requiring different types of strategies. In essence, this question sought to determine whether children, who were strategic on one task, were also
strategic on the other tasks. Figure 1 places the children into categories based upon the number of subtests on which they used at least one strategy. As the figure shows, the highest percentage of children (32.9%) demonstrated strategic behavior on two out of the three subtests. Of those children who fell into this category, 50% (n = 24) used strategies on Matching Numbers and Planned Codes, 27% (n = 13) used strategies on Matching Numbers and Planned Connections, and 23% (n = 11) used strategies on both Planned Codes and Planned Connections. Of those children demonstrating strategic behavior on only one of the Planning subtests (29.5% of all children), 70% (n = 30) were strategic on Planned Codes, 21% (n = 9) were strategic on Matching Numbers, and 9% (n = 4) were strategic on Planned Connections. Thus, the majority of children did use strategies on more than one task, but less than 20% of children were strategic on all three tasks.

**Matching Numbers**

*Strategy Use by Age.* Figure 2 plots the percentage of children in each of the different age groups who either reported or were observed using each of the ten strategies (not limited to effective strategies). Except for *Scanned row for match*, the use of any specific strategy was rare, occurring in, at most, 27% of the age group. Only the first strategy (*Look at first, last, then middle number*) appears to increase linearly with age and only verbalization seems to decrease with age: The others do not show predictable change with age. Next, age-related changes in strategy diversity (i.e., the number of different strategies used by each child) were examined. Figure 3 shows the overall percentage of children at each age that used zero, one, or two or more “effective” strategies. The use of multiple effective strategies was rare across all age groups. The use of one effective strategy increased with age, beginning with approximately 20% of 8-year-olds using one effective strategy and peaking with around 40% of 10-year-olds using one
effective strategy. Conversely, non-strategic behavior decreased with age, reaching a maximal low at age 10.

Logistic regression was performed to seek statistical confirmation of the age-related trends presented in Figures 2 and 3. Only the presence of verbalization during the task showed age-related change, and in particular, decreased with age, $B = -.976$, Wald $\chi^2(1) = 4.097$, $p = .043$, odds of verbalization are multiplied by 0.377 with each added year of age. This result aligns with that of Winsler and Naglieri (2003), who found a decrease in overt verbalization with age. Neither strategy presence—the presence of any strategy—nor effective strategy presence—the presence of an effective strategy—increased or decreased with age, $p > .10$.

The relations among time, accuracy and number of strategies. The associations among total time, number correct, number of effective strategies used, and age were examined in order to see how age and strategy use were related to performance. Age was a significant predictor of both total time, $B = -14.075$, $t (143) = -2.869$, $p = .005$, $R^2 = .054$ and number correct, $B = 1.465$, $t (143) = 5.229$, $p = .000$, $R^2 = .161$, indicating that with increasing age children completed the task faster and more accurately. On the other hand, age was unrelated to the number of effective strategies used. The correlations among total time, number correct, and number of effective strategies are presented in Table 2. Interestingly, total time and number correct were negatively correlated, suggesting that the more quickly children completed the task, the more accurately they did so ($p < .01$). This held true even after controlling for age. Also, the number of effective strategies used was related to increased accuracy, but unrelated to time taken to complete the task. This indicates that by using more effective strategies, the children improved their task accuracy. To see if this relationship was consistent across all ages, multiple regression was performed. The product term (age x effective strategy use) was not significant ($p > .05$), but as
indicated by the previously computed correlations, both age \((p = .000)\) and number of effective strategies \((p = .024)\) predicted Matching Numbers accuracy. It appears then that the relationship between effective use and accuracy is not moderated by age.

_**Scanning and matching numbers performance.**_ Because scanning was the most common strategy observed or reported (see Figure 2), more fine-grained analyses were performed on it and its relation to Matching Numbers performance. To test the hypothesis that scanning may actually aid performance for older children but not for younger ones, multiple regression analysis was performed with the non-standardized performance score as the dependent variable. The product (age x scanning presence) was not a significant predictor of raw Matching Numbers performance, nor was the use of scanning \((ps > .10)\).

Follow-up multiple regression analyses were performed to determine if perhaps scanning was related to time and accuracy differentially. Total time and number correct (both summed across the individual items of the Matching Numbers subtest) were entered as the dependent variables in separate models. In neither model was the interaction term (age x scanning) significant \((ps > .10)\). Only in the model predicting total time to complete the subtest was scanning behavior a significant predictor, \(B = 26.807, t (139) = 2.451, p = .015\), suggesting that scanners on average completed the Matching Numbers subtest 26.807 seconds (or 6.8%) faster than non-scanners. It appears then that scanning does confer some benefits to performance by allowing the children to complete the Matching Numbers task faster, but not more accurately.

_**Scanning and working memory.**_ To explore the possibility that those children who scanned on the Matching Numbers subtest might have better working memory performance than those children who did not scan, performance on the Word Series and Sentence Repetition tasks was analyzed. Because the Word Series and Sentence Repetition scores were only available in
their standardized forms, it was not possible to determine age-related changes in working memory. Instead, differences in working memory between scanners and non-scanners were tested.

For performance on Word Series, there was a significant main effect for scanning behavior, $F(1, 142) = 8.365, p = .004, \eta^2_p = .056$, such that scanners ($M_{score} = 11.607, n = 28$) performed better than non-scanners ($M_{score} = 10.118, n = 118$) on the Word Series subtest. With Sentence Repetition score as the dependent variable, there was not a significant main effect at the traditional level of significance ($\alpha = .05$), although the main effect for scanning behavior was marginally significant ($p = .087$), with scanners ($M_{score} = 10.857, n = 28$) showing higher scores than non-scanners ($M_{score} = 10.042, n = 118$). Overall, these analyses provide support for our working memory hypothesis in that scanners, regardless of age, performed better on the working memory tasks than non-scanners.

**Summary.** Except for the use of scanning, strategy use on Matching Numbers was rare. Moreover, only verbalization showed any marked changes with age as it decreased linearly with increasing age. Using a variety of effective strategies was related to better accuracy on the task but was unrelated to time to task completion. Finally, the use of the scanning strategy led to faster task completion for children of all ages and was also related to higher working memory.

**Planned Codes**

The two items of the Planned Codes subtest were initially examined separately since they differed in the arrangement of the codes in the matrix (vertical versus diagonal arrangement).

**Strategy use by age: Item 1.** In Figure 4 the percentage of children in each group using each of the eight search strategies is plotted. Unlike Matching Numbers, strategy use (i.e., the presence of one strategy) was fairly prevalent on Planned Codes: Item 1, especially for coding
the entire row and coding the letters by column. For the former, coding the entire row from left
to right, younger children used this strategy much more frequently than older children, with
approximately 40% of 8-year-olds using it but only 20% of children 10.5 or older using it. The
latter, coding the letters by column in alphabetical order, increased with age, from approximately
45% in 8-year-olds to 60% in children 10.5 or older. The other strategies, on the other hand,
ocurred less frequently, with less than 20% of children at any age using any of them. Figure 5
displays the diversity of effective strategies used. As with Matching Numbers, multiple strategy
use was rare; however, the use of at least one strategy exceeded no strategy use at all ages.

To find confirmatory statistical support for age-related changes in specific strategy use,
logistic regression was performed. The apparent changes in strategy use with age displayed in
Figures 4 and 5 were not confirmed by these analyses, \( p > .10 \).

**Strategy use by age: Item 2.** Figures 6 and 7 display the percentage of children by age
group using each of the 9 possible strategies and the variety of effective strategies used,
respectively. As Figure 6 suggests, it appears that there is a precipitous drop in the first strategy,
*coded entire row from left to right*, with a prevalence of 50% in 8-year-olds but only 10% in
children 10.5 and older. Conversely, coding the letters diagonally in alphabetical order increased
dramatically with age, from roughly 10% in 8-year-olds to 38% in the oldest children. These
contrasting age trends make sense because the former strategy is rather unsophisticated while the
latter one can be highly effective. It would be expected that older children would be more
inclined to use a more sophisticated strategy but less likely to use an unsophisticated one
(Siegler, 1996). Turning to Figure 7, non-strategic behavior far exceeded the use of one or
multiple effective strategies, contrasting with the results of Item 1 (see Figure 5). That said,
Figure 7 does suggest a trend toward increased strategy use with age as only 10% of the youngest children used an effective strategy, but nearly 40% of the oldest children did.

Again, logistic regression was performed to seek confirmation of the above trends. Here, the findings from Figure 6 were confirmed: (a) there was a decrease in coding the entire row, left to right, $B = -.425$, Wald $\chi^2(1) = 4.010$, $p = .045$, odds of using this strategy are multiplied by 0.654 with each added year of age, and (b) there was an increase in coding the letters diagonally and in alphabetical order, $B = .547$, Wald $\chi^2(1) = 4.503$, $p = .034$, odds of coding diagonally are multiplied by 1.729 with each added year of age. Figure 7 was partially confirmed via logistic regression: The use of at least one effective strategy increased with age, $B = .444$, Wald $\chi^2(1) = 3.496$, $p = .062$, odds of effective strategy use are multiplied by 1.560 with added year of age. Older children, therefore, are more likely to use an effective strategy than younger children.

The relations among time, accuracy and number of strategies. The relationship between total time, number correct, number of effective strategies used, and age was examined. The correlations among these variables are presented in Table 2. An initial set of analyses revealed that age was a significant predictor of total time and number correct for both Items 1 and 2. That is, time and accuracy increased with age for both Planned Codes items. Therefore, total time and number correct were aggregated across the two items for these analyses. Age was a significant predictor of both total time, $B = -.184$, $t(143) = -1.977$, $p = .050$, $R^2 = .027$ and number correct, $B = 5.540$, $t(143) = 4.825$, $p = .000$, $R^2 = .140$ on Planned Codes, indicating that with increasing age children completed the task faster and more accurately.

Returning to Table 2, the number of effective strategies employed by the child was strongly related ($p < .001$) to the number correct on both Items 1 and 2, but was unrelated to time
to completion, which was also found in Matching Numbers. Unlike those findings of Matching Numbers, total time and number correct were unrelated for both Items 1 and 2 of Planned Codes.

To examine more closely the relationship between effective strategy use and number correct, a set of follow-up analyses were performed. ANCOVA was performed on both Item 1 and Item 2, with number correct as the dependent variable in each. For both items, the number correct differed significantly by number of effective strategies used. For Item 1, the omnibus test was significant, $F(2, 134) = 11.014, p = .000, \eta^2_p = .141$, and the number of effective strategies used was clearly related to the number correct in a linear fashion, $t(134) = 2.569, p = .011$:

- $M_{adj} = 26.037$ for 0 effective strategies ($n = 54$),
- $M_{adj} = 31.363$ for 1 effective strategy ($n = 88$),
- $M_{adj} = 37.622$ for 2 effective strategies ($n = 2$).

Similarly for Item 2, the omnibus test was significant, $F(2, 133) = 20.529, p = .000, \eta^2_p = .236$; however, a quadratic trend, $t(133) = -2.859, p = .005$, fit the marginal means of number correct better than a linear trend did ($p > .10$):

- $M_{adj} = 18.486$ for 0 effective strategies ($n = 114$),
- $M_{adj} = 27.265$ for 1 effective strategy ($n = 28$),
- $M_{adj} = 21.101$ for 2 effective strategies ($n = 2$). With the small number of children actually using 2 effective strategies on either Item 1 or 2, it is unwise to draw conclusions about the effect of using two or more effective strategies. However, the use of one effective strategy clearly is related to improved accuracy as compared to those children who did not use any effective strategy.

**Specific strategy use and planned codes performance.** Finally, strategy effectiveness was examined for one particular strategy—*the child coded A’s in the first column, B’s in the second column, etc*—on Item 1. This is coded as Strategy 4 in the CAS Record Form. This strategy was of particular interest because it was reported or observed much more frequently than any other Planned Codes strategy (47.3% on the pretest) and because it clearly seemed to be a superior
strategy based on the task demands. As stated earlier, there were no age-related differences in the use of this strategy, but perhaps its use was related to higher scores on the Planned Codes: Item 1 subtest. ANOVA confirmed its effectiveness: Those who used this strategy on the pretest (n = 69, $M_{score} = 10.507$) did better than those who did not use it (n = 77, $M_{score} = 8.935$), $F(1, 144) = 21.663, p = .000, \eta^2_p = .131$. As with the overall analysis of Planned Codes, the improved performance was due to increased accuracy, $F(1, 135) = 25.493, p = .000, \eta^2_p = .159$, and not to decreased time to completion ($p > .10$). Finally, the relation between the use of this strategy and increased accuracy was not moderated by age, indicating that the strategy conferred the same benefits to children across the age range of 8 to 11.

Summary. Strategy use on Planned Codes was more frequent than Matching Numbers strategy use. For Item 1, coding the letters column by column (Strategy 4) was quite prevalent, especially in the older children, and the use of this strategy was related to improved accuracy. For Item 2, the use of an unsophisticated strategy decreased with age while the use of a decidedly more sophisticated strategy increased with age. This gives support to the notion that sophisticated strategy use increases with age. In accord with Matching Numbers, the use of a variety of effective strategies was related to improved accuracy but not to completion time.

Planned Connections

Strategy use by age. Figure 8 shows the percentage of children in each age group using each of the possible strategies. As stated previously, only one of these was considered an effective strategy a priori: Looked back at last number or letter. Based solely on the figure, there does not appear to be any predictable increases or decreases in strategy use with increasing age; the strategies appear highly variable across age. For example, lifting one’s hand off the page spiked both at age 8 ½ and age 10 to over 30% prevalence while looked back at last number or
letter increased from non-use in the youngest children to peaking at approximately 15% prevalence in 9 ½ year-olds and then drops off again to non-use in the oldest children. Logistic regression confirmed this lack of linear age-related change in specific strategy use, \( p > .10 \).

**Age, strategy use, and planned connections performance.** The performance score on Planned Connections was composed solely of the amount of time needed to complete the task (any incorrect moves were corrected by the test administrator during the testing session). The relationship between pretest age and amount of time to complete the task was examined using a simple regression analysis (pretest age as the predictor and time as the dependent variable). With increasing age, time to complete the task decreased, \( B = -38.801, t(143) = -5.076, p = .000, R^2 = .153 \). Next, the relationship between number of effective strategies and time to complete the task were explored. Analysis of covariance was performed with the number of effective strategies entered as the independent variable, pretest age and cohort as covariates, and total time to complete the task as the dependent variable. There were significant differences based on the number of strategies used, \( F(1, 140) = 5.606, p = .005, \eta^2_p = .074 \), with children using 0 effective strategies (n = 56) requiring 274 seconds on average and children using the one effective strategy (n = 89) taking 239 seconds. Thus, using the one *a priori* effective strategy did in fact aid performance by reducing the time needed to complete the task.

**Scanning behavior and planned connections performance.** Similar to the analysis of scanning behavior on the Matching Numbers subtest, an examination of scanning (*child scanned page for next number or letter*) was performed on this subtest. Multiple regression was performed with pretest total time to completion as the dependent variable, and age (centered around the mean) and scanning behavior as the independent variables. The age by scanning
interaction was not significant \((p > .25)\), nor was the main effect for scanning \((p > .50)\). According to these results, scanning on Planned Connections did not confer any benefits to performance as it did on Matching Numbers.

**Summary.** Strategy use was most infrequent on Planned Connections, and there were no linear increases or decreases in strategy use with age. Using the one *a priori* effective strategy did lead to faster completion of the task, but scanning was unrelated to performance.

**Developmental Changes in Performance**

The final interest with regard to the pretest data was to examine whether the developmental trajectories for time and accuracy differed. The raw time and accuracy measures were summed separately across the three subtests and converted to standard scores \((M = 10, SD = 3)\) based on the mean and standard deviation of the entire sample \((n = 146)\). Based on these standardized scores, the mean for each performance measure was calculated for each age group, with each age group spanning \(\frac{1}{2}\) year of age (*note*: the 10.5+ age group also included 11- and 11.5-year-olds because of the small numbers in each). Figure 9 displays these means and depicts the steady increase in performance, both time and accuracy, with increasing age. The trajectories are quite similar except that between age 10 and the oldest age group accuracy appears to level out while completion time continues to improve.

Next, \(d\) ratios were calculated, providing a measure of the magnitude of change from one age group to the next in standard deviation units. To do this, the mean of a younger group was subtracted from the mean of the adjacent older group (e.g., the mean of 8.5-year-olds minus the mean of 8-year-olds) and then divided by the average standard deviation of those two groups. Cohen’s (1988, pp. 24-27) guidelines of \(d\) ratios equal to 20, .50, and .80 indicating, respectively, small, medium, and large magnitudes of change were followed. Figure 10 plots these \(d\) ratios.
The magnitude of change between adjacent age groups was considered small for the majority of comparisons, but was larger for accuracy than for completion time between the ages of 8.5 and 10. Between age 10 and the oldest age group, however, completion time decreased to a moderate-large degree while accuracy improved very little. Examination of the raw data revealed that the latter was not the result of ceiling effects.

Posttest

The objective of examining strategy use on the posttest was to determine whether or not strategy use played a mediating role in the link between aerobic exercise and EF. Davis et al. (2007; under review) found a dose-response benefit of the aerobic intervention on the Planning scale only. That is, with increasing aerobic exercise dose—from control to 20 minute to 40 minute duration—Planning scale scores improved relative to pretest (significant linear contrast, \( p = .015 \)). There was no dose-response benefit for the three remaining CAS scales. Based on these findings, it is hypothesized that the aerobic intervention led to changes in strategy use, which in turn, increased task performance. Davis et al. (2007; under review), however, did not examine the specific tasks within the Planning scale to determine whether the dose-response benefit existed for each, nor did they examine the un-standardized time and accuracy scores that underlie the standardized performance scores. Thus, these fine-grained analyses were also conducted.

Table 3 presents the mean number of effective strategies used, both observed and reported, and standard deviations for the three levels of the exercise intervention. Looking at Table 3 and excluding Planned Connections, it appears that strategy use increased from pretest to posttest for most treatment levels. Paired t-tests indicate that this increase is significant in the 0 and 20 min groups for both Planned Codes Item 1 and Item 2 (all \( ps < .05 \)). A detailed examination of the relation between strategy use and the exercise intervention follows.
First, differences in posttest strategy use based on treatment level were explored. Analysis of covariance revealed significant differences in posttest strategy use across the treatment levels, $F(2, 134) = 3.866, p = .023, \eta^2_p = .055$. Post hoc pair-wise comparisons with Bonferroni adjustment showed significantly more effective strategies used by the 40 min group ($M_{adj} = .600$) compared to the 20 min group ($M_{adj} = .267$), $t(134) = 2.775, p = .019$. The control group ($M_{adj} = .410$) was not significantly different from either the 40 min or 20 min group in number of effective strategies used, $p > .36$. A post hoc trend analysis was also performed that suggested a quadratic trend best fit the use of effective strategies across the three groups, $t(134) = 2.28, p = .024$. Although the 40-minute group showed increased strategy use, the control group did as well. The fact that those children in the control group also increased in strategy use from pre- to posttest is inconsistent with our hypothesis concerning the mediating role of strategy use in the aerobic exercise—EF association. The 20-minute group actually decreased in the number of strategies use from pretest to posttest.

To see if this coincided with a similar pattern of Matching Numbers performance across the treatment levels, ANCOVA was performed with the standardized performance as the dependent variable. There were differences in performance based on treatment level, $F(2, 140) = 3.404, p = .036, \eta^2_p = .046$; however, post hoc trend analysis suggested a linear trend rather than a quadratic one, $t(140) = 2.55, p = .012$. Follow-up ANCOVA examined whether these performance differences were specific to differences in time to complete the task or accuracy in completing the task. Since these scores were not standardized, age was also included as a covariate. Surprisingly, there were no significant differences between treatment levels in terms of time to complete task or accuracy, $p > .10$. Overall, though there were significant
differences in both the number of strategies used and in the standardized performance score among the exercise doses, these differences did not follow a common pattern. This suggests that strategy use does not mediate the relationship between the exercise intervention and Matching Numbers performance. A formal test of mediation using regression (Baron & Kenny, 1986) also provided disconfirmation.

Finally, the possibility of an interaction between strategy use and treatment was tested using ANCOVA (with age, gender, race and pretest performance as covariates). This analysis was performed both to examine interactions between specific strategy use and treatment and interactions between effective strategy presence (i.e., use of at least one effective strategy) and treatment. Further, separate analyses were performed with time to complete task and number correct as the dependent variables. Although no interaction was significant under the $\alpha = .05$ guideline, the interaction between effective strategy presence and exercise treatment when the dependent variable was time to complete task was marginally significant, $F(2, 135) = 2.967$, $p = .055$, $\eta^2_p = .042$. To examine the nature of this interaction, simple effects were computed. For those children who did not use an effective strategy on the posttest, there were significant differences in time to complete task based on treatment level, $F(2, 84) = 4.009$, $p = .022$, $\eta^2_p = .087$, with a steady decrease in time with increasing exercise. This is illustrated in Figure 11. For those children who did use an effective strategy, however, there were no significant differences between the treatment levels, $p > .10$. There were neither significant nor marginally significant interactions between any specific strategy use (e.g., scanning) and treatment with regard to performance—standardized performance, time to complete task, or accuracy—on Matching Numbers.
Planned Codes

As with Matching Numbers, differences in posttest strategy use as a function of treatment level were examined. There were no significant differences in strategy use across the treatment levels for either Item 1 or Item 2, $p > .10$. Furthermore, there were no significant differences in performance (either standardized score, total time or accuracy) across the treatment levels, $p > .10$.

Potential interactions between strategy use and treatment level were also examined for Planned Codes using ANCOVA (with age, gender, race and pretest performance as covariates). There was not a significant interaction between effective strategy presence and treatment, $p > .10$, but there was a significant interaction between the presence of a specific strategy on Item 1—*the child coded A’s in the first column, B’s in the second column, etc*—and treatment level when the number correct on Item 1 was the dependent variable, $F(2, 135) = 6.372$, $p = .002$, $\eta^2_p = .086$. Investigation of the simple effects revealed the nature of this interaction: For those children who did not use this particular strategy (57% of whom did not use any effective strategy on this task), there were significant differences between the groups in the number correct on Item 1, $F(2, 55) = 10.089$, $p = .000$, $\eta^2_p = .268$, with substantial increase in accuracy from the 20 minute exercise group to the 40 minute exercise group (see Figure 12). One explanation for this increase in accuracy is that those children in the 40 min group are using other strategies that those children in the 20 min or control group are not using. This is unlikely given that a similar percentage of children in each treatment group did not use any other strategy (65% of the control group; 63% of the 20 min group; 43% of the 40 min group). To statistically examine whether these percentages were actually different, a cross-tabulation using Somer’s $d$ was conducted and suggested no significant differences ($p > .10$). On the other hand, there were
no significant differences in performance based on treatment for those children who did use this particular strategy \((p > .10)\).

**Planned Connections**

There were neither differences in posttest effective strategy use nor differences in performance (either standardized performance score or total time) across the treatment levels. As with the other tasks, interactions between strategy use and treatment were examined. None of the interactions was significant, \(p > .10\). Given the fact that so few children demonstrated strategic behavior on Planned Connections on the pre or posttest (see Table 3), the lack of any significant differences across groups is not all too surprising.
### Table 1

**Number of Effective Strategies Used, Both Reported and Observed, by Age, with Conditions Combined**

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<th>9-year-olds</th>
<th>9.5-year-olds</th>
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Table 2

Correlations between Variables. * Strategy Use Refers to the Effective Strategies of the Particular Subtest Except that the Correlation between Age and Strategy Use Represents the Correlation between Age and Strategy Use Summed Across the Three Subtests. ** PCn = Planned Connections. * p < .05, ** p < .01.

<table>
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<tr>
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<th>Planned Codes Item 2</th>
<th>Planned Connections</th>
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<td>Accuracy</td>
<td>Time</td>
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<td>-.064</td>
<td>-.405**</td>
<td>-.052</td>
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<td>-.219**</td>
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Figure 1. Strategy use (percent of all children, n = 146) across subtests.

Figure 2. Frequency of specific strategy use on Matching Numbers by age.
Figure 3. Frequency of the number of effective strategies used on Matching Numbers by age.

Figure 4. Frequency of specific strategy use on Planned Codes: Item 1 by age.
Figure 5. Frequency of the number of effective strategies used on Planned Codes: Item 1 by age.

Figure 6. Frequency of specific strategy use on Planned Codes: Item 2 by age.
Figure 7. Frequency of the number of effective strategies used on Planned Codes: Item 2 by age.

Figure 8. Frequency of specific strategy use on Planned Connections.
Figure 9. Standard performance means for each age group.

Figure 10. The rate of change in pretest performance between age groups expressed in d ratios.
Table 3

*Number of Effective Strategies Used, Both Reported and Observed, by Exercise Group*

<table>
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<th>20-min Group</th>
<th>40-min Group</th>
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Figure 11. Posttest Matching Numbers time to complete task ($M_{adj}$) based on treatment level and effective strategy presence.

Figure 12. Posttest Planned Codes Item 1 number correct ($M_{adj}$) based on treatment level and use of the strategy “Coded A’s in the first column, B’s in the second column, etc.”
CHAPTER 4: DISCUSSION

The two general aims of this thesis investigation were to 1) test the hypothesis that the relation between aerobic exercise and EF is mediated (at least partially) by changes in strategy use as a result of the learning components of structured aerobic activities and 2) examine the developmental trends in strategy use on a measure of EF, including the relation of strategy use to performance and working memory capacity. Regarding the primary aim, there was little support for our hypothesis that strategy use assumes a mediating role between aerobic exercise and enhanced executive functioning. Regarding the second aim, the results broaden our knowledge base about developmental trends in strategy use and its relations to performance and working memory and point strategy research in some interesting new directions. A detailed discussion of the results of each research aim follows.

The Role of Strategy Use in the EF Hypothesis

There was reason to believe that the learning components intrinsic to the aerobic exercise intervention may encourage children to become more strategic. It was further hypothesized that these increases in strategic behavior would be reflected in increased strategy use on the CAS Planning subtests. Yet only on the posttest Matching Numbers task were there significant differences in the number of effective strategies used across the aerobic exercise treatment groups. The nature of the differences, however, was inconsistent with the a priori hypothesis: Instead of a linear dose-response effect corresponding to the effect detected by Davis et al. (2007; under review), there were increases in effective strategy use in both the 0min and 40min groups yet decreases in the 20 min group from pretest to posttest. There were no significant differences in posttest effective strategy use on either Planned Codes (Item 1 or 2) or Planned
Connections as a function of exercise dose. Regarding Planned Connections, this is not surprising given that so few children used an effective strategy on the pre- or posttest (see Table 3).

There are at least a few explanations for why no effect was found in favor of the mediating role of strategy use in the aerobic exercise—EF connection. First, it was believed that strategic behavior would increase as a result of the learning components of the exercise intervention. In the current study, this increase in strategic behavior was conceptualized as an increase in the variety of effective strategies used; however, it is possible that the change of a qualitative nature rather than a quantitative one. That is, perhaps children used different types of strategies as a result of the exercise intervention. If this was the case, we were unable to detect these qualitative changes via the current analyses as there was no evidence that children were using different strategies on the posttest as a function of exercise dose.

It is also possible that examining quantitative changes in strategy use is not sufficiently sensitive to the changes induced by the exercise intervention. This insensitivity could be related to the fact that the number of strategies used by the children generally increased from pre- to posttest, irrespective of exercise dose (see Table 3). One explanation for this increase in strategy use from pre- to posttest is provided by Siegler’s Moderate Experience Hypothesis, which posits that children are most likely to use a maximum number of strategies when they have a moderate amount of experience with the task at hand (Siegler, 1996). Both children with little experience and those with great experience with a task will use fewer strategies. Siegler argues that through the process of gaining extensive task experience, children will discover the most effective strategy and will settle on that single approach. On the other hand, children with little task experience will stumble upon a strategy (or arbitrarily choose a strategy) and also use it
consistently. It is only with moderate task experience that children begin to experiment with diverse strategies in order to select the most effective one.

Siegler found evidence for the hypothesis by exposing children to problems requiring the use of a balance scale (Siegler & Taraban, 1986). With increasing experience with balance scale problems, the children began using an assortment of strategies. After quite a bit of experience, the children began to discard less efficient strategies until they primarily used a retrieval strategy exclusively. It is not unlikely that the moderate experience hypothesis applies to the current study as well. The CAS Planning tasks would certainly be novel to the children during the pretest; after all, the tasks are intended to be new and require executive processes rather than automatic ones (e.g., retrieval). On the second exposure during the posttest, the children may try new strategies, particularly in the case that those strategies employed on the pretest were ineffective. Or perhaps the children will maintain the strategies used on the pretest and add new ones as well. If this is the case, then it would be expected that all children would demonstrate quantitative increases in strategy use from pre- to posttest, and it would not be surprising that even children in the control condition increased their strategy use.

A second possibility for the null findings is that the strategy use collection process, as delineated by the CAS examiner instructions, is insufficient for this particular research aim. Children were only asked to report their strategies after completing the entire task rather than after each item (with the exception of Planned Codes). For example, the early items of Matching Numbers contain fewer digits (beginning with 2) than the latter items (ending with 7 digits per number). Thus, it might be that one strategy may be effective for matching numbers only containing 2 digits (e.g., scanning because of lesser working memory demands), yet an entirely different strategy would be effective for matching 7-digit numbers (e.g., a strategy that
decomposes the numbers into smaller chunks). As a result, one strategy may be effective for part of the task, but other strategies may be effective for other parts of the task. This also suggests that certain cognitive behaviors that would not typically be considered strategic (e.g., scanning) may actually be superior in certain situations. Overall, these possible explanations for the null effect speak to the complexities involved in strategy use. Only by our continued investigations of children’s strategy use will we be able to pinpoint, describe, and explain these complexities. Such future investigations should include detailed task analyses and fine-grain collection of strategy use.

Despite the lack of evidence for mediation, the two instances of interactions between specific strategy use and exercise dose do provide intriguing results. In the first case, exercise dose interacted with effective strategy presence in its impact on time to complete the Matching Numbers task. There were no significant changes in time across the exercise doses for children who used at least one effective strategy—perhaps effective strategy use nullified the benefits to EF conferred by the aerobic exercise. Instead, differences arose across the exercise doses only for those children who did not use any effective Matching Numbers strategy (see Figure 11). The time to complete the task dramatically decreased with increasing exercise dose (approximately a 9% decrease in time from control to the 40 min dose). The second finding involved Planned Codes Item 1 response accuracy and the interaction between exercise dose and the specific strategy child coded A’s in the first column, B’s in the second column, etc. Again, the children of interest were those who did not use this particular strategy (57% of whom also did not use any other strategy on this subtest). Here, there was a dramatic increase in number correct between the 20 min group and the 40 min group, such that those children in the 40 min group who did not use
this particular strategy were nearly as accurate as those children who did use this effective strategy (see Figure 12).

These two interactions suggest a third explanation for the null results, which is that strategy use does not act as a mediator in the path from chronic aerobic exercise to EF. Perhaps aerobic exercise directly impacts cognitive efficiency in a manner irrespective of strategy use. For example, Hillman, Castelli, and Buck (2005) found that high-fit children displayed faster cognitive processing than low-fit children. Others have found improvements in children’s response time immediately following an acute bout of exercise and have suggested that it is via increased arousal that exercise increases response speed and to more accurate performance (Tomporowski, 2003; Zervas, Apostolos, & Klissouras, 1991). Though these results support the plausibility of this explanation, they should not be taken as direct support. The current study used a randomized control design and a chronic exercise intervention. Thus, comparisons to studies employing correlational designs using aerobic fitness as a proxy for chronic aerobic exercise or studies examining acute exercise bouts should only be done cautiously. First, children who differ in aerobic fitness may differ in many ways, only one of which could be the amount of time spent participating in aerobic exercise. In other words, correlational studies lack the experimental control that is present in the current study carried out by Davis et al. (2007; under review). Second, it would be expected that the short term impact of an acute exercise bout would differ quite significantly from the long term impact of chronic exercise (Tomporowski et al., 2007).

There are other reasons why the results of both interactions should be taken cautiously and why the conclusions drawn from them as speculative. For one, there were no significant differences in either response accuracy or completion time across the exercise groups when strategy use was not controlled. If exercise in fact did directly impact either response accuracy or
completion time, we would expect the main effect of exercise dose to be significant. Second, the finding of only two interactions (the first being marginally significant, \( p = .055 \)) does not provide irrefutable evidence. Moreover, the fact that one interaction regarded response time and the other response accuracy portrays an inconsistent picture of what is actually occurring here. Finally, if chronic exercise led to sustained benefits to cognitive processing (either manifested in faster task completion or greater accuracy), then we would expect to find benefits to performance on the other CAS scales (i.e., the Attention, Simultaneous, and Successive scales) as well.

All these cautions being stated, the current findings do hint at an interesting topic for future exploration. Since no other previous research in this area has considered the impact of strategy use on the EF hypothesis, it would be worthwhile to investigate further. Specifically, it would be informative to consider the impact exercise has on strategy use and the impact aerobic exercise has on EF when differences in strategy use are accounted for (e.g., the impact of exercise on children who are non-strategic). Further consideration also needs to be given to whether exercise causes quantitative or qualitative changes in strategy use.

*Age Differences in Strategy Use (Pretest)*

Examination of strategic behavior on the pretest also provided valuable information. Few studies have examined strategy use on measures of EF, and none on a standardized test with good psychometric properties. Additionally, the use of the CAS allowed for an examination across three qualitatively different EF tasks and permitted the investigation of the relation of strategy use to time and accuracy differentially. Therefore, it is possible to discuss global findings that were consistent across the three tasks and also specific findings that apply more narrowly to the individual subtests. Moreover, the global findings can be subdivided into those
specifically related to strategy use, those related to task performance, and those connecting strategy use and task performance. This organization is used in the following discussion.

Global Findings

The low prevalence of strategy use, particularly on Planned Connections, was clearly the most salient pretest finding (see Table 1). Very few strategies were used by more than half the children at any age, with the exception of one Planned Codes Item 1 strategy (the child coded A’s in the first column, B’s in the second column, etc). One explanation for the low prevalence of strategy use in this sample of overweight children is the very fact that overweight in children is related to poor academic achievement (Dwyer et al., 2001). It is quite possible that part of this link to poor academic achievement involves diminished strategy use as compared to normal weight children. Indeed, in comparison to the strategy use data from the CAS standardization sample (n = 2,200, nationally representative; Naglieri & Das, 1997), strategy use by this sample is quite low: For all three Planning subtests, over 90% of all children ages 8 – 12 in the standardization sample used at least one strategy. In stark contrast, strategy use in our sample hardly exceeded 50% and peaked at 70% in the oldest children (10.5+ years-of-age) on Planned Codes. One point of similarity, however, is that in both samples the scanning ‘strategy’ was the most common specific strategy on Matching Numbers (with 30%-45% prevalence in our children versus 65%-80% prevalence in the nationally representative children). Because of this discrepancy in strategy use between the two samples, perhaps one manner to effectively improve the academic achievement of overweight children is to provide interventions focused on using effective strategies.

For example, Naglieri and Johnson (2000) provided a discussion-based intervention to children (ages 12 to 14) grouped into either high or low CAS Planning scores. The discussions
sought to encourage ‘planful’ and strategic behavior while solving math problems. After controlling for pretest math performance, those children identified as having weak Planning scores made greater improvements in math performance compared to those children without planning weaknesses or children identified as having weaknesses in one of the other PASS scales. This finding is suggestive of an aptitude-by-treatment interaction (ATI), meaning that the intervention was more beneficial to those children with a planning weakness. Naglieri (2005) argues that the presence of this ATI is a highly important finding and has implications for effective academic interventions: By first administering the CAS and pinpointing a child’s area of weakness, an intervention can be crafted or selected that will optimally address that weakness.

In another example, Ashman and Conway (1993) utilized Process-Based Instruction (PBI), which also focuses on plan formation, its execution, and organization strategies. The PBI approach is a general teaching framework that can be applied to instruction in many content areas. Here, PBI was applied in grades 4 through 7 during both English and mathematics lessons. It was found that those children receiving PBI made greater gains from pre- to posttest on measures of mathematics and reading comprehension compared to those children receiving normal instruction. The authors stress that children receiving PBI did not receive additional lessons or material but only received instruction modified to focus on planning. In general, these findings suggest that strategy-based interventions may benefit academic performance.

A second global finding was the moderate consistency in children’s tendency to be strategic across the tasks, particularly on both Matching Numbers and Planned Connections. This finding is striking, given that only one strategy was deemed effective for Planned Connections (looked back at last number or letter) and that so few children actually used this strategy (less than 15% of children in any age group). Perhaps these two tasks are more similar in their
demands than either is to Planned Codes. Matching Numbers has been described as a task requiring systematic search strategies for successful completion (Winsler, Naglieri, & Manfra, 2006). It is also reasonable to argue that Planned Connections would also benefit from a systematic search for the next number or letter in the sequence. Also, both tasks require children to search for numbers.

Turning to the performance measures, there was also a strong negative correlation ($p < .01$) between the number of correct answers and time to complete task on Matching Numbers, suggesting that the faster children completed the task the more accurately they did so. Contrary to this finding, others (e.g., Davidson, Amso, Anderson, & Diamond, 2006) have found support for a speed/accuracy trade-off on measures of EF such that children will decrease their response speed in order to preserve high accuracy. In fact, the speed/accuracy trade-off is thought to increase through childhood: Younger and older children may complete a task in the same amount of time; however, older children will complete it more accurately. This is particularly true for more difficult trials that tax multiple cognitive processes. For example, Davidson et al. (2006) employed a task that had both high inhibitory and working memory demands and found that with increasing age, children compromised speed in order to preserve high accuracy.

Being primarily tasks of plan formation and execution, the CAS Planning subtests may not place equally high demands on both working memory and inhibition. Based on findings discussed previously that working memory is important in planning ahead and in strategy execution (Gilhooly et al., 1999; Imbo & Vandierendonck, 2007), it is plausible that the CAS Planning tasks place greater demands on working memory and fewer demands on inhibition.
This may explain the discrepancy between the current findings and those of Davidson et al. (2006).

There was also a reliable association between performance and age. Both completion time and accuracy had similar developmental trajectories and showed improvements with increasing age. The $d$ ratios depicted in Figure 10 show that the magnitude of change between adjacent age groups was small to moderate (Cohen, 1988) in most cases. This aligns with previous research that suggests that large increases in EF performance in early and middle childhood are followed by more subtle increases in late childhood and adolescence (see Romine & Reynolds, 2005 for a meta-analysis of EF development studies). The only significant discrepancy was that while accuracy leveled off between the oldest two age groups, completion time continued to decrease considerably. This finding suggests that even when a skill has been completely acquired as evidenced by the leveling off in accuracy, development can still occur as the speed of execution decreases. It is an intriguing finding that highlights the importance of including both speed and accuracy measures of performance. Each provides unique information about development.

Finally, there was strong interest in how strategy use related to the performance measures. The number of effective strategies used was consistently and significantly related to the accuracy measure. This held true for all Planning tasks that included accuracy measures (i.e., all but Planned Connections). This finding corroborates previous strategy use research, particularly research in the realm of memory development. As outlined previously, strategy diversity in children is related to improved recall performance (i.e., accurate recall). For example, Coyle and Bjorklund (1997) found a positive association between the numbers of
strategies used and recall performance. Additionally, Coyle (2001) discovered that strategy diversity was related to improved memory recall in children.

On the other hand, the correlation between effective strategy use and completion time was always positive but non-significant. This may suggest that increased strategy use leads to lengthened time to completion, which is reasonable given that time must be allocated to the strategy selection process (Imbo & Vandierendonck, 2007) and also to the implementation of the strategy in the process of solving the problem. The type of strategy used may also depend on whether completion time or accuracy is considered a more prized indicator of performance. For example, Gardner and Rogoff (1990) instructed children to either solve mazes accurately or quickly and also manipulated the mazes’ complexity. With emphasis placed on accuracy and when presented complex mazes, children produced more complete plans prior to completing the mazes. On the other hand, with the emphasis placed on speed or when the mazes were simple, children spent less time planning and therefore formulated incomplete plans. In other words, children created less effective strategies when speed is emphasized, and this suggests that children adapt their strategic behavior to the particular task demands.

Interestingly, impulsive children with poor reading skills seem to value speed over accuracy in general. Such children also prefer using a retrieval strategy on cognitive tasks (as opposed to more time-consuming strategies) but tend to retrieve inaccurately (Siegler, 1988). However, these children will readjust their focus to accuracy over speed given circumstances that reward accurate performance. In the case of the CAS, perhaps children who use strategies ‘consider’ accuracy to be of higher importance (although this is not necessarily a conscious consideration). This is a valuable and unique finding. It is clear that strategy use on the CAS relates differentially to the completion time and accuracy measures of performance. Effective
strategy use appears to compromise completion time, but only trivially, and it does enhance accuracy. Because the Planning scale of the CAS provides not only a standardized measure of performance but also a raw measure of time and accuracy, these findings were revealed.

Specific Strategy Findings

The main interest with regard to specific pretest strategy use was any age-related change in strategy use. On Matching Numbers, one specific strategy (the child verbalized the numbers) decreased significantly with age. This aligns well with the main finding by Winsler and Naglieri (Winsler & Naglieri, 2003; Winsler, Naglieri, & Manfra, 2006), who found that overt verbalization on Matching Numbers and Planned Connections decreased with age. This finding also supports the classic Vygotskian theory of the rise of private speech in early childhood and its gradual replacement by inner speech over the school years. Speech of this kind, whether internalized or not, is employed to mediate problem-solving tasks. On the other hand, there were no significant age-related changes in verbalization on Planned Connection: The use of either overt or covert verbalization on this task was highly variable across age.

On Planned Codes Item 2, two strategies changed significantly with age. The use of the rather unsophisticated strategy (the child coded the entire row, left to right, top to bottom) decreased with age. This strategy was unsophisticated because by coding left to right, top to bottom, the child ignores the diagonal pattern of the letters, which could potentially expedite the time to complete the task. The linear decrease in its use is sensible given the general finding that less sophisticated strategies decreased in use with increasing age (e.g., see Siegler’s overlapping waves model; Siegler, 1996). On the other hand, the use of the more sophisticated strategy (the child coded diagonally in alphabetical order) increased in a linear fashion with increasing age. Again invoking Siegler’s model, just as the use of simpler strategies gradually decrease with age,
the use of advanced strategies increase with age. In sum, these two contrasting developmental
trends provide support for Siegler’s model as well as the general notion that strategies become
more sophisticated through development.

Finally, there was an interest in the relation of strategy use to working memory. As others
have suggested (e.g., Imbo & Vandierendonck, 2007; Lehmann & Hasselhorn, 2007; Miller,
1990; Miller & Seier, 1994) working memory is crucial to effective strategy use. Scanning
behavior was the most frequent strategy on Matching Numbers (in accord with the findings by
Winsler, Naglieri, & Manfra, 2006). Although it was initially considered to be an ineffective,
nonsystematic strategy, the possibility that scanning may actually represent a systematic,
purposeful scan for a match was explored. Additionally, with the support of past research that
suggests a linear increase in working memory through middle childhood (e.g., Gathercole,
Pickering, Ambridge, & Wearing, 2004), it was believed that older children would have higher
functioning working memory than younger children. Unfortunately, because un-standardized
scores for the working memory task were not available, we were unable to empirically test this
final point.

There was not support for the hypothesis that older children would use scanning more
effectively than younger children. Instead, it was found that scanners, regardless of age,
performed the Matching Numbers task faster and also performed better on the Successive scale
tasks, putative measures of working memory, than non-scanners. This finding contradicts the a
priori decision to exclude scanning from the list of effective strategies. However, it is interesting
that unlike the other effective strategies, scanning was associated with faster completion and not
with greater accuracy. It was mentioned earlier that one of the global findings was that effective
strategy use was related to increased accuracy but not significantly related to completion time.
Scanning seems to have a qualitatively different relation to performance and, therefore, is quite different from the other strategies.

Also, it is interesting that children who used the scanning strategy scored significantly higher on the putative working memory tasks than children who did not scan. This is supportive of our initial hypothesis, but, inconsistent with our predictions, this association was not moderated by age. There are several possibilities for this association. One is that the efficient use of scanning requires larger working memory. That is, given a large enough working memory capacity, other strategies that isolate certain digits of the numbers in order to find the match, or otherwise reduce cognitive demands, may not be necessary. Instead, simply scanning the row of numbers, adding each consecutive number to working memory, would be sufficient in finding the two identical numbers. This idea is supported by a study performed by Lustig, Hasher, and Tonev (2006) in which it was found that older adults (representing low working memory capacity) were particularly affected by matching large letter strings while younger adults (representing high working memory capacity) matched larger and smaller letter strings with similar accuracy. Consequently, individual differences in critical cognitive processes (e.g., working memory) need to be considered in evaluating a certain strategy’s effectiveness.

A second possibility for this association is that scanning on Matching Numbers might rely more on successive processing than planning processing (J. Naglieri, personal communication, May 8, 2008). Successive processing is recruited when a person “works with stimuli in a specific serial order to form a chain-like progression” (Naglieri, 2005, p. 442). By scanning the row from left to right, the child would in fact be processing the numbers in a serial order and would be recruiting successive processes. One would therefore expect a positive association in task performance between Matching Numbers and the Successive tasks when the
child scans on the former task. This possibility highlights the powerful role of strategy use in task completion. The use of one strategy over another may transform the task dramatically such that different cognitive processes are recruited depending on the strategy executed.

Scanning was also recorded for the Planned Connections tasks. Children who scanned on Matching Numbers also tended to scan on Planned Connections, but here, scanning was unrelated to performance. It seems, then, that scanning may be effective for certain tasks but ineffective for others. Other research on visual searches and strategy use suggests that scanning effectiveness may be moderated by task demands. In fact, Smilek et al. (2006) distinguish active scanning (systematically directing one’s attention to the target stimulus) from passive scanning (allowing the target to ‘pop’ into one’s mind) and suggest that a passive scan may be particularly useful during difficult visual searches. They argue that by passively scanning, the participant disengages executive control, thereby allowing for automatic cognitive processes to perform the search, and in doing so, the participant increases search efficiency. This finding adds a further consideration to the idea of scanning as strategic: Systematic scanning that likely recruits EF may not be the best strategy. Instead, a more passive, non-systematic search may be best for certain tasks.

These findings emphasize the complexity inherent in the study of strategy use and its effectiveness. One strategy may aid performance by increasing accuracy, while another may expedite time to completion. Moreover, a particular strategy (e.g., scanning) may be effective for certain tasks, such as matching numbers, but ineffective for others, such as connecting numbers and letters. Strategy effectiveness may also be moderated by individual differences in cognitive processing. Finally, the type of strategy used may alter what underlying cognitive processes are activated. For example, scanning may recruit more successive processing, but other strategies
may recruit planning processes. Even more specific, scanning may signify different processes, depending on whether the scan is passive or active.

**Conclusions and Future Directions**

Although this reexamination and expansion of the data collected for a study by Davis et al. (2007; under review) did not provide clear support for a mediating role of strategy use in the EF hypothesis, the detailed examination of performance, strategy use, and the associations between the two was fruitful. First, it is clear that strategy use is infrequent in this sample of overweight children. In light of the knowledge that overweight is linked to poor academic achievement (Dwyer et al., 2001; Taras & Potts-Datema, 2005), academic interventions with similar children may benefit from targeting and bolstering strategy use (Ashman & Conway, 1993; Naglieri & Johnson, 2000). Second, it is clear that the use of those strategies considered effective *a priori* is associated with greater accuracy but unrelated (at least in the sense of statistical significance) to time to completion. Given that this is the first examination of trends in strategy use on a psychometrically validated measure of EF and that the associations of strategy use to time and to accuracy were examined, these results are important and extend our knowledge base concerning the association of strategy use to task performance.

A related strength is that multiple strategy use was examined. The CAS examiner’s booklet allows for the collection of numerous strategies. Many previous studies regarding children’s strategy use merely examine the use of one or, at most, three to four strategies within a single trial (Coyle & Bjorklund, 1997; Lehmann & Hasselhorn, 2007). In this study, eight or more potential strategies were examined on each Planning task. It also confirms previous research that strategy use tends to become more sophisticated with age as children discard ineffective strategies in order to execute more effective ones. This finding was most apparent on
Planned Codes Item 2, in which simply filling in the codes from left to right decreased with age while filling in the codes according to the diagonal arrangement of the letters increased with age.

There are, however, certain limitations to this study, and several of these revolve around the collection of the strategy use data. Given that the primary aim of the study from which these data came (Davis et al., 2007; under review) did not concern strategy use, it is not surprising that greater attention was not given to these issues at the time. First and as mentioned previously, there were significant differences in both reported and observed strategy use across the three test examiners (i.e., the frequency of children’s strategy use varied greatly across examiners), suggesting low inter-rater reliability. Unfortunately, specific information concerning inter-rater reliability was not available. These differences were controlled for statistically in all relevant analyses, but greater uniformity in the collection of strategy use data would have added statistical power to those analyses. Also, the results are limited because it was difficult to elicit the specific strategies used by the children despite the standard CAS protocol designed to obtain specific strategy use. Often, the children reported vague types of behavior that could not be placed easily into one of the predefined strategy categories. This problem likely was a reason for the general finding of infrequent strategy use in this sample. Given that strategy use was so low, it was only by combining reported and observed strategies into a single variable that meaningful analyses could be performed. This excluded the possibility to examine reported and observed strategies separately or the associations between the two. In future studies that examine strategy use on the CAS, greater training needs to be given to the CAS examiners in order to ensure greater uniformity in strategy collection and the elicitation of specific strategies. In turn, this likely will lead to a more frequent reporting and observation of strategies.
Other limitations are inherent to the standard CAS protocol. One is that only the presence of each strategy is recorded (i.e., either present or not), rather than the frequency of each strategy’s use, the degree to which it is used, or for what task items it was used. Information as to these aspects of strategy use would add a rich dimension to the analyses of trends in strategy use and the relation to performance. Another limitation previously noted by Winsler et al. (2006) is that the children were asked to report their strategies only after completing all items in each task. It is possible that children used one strategy on an early item and a different strategy on a subsequent task item but only reported the latter strategy used. This in turn could lead to underreporting of the strategies used throughout each Planning task. Future research needs to address this limitation by employing a more fine-grained strategy collection protocol.

Still other limitations specific to the aerobic exercise intervention are mentioned elsewhere (Davis et al., 2007). Since these do not directly concern strategy use, they will not be repeated except to mention the following. First is that the control group did not receive any sort of non-exercise intervention. Given the same results using an attention control group (i.e., receive some form of after school non-exercise programming) would rule out the possibility that it was other, non-aerobic exercise components (e.g., attention given by the instructors) that caused the improvements in EF. Finally, the exclusive use of overweight children in this study could be seen as a limitation. The impetus for forming this sample was the belief that overweight sedentary children might be more responsive to the aerobic exercise intervention; however, in doing so, generalizability to the greater national population perhaps was compromised. Still, in light of the dramatic increase in childhood overweight and its prevalence particularly in the local population (Davis et al., 2005), it is becoming increasingly necessary to examine cognitive development in overweight children. For this reason, these results are highly pertinent.
Because of the sparse literature on the subject, there is a clear need for more research concerning strategy use on measures of EF, particularly psychometrically validated measures. According to Berg and his colleagues (Berg & Byrd, 2002; Berg et al., 2006), these investigations will be most beneficial if they involve standardized tasks, include multiple measures of performance, and examine strategy development. Since the CAS was utilized as the measure of EF, the current investigation expands upon past strategy research—most of which has used memory tasks—and also improves upon this research by meeting Berg’s recommendations.

The current investigation raises important issues on strategy development. It suggests that strategy use is complex and that a strategy’s effectiveness rests in the context of task demands and individual differences. For example, simply scanning may be an effective strategy in situations where working memory demands are low or for children with high working memory capacities. This latter point suggests that individual differences in cognitive processing should also be considered in these types of investigations.

The specific study of EF tasks is also important for another reason. These sorts of tasks require cognitive processes critical to the execution of goal-oriented behavior, processes such as planning, inhibition, and working memory. These very same processes are also recruited during complex problem-solving tasks that children routinely encounter in the classroom. It is reasonable, then, that inferences can be made as to how children behave strategically in classroom situations from the investigations of their strategic behavior on measure of EF. Future research should employ the CAS as such a measure of EF. It is both theoretically based and empirically supported. The Planning scale, in particular, has been connected to academic achievement (Naglieri & Rojahn, 2004). It stands to reason that valuable information—
information that may be directly applicable to the classroom—can be garnered from the investigation of strategic behavior on the CAS.
REFERENCES


Appendix A

Sample from Matching Numbers Task

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Appendix B

Sample from Planned Codes Item 1 Task
Appendix C

Sample from Planned Connections Task

Item 8