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CONTRIBUTIONS OF RESPONSE SET AND SEMANTIC RELATEDNESS TO CROSS-MODAL STROOP-LIKE PICTURE-WORD INTERFERENCE IN CHILDREN AND ADULTS

by

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Abstract

Contributions of Response Set and Semantic Relatedness to Cross-modal Stroop-like Picture-Word Interference in Children and Adults

by

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Resistance to interference from irrelevant auditory stimuli undergoes developmental changes throughout childhood. To determine whether semantic processes or executive demands such as selective attention, working memory and inhibition account for age-related changes in performance on an auditory-visual cross-modal Stroop and a Stroop-like picture-word interference task, children (3- to 12-year-olds) and adults named color blocks (Experiment 1) and pictures (Experiments 2 - 4) while listening to auditory distractors varying in terms of semantic relatedness to the visual stimuli, stimulus asynchrony (0 ms vs. -500 ms offset) and response set membership. Findings, in Experiment 1, that the cross-modal Stroop effect occurred in young children even when the auditory distractor was presented 500 ms in advance of the color patch support the hypothesis that young children have difficulty resisting interference and inhibiting the distracting stimuli. This inhibition account posits that the irrelevant word enters a phonological buffer and is injurious to color and picture naming if the participant is unable to suppress its representation in time. However, because the color-word distractors named colors which were a part of the response set in Experiment 1 (i.e., the color patches), it could not be determined if the interference effect was due to the semantic relatedness of the auditory distractors to the target colors or to their being members of the same response set. Therefore, in Experiments 2 and 3, using animal and clothing pictures, response set membership varied. In Experiments 2 and 3, the interference effect observed in children, but not adults, depended on the auditory distractors' status as members of the response set and was not associated with semantic relatedness to the visual stimuli. In Experiment 4, with semantically unrelated pictures, adults, but not children, showed greater interference on trials with auditory distractors in the response set. These results indicate that, contrary to results previously reported in the literature, picture-word interference is not exclusively semantically based (Jerger, Martin & Damian, 2002), and that age-related changes observed in the cross-modal Stroop and Stroop-like picture-word interference task involve inhibition of the auditory distractors and the establishment of a response set in working memory.

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Chapter 1: Introduction

The environment is filled with information that individuals must learn to process selectively. The ability to selectively attend to our environment prevents information from overwhelming the human processing system. In a noisy, distracting world, selective attention, inhibition and working memory play an important role in task performance, problem-solving, and learning. They allow one to process and respond judiciously to relevant information while ignoring irrelevant information. The cognitive processes underlying these abilities are often studied under the rubric of executive functioning.

Executive functions are an inexact but important construct that generally refer to the psychological processes involved in the conscious control of thought and action. They involve selective attention, working memory, inhibition, mental flexibility, abstract reasoning, temporal knowledge/ordering, social discourse, planning, problem solving, rule use, semantic associations, concept formation, hypothesis testing, shifting sets, and cognitive control (Becker, Isaac, & Hynd, 1987; Espy, 1997; Gnys & Willis, 1991; Hughes, 1998; Levin et al., 1991; Passler, Isaac, & Hynd, 1985; Robin & Holyoak, 1998; Welsh, Pennington, & Groisser 1991). Although executive functions have long been studied from a neuropsychological perspective, with researchers seeking to map function onto neurological structures, they are now the focus of intensive research from a variety of other perspectives, including the perspectives of developmental psychology and developmental psychopathology. Developmental research on executive functions has revealed that: (a) specific executive functions, such as rudimentary working memory, selective attention and inhibitory control, first emerge early in development, probably around the end of the first year of life (Bell & Fox, 1992; Diamond, 1985; 1988;

Diamond & Goldman-Rakic, 1989), (b) certain aspects of executive functions (e.g., ability to switch sets, inhibitory control) develop across a wide age range with important changes occurring between about two and seven years of age, with adult-level performance on many standard tests of executive functions (e.g., the Wisconsin Card Sorting Task) being reached at about 12 years of age, and performance on some measures (e.g., the Stroop task) continuing to change into adulthood (Chelune and Baer, 1986; Gerstadt, Hong, & Diamond, 1994, Golden, 1981; Luria, 1973; Zelazo, Frye, & Rapus, 1996; Zelazo, Reznick, & Spinazzola, 1998) and (c) failures of executive functions occur in different situations at different ages (Becker, Isaac, & Hynd, 1987; Espy, 1997; Frye, Zelazo, & Burack, 1998; Gnys & Willis, 1991; Hughes, 1998; Levin et al., 1991; Passler, Isaac, & Hynd, 1985; Welsh, Pennington, & Groisser 1991).

Definitional Issues

Historically, the construct of executive functions was derived from analysis of the consequences of damage to the prefrontal cortex (PFC). These consequences are numerous, diverse, and often described as a list of partially overlapping deficits. Wise, Murray, & Gerfen (1996, p. 325) provided one such list:

> "Lesions of PF in humans yield a constellation of neuropsychological deficits that have been described variously as difficulties with planning, concept formation, abstract thinking, decision making, cognitive flexibility, use of feedback, temporal ordering of events, fluid or general intelligence, and monitoring one's own actions."

The construct of executive functions is intended to capture the psychological abilities whose impairment is presumed to underlie these manifest deficits; but again, researchers often rely on what amounts to a list: the ability to plan, the ability to form concepts, the ability to translate knowledge, and, amongst others, the ability to integrate isolated details (Shute & Huertas, 1990). After reviewing several such lists, Tranel, Anderson, and Benton (1994, p. 130) attempted "to distil a fairly cohesive notion of what is meant by the term executive functions," and suggested that they correspond to the following: planning, decision-making, judgment, and self-perception.

Luria's (1973) approach to neurological systems suggests a way to capture the diversity of the cognitive abilities attributed to executive functions that goes beyond a simple listing. For Luria, PFC and other neurological systems consist of interactive functional systems that involve the integration of subsystems. Subsystems have specific roles to play, but cannot be considered outside of the larger systems of which they are a part. Functions are essentially behavioral constructs defined in terms of their outcome--what they accomplish. In the case of executive functions, according to Zelazo, Carter, Reznick, & Frye (1997), the task of characterizing such complex executive functions is a matter of describing its hierarchical structure, characterizing its subfunctions, and organizing these subfunctions around their constant common outcome.

For example, consider the Wisconsin Card Sorting Test (WCST; Grant & Berg, 1948), widely regarded as "the prototypical executive function task in neuropsychology" (Pennington & Ozonoff, 1996, p. 55). The WCST taps numerous executive functions, and, as a result, the origins of errors on this task are difficult to determine (e.g., see Delis, Squire, Bihrle, & Massman, 1992). To perform correctly on the WCST, one must first construct a representation of the problem space, which includes identifying the relevant dimensions. Then, one must choose a promising plan--for example, sorting according to shape. After selecting a plan, one must (a) keep the plan in mind long enough for it to guide one's thought or action, and (b) actually carry out the prescribed behavior. Keeping a plan in mind to guide behavior is referred to as intending; translating a plan into action is rule use. Finally, after acting, one must evaluate one's behavior, which includes both error detection and error correction.

Most developmental research on executive functions has focused on global neuropsychological tests that are either taken directly from the adult literature or adapted from adult tasks (e.g., Becker, Isaac & Hynd, 1987; Passler, Isaac & Hynd, 1985; Welsh, Pennington & Grossier, 1991). For example, Chelune and Baer (1986) documented a linear increase in performance on the WCST between the ages of 6 and 10 years, with 6-year-olds performing at the level of patients with PFC damage and 10-year-olds performing like healthy adults. This pattern was obtained for the three measures assessed: number of perseverative errors, number of categories achieved, and failures to maintain set. Several other studies (e.g., Levin et al., 1991; Welsh, Pennington, & Grossier, 1991) also used the WCST with typically developing children (in comparison with clinical samples), and these studies generally replicated Chelune and Baer's (1986) results. Using comprehensive neuropsychological batteries, Passler, Isaac and Hynd (1985) and Becker, Isaac, and Hynd (1987) tested children between the ages of six and twelve on tests of verbal and nonverbal behavior such as conflict tasks and found a step-wise developmental progression. Welsh, Pennington and Grossier (1991) investigated children's performance on tests of executive function using tasks sensitive to frontal lobe dysfunction in adults, but also included preschoolers to further investigate the development of executive skills. They demonstrated that with appropriate measures (e.g., F-A-S task, in which participants have to name objects beginning with the letters "F," "A," and "S" in addition to objects such as fruit or animals in a 45 second interval), rudimentary forms of prefrontal skills, such as selective attention, planning and inhibition, were exhibited by young children.

A basic assumption of all these studies is that the tasks used to measure executive function in adults measure the same abilities in children; but basing assessment of children on adopted adult measures must be made with caution (Gnys & Willis, 1991). However, these studies do enable researchers to identify factors and cognitive processes (e.g., inhibition, selective attention and working memory) important to the concept of executive functions. Note that the same tasks are often clustered with different tasks, and characterized by different labels. For example, the WCST is considered part of a "Perseveration/Disinhibition" factor by Levin et al. (1991) and part of a "Set Shifting or Cognitive Flexibility" factor by Pennington (1997). In the absence of a thorough understanding of underlying cognitive processes, it is unclear whether this approach can tell us anything at all about the structure of executive functions. For example, does cognitive flexibility rely on inhibitory control or is inhibition an outgrowth of flexibility? It is also impossible to determine the extent to which correlations among tasks are due to shared method variance, or influenced by differential sensitivity to individual differences at different ages. Nonetheless, this approach can provide an empirical characterization of correlations among tasks, as opposed to processes, and it can be used to generate hypotheses about executive functions and its components, such as inhibition, working memory, and selective attention that can then be tested experimentally.

Due to the fact that the construct of executive functions encompasses many cognitive processes and skills, it is unreasonable to examine each within the scope of this dissertation. In addition, most researchers would agree that no one task could possibly examine all executive functions. Thus, there is a need to further dissect and explore the cognitive processes often referred to as "executive functions" that will be discussed throughout this paper. In a distracting world, we are regularly confronted with situations in which we have to resolve conflict in order to behave appropriately. In these situations, we utilize the cognitive processes of selective attention, working memory, and inhibition. Selective attention is the ability to focus on one particular aspect of a stimulus or situation while defocusing other aspects of the same stimulus/situation (Bedi, Halperin, & Sharma, 1994). It is the ability to deemphasize or ignore stimuli while highlighting other more salient stimuli. This allows for concentrated focus of attentional systems on the salient information for comprehension or problem solving. Working memory (Baddeley, 1986) holds recently activated information in long term memory as it moves the activated elements in and out of the brief term storage of short term memory. Thus, the information can be actively held in memory and worked on or manipulated for comprehension or problem solving. Another important cognitive construct involves 'attentional inhibition' (Zacks, Radvansky & Hasher, 1996) or what has also been referred to as 'resistance to interference' (Wilson & Kipp, 1998). Zacks et al. have defined attentional inhibition as the suppression of extraneous information so that it does not enter working memory. In turn, 'resistance to interference' is defined as the ability to control interference from multiple stimuli in the environment that are trying to enter working memory (Wilson & Kipp, 1998). Throughout the literature, the terms attentional inhibition and resistance to interference have, at times, been used synonymously. Each concept describes a cognitive process in which information is inhibited at the level of encoding.

Many early efforts to explain age-related changes in executive function relied on the construct of inhibition or suppression (e.g., Luria, 1966), and this approach has remained popular (e.g., Carlson, Moses & Hix, 1998; Dempster, 1992; 1993). Conceptualizing executive function as inhibitory control appeals because failures of executive function are often manifested as perseverative errors. Perseveration implies that behavior is emitted that should have been inhibited. Therefore, perseveration seems to implicate inhibition by definition. Infants often demonstrate a lack of inhibition by perseverating, repeating prepotent or habitual behaviors when they no longer make sense. For example, in the A-not-B task, an object is conspicuously hidden at one location, location A, and an infant is allowed to retrieve it. A delay of 0 to 10 seconds is then imposed. After the delay, the object is hidden at another location, location B, and the infant is allowed to search for it. Seven and one-half to nine-month-old infants often persist in searching at location A (the A-not-B error). These infants are able to find the object correctly at location A, but when the object is moved to location B, they perseverate and reach to location A(Diamond, 1985; Piaget, 1954). Infants will even perseverate when objects are fully visible in front of them. For example, when faced with two towels to pull—one with a distant toy on it and one with a toy behind it—infants will choose the towel with the toy on it. However, if the towels are switched so that the towel that was to the infants' left (e.g., with the toy on it) is now to the infants' right, infants perseverate, continuing to pull the towel on the same side as before though it does not yield the toy (Aguiar & Baillargeon, 2000). Performance on the A-not-B and related tasks continues to improve with age so that by 12 months, infants can find the hidden object correctly in both A and B, with delays as long as 10 seconds. Success on this task has been linked to both memory and the ability to inhibit a prepotent response (Diamond & Goldman-Rakic, 1986).

These perseverative behaviors are not limited to infancy; both younger and older children also demonstrate them quite reliably. One commonly used task that assesses perseveration in addition to selective attention and inhibition is the dimensional change card sort (DCCS) task of Zelazo, Frye, and colleagues (e.g., Frye, Zelazo, & Palfai, 1995; Zelazo & Reznick, 1991; Zelazo et al., 1996). In the DCCS, preschoolers are presented with bi-dimensional cards (e.g., with varying shapes and colors) to sort into piles according to explicitly stated sets of rules. Children are shown two model cards (e.g., a yellow flower and a green shoe) and are given sorting cards that differ from the model cards in one dimension (e.g., green flowers and yellow shoes). Children are asked to sort cards according to specific rules about a particular dimension. For example, when playing the "shape" game, children are instructed to place cards with flowers next to the yellow flower and cards with shoes next to the green shoe because they are the same shape. After a series of trials, children are told that they are to play a new game, the "color" game, and will no longer be playing the "shape" game. In the "color" game, they are instructed to place yellow cards next to the yellow flower and green cards next to the green shoe because they are the same color. In the DCCS, preschoolers can readily be trained to sort according to both dimensions, but they have difficulty switching from one to the other. Three-year-olds tend to respond perseveratively, following the first set of rules rather than switching to the new set, suggesting that either their original response pattern interfered with comprehension of the post-switch rules or that they could not inhibit the first set of rules. Zelazo et al. (1996) found that even when they sorted perseveratively, children often could express knowledge of the post-switch rules when asked, for example "Where do the yellow cards go in the color game?" This demonstrates a dissociation between their awareness of the rules and ability to execute them. Six-year-olds show the same pattern when asked to judge a speaker's feelings from utterances with conflicting emotional cues (e.g., a sentence with happy content—"I won a prize" spoken in a sad tone of voice). When instructed to judge the speaker's feelings from her tone of voice, many 6-year-olds perseverate, continuing to base their judgments on content (Morton & Trehub, 2001).

In all of these cases, infants and children appear quite sensible in their initial behaviors—searching in the correct location for the hidden toy, pulling the appropriate towel, sorting cards and judging utterances according to experimenter instructions. However, they appear quite inflexible in their subsequent behaviors, perseverating with their previous responses when they no longer make sense—searching in the incorrect location for the hidden toy (making the "A-not-B" error), pulling the inappropriate towel, sorting cards and judging utterances without apparent regard for the experimenter's current instructions.

In contrast to inhibition accounts, a number of researchers have attributed age-related changes in executive functions to changes in working memory capacity (e.g., Case, 1972; 1985; Roberts & Pennington, 1996). This approach probably has its origin in early work by Jacobson (1936), who demonstrated that PFC-lesioned monkeys showed impairments on a version of Hunter's (1917) delayed-response task. During this task, an object is placed under one of two or more identical stimuli (e.g., cups). A delay is then imposed during which the stimuli are hidden by an opaque screen. After the delay, the screen is raised and the infant or child is allowed to obtain the stimulus. The primary dependent measure is the number of correct responses. Consistent with this approach, developmental studies using delayed-response tasks (e.g., Hunter, 1917), span tasks (e.g., the counting span task; Case, 1985), and Self-Ordered Pointing (Archibald & Kerns, 1999) have shown that there are regular age-related increases in the amount of delay time and accuracy of the responses throughout childhood (see Gathercole, 1998).

Conflict tasks have also been utilized by researchers to separate the processes involved in executive functions. To solve such tasks, one must be able to suppress or override competing stimuli (Allport, 1987; Cohen & Servan-Schreiber, 1992; Kahneman, Treisman, & Burkell, 1983). This construct has been refined and incorporated into a number of theories of attention and memory and referred to in a number of ways (e.g., "central executive", "attentional bias"; Baddeley, 1986; Cohen, & Servan-Schreiber, 1992; Desimone & Duncan, 1995; Shallice, 1988). Each of these terms suggests a mechanism that directs or guides appropriate attentional responses or actions (Miller, & Cohen, 2001). For example, Shallice (1998) proposed a "supervisory attention system" as a system for inhibiting or replacing routine, reflexive behaviors and thoughts with more appropriate behaviors and thoughts. Desimone and Duncan (1995) describe top-down biasing signals as important in attending to relevant information by virtue of mutual inhibition or suppression of irrelevant information. A common theme that has emerged from this work is that a primary function of cognitive control is to reduce conflict in processing of information (Baddeley, 1986; Cohen, & Servan-Schreiber, 1992; Desimone & Duncan, 1995; Shallice, 1988). Thus, one critical component of cognitive control is the ability to suppress or override competing mental and behavioral responses. Norman and Shallice (1986) thought that a high level executive attention network is needed to perform such tasks as resolving conflict between competing responses, correcting errors, planning, and developing novel ideas.

Anatomical Issues

Although executive functions can be studied in purely functional terms, consideration of certain neurological systems provides an important source of constraints on purely functional models of executive functions. It should be noted, however, that although executive functions have traditionally been linked to PFC, they clearly depend on the integrity of other brain regions as well (e.g., the basal ganglia and limbic system). Indeed, although the terms are often used interchangeably, executive functions are not synonymous with PFC function: whereas some patients with PFC damage do not show impairments in executive function (e.g., Shallice & Burgess, 1991), some patients with damage outside of PFC do (e.g., Anderson, Damasio, Jones, & Tranel, 1991). More generally, despite current interest in modular processes in the brain, which may (but need not) encourage researchers to adopt a localizational approach, there are good reasons to reject this approach in the case of complex functions such as executive functions (Goldberg, 1995; Jonides & Nee, 2004; Luria, 1966; Stuss & Benson, 1986).

The prefrontal cortex is the region of cerebral cortex anterior to premotor cortex and the supplementary motor area. In humans, this region comprises between a quarter and a third of the cortex (Fuster, 1989; 1997). In general, the patterns of reciprocal connectivity between PFC and other, more subcortical and posterior brain regions make PFC uniquely suited for the integration (or association) of information and the regulation of emotion, thought, and action.

Over the years, different investigators have provided very different accounts of PFC function, emphasizing the consequences of damage to different parts of PFC. For example, the prefrontal cortex has been found to play a critical role in reducing perseveration and in supporting flexible behavior (Miller and Cohen; 2001; Miyake & Shad, 1999; O'Reilly, Braver, & Cohen, 1999; Roberts & Pennington, 1996; Stuss & Benson, 1984). Although PFC comprises several distinct areas, an extensive review of all PFC regions is beyond the scope of this paper. Therefore, this review is concerned in particular with the dorsolateral portion of the prefrontal cortex (DLPFC), since it is one area that historically has been closely associated with the functions addressed here (Luria, 1966).

Neuroimaging studies of adults have been fairly consistent in showing activity in midline frontal areas during tasks that involve conflict (Carter, Braver, Barch, Botvinick, Noll & Cohen, 1998), error (Bush, Whalen, Rosen, Jenike, McInereny, Rauch, 1998), or novel ideas (Posner & Raichle, 1994). A more ventral area of the anterior cingulate and orbito-frontal cortex is active when the task involves emotions, and a more dorsal area is involved in more purely cognitive tasks, such as is required with the Stroop task (Bush, Luu, & Posner, 2000; MacDonald, Cohen, Stenger, Carter, 2000). Although both lateral and medial frontal areas are frequently active together on conflict tasks (Duncan & Owen, 2000), an event related MRI study has dissociated the two (MacDonald et al., 2000). MacDonald and colleagues (2000) demonstrated that the lateral area was active in holding in mind the instruction provided by a cue, while the medial area was active when conflict about the target was present.

During development, the prefrontal cortex is the last to mature, as indicated by its late myelination, and the DLPFC expands more than orbital or medial areas (Ariens Kappers, Huber, & Crosby, 1960). The correlation between late ontogenetic development of DLPFC and the evolution of increasingly complex executive function abilities hints at a possible role of DLPFC in advanced cognitive functions.

Developmental Issues

An early, influential idea held that the PFC was not functional during early childhood. The origin of this idea can perhaps be traced to Luria (1973, p. 87), who estimated that PFC did not "become finally prepared for action" until about 4 to7 years of age. Golden (1981) took this suggestion a step further, proposing that DLPFC was not functional at all until about 12 to 15 years of age, and noted that DLPFC development was often incomplete until 24 years of age.

Earlier findings that DLPFC is not functional during childhood have now been convincingly refuted: Behavioral studies of non-human animals (e.g., Diamond & Goldman-Rakic, 1986; 1989; Goldman-Rakic, 1987), imaging data (e.g., Casey, Thomas et al., 2000), and case studies of children with brain lesions (Eslinger, Biddle, & Grattan, 1997) and closed head injuries (Scheibel & Levin, 1997) all indicate some DLPFC function as early as 12 months of age. For example, as noted earlier, Diamond and Goldman-Rakic (1989) demonstrated the early functioning of the DLPFC in one-year-old infants using the A-not-B task. In addition, these investigations showed that in monkeys, performance on the A-not-B task depends on intact DLPFC. Their work suggests that 12-

month-old human infants who succeed on the task rely on DLPFC and that the failure of 7 ½ - 9 month infants' to succeed in the task is attributable to inhibitory inefficiency and immaturity of the DLPFC. Thus, by 12-months of age, inhibitory mechanisms are beginning to emerge.

Further support for the suggestion that inhibitory functions emerge early in development comes from Bell and Fox (1992), who measured electroencephalographic (EEG) activity longitudinally in infants between 7 and 12 months of age, and found a correlation between performance on A-not-B (being able to tolerate longer delays) with increased age on the one hand, and frontal EEG power and frontal/parietal EEG coherence, on the other. As a final example, contrary to the notion that childhood lesions of DLPFC are symptomless ("silent"), several studies indicate that DLPFC damage does indeed produce symptoms in children, whether assessed retrospectively or by direct testing during childhood (e.g., Eslinger et al., 1997). Children with early DLPFC damage in Eslinger et al.'s (1997) study performed more poorly than normal, age-matched controls on tasks such as a modified Stroop task.

Casey and colleagues have published a number of normative pediatric fMRI studies examining prefrontal cortical activity in children during tasks involving the suppression of interfering information (Casey, Cohen et al., 1995; Casey, Trainor, Giedd, et al., 1997; Casey, Trainor, Orendi, et al., 1997; Thomas et al., 1999). Casey, Trainor, Orendi, et al. (1997) examined the development of inhibitory control using a go/no-go task with fMRI to examine prefrontal activity in children aged 7 to 11 years and adults. Although several regions in prefrontal cortex were active, only the region of the orbitofrontal and anterior cingulate cortices correlated with behavioral performance.

Further, they showed that activation of dorsolateral prefrontal cortex discriminated children from adults with an overall greater volume of activity in this region (middle and superior frontal gyri) in children. One explanation for this finding is that the children had greater difficulty with the task (twice as many errors overall) than adults and thus were recruiting more prefrontal cortex.

At least three other studies have been published on children between the ages of 8 and 12 using working memory tasks that involve the representation of verbal or spatial information against interference (Casey, Cohen et al.,1995; Nelson et al., 2000; Thomas et al., 1999). All three studies used versions of the n-back task in which the children had to remember the identity or location of a stimulus either 1, 2, or 3 trials back. The interference in this type of task comes from the information in intervening trials. Only the Thomas et al. (1999) study included adults. In that study, even though attempts were made to equate behavioral performance between children and adults by using different memory loads (1-back for children versus 2-back for adults), children consistently performed worse on the task. Across all three studies, dorsolateral regions of prefrontal cortex were the most reliably activated. These results may be of relevance to some of Miller's findings (e.g., Miller, 1999; Asaad, Rainer & Miller, 2000) implicating the flexibility of dorsolateral prefrontal cortex in representing different types of information in nonhuman primates depending on the context of the task.

At the same time, there is some support for Golden's (1981) suggestion regarding silent lesions of DLPFC. Eslinger et al. (1997) reviewed several case studies of early DLPFC damage and found that the immediate consequences of such lesions in children are often less noticeable than are the consequences of comparable lesions in adults.

Moreover, behavioral impairments may appear later in development, when late-developing functions would normally emerge (Kolb & Fantie, 1997), although it is unclear to what extent these impairments are secondary consequences of a disrupted epigenetic process or a direct consequence of the lesion. For example, Goldman (1974) found that when rhesus monkeys received frontal lobe lesions in infancy, they could solve frontal-lobe sensitive tasks as juveniles, but they lost this ability as they matured into adults. The fact that identical lesions can also have different consequences at different ages (e.g., Kolb et al., 1998; Stiles, 1998) underscores the need for a developmental approach to the problem of mapping function to neurological structure.

In sum, the available data from neuroimaging, behavioral and neuroanatonical studies with both human and non-human primates, suggest protracted development of the prefrontal cortex which seems to parallel the course of development of working memory, selective attention, and inhibition. Indeed, it is clear that both DLPFC structure and function follow an extremely protracted developmental course as evidenced by (but are not limited to) the following: (a) head circumference_(e.g., Epstein, 1986), which shows peak growth rates at 7, 12, and 15 years; (b) myelination (e.g., Yakovlev & Lecours, 1967), which starts postnatally in DLPFC and continues into adulthood; (c) interhemispheric connectivity, which shows peak growth rates between 3 and 6 years, as indicated by structural imaging of anterior regions of the corpus callosum (Thompson, Giedd, Woods, et al., 2000); (d) synaptic density (in layer III of the middle frontal gyrus), which reaches a peak at about 1 year of age that is considerably higher than the adult level, remains high until about age 7 years, and then declines until about age 16, when the adult level is finally attained (e.g., Huttenlocher,1990; 1997); and (e) metabolic and electrical activity (e.g., Chugani & Phelps, 1986; Thatcher, 1992), which show age-related changes in DLPFC that continue well into adolescence and are correlated with changes in performance on cognitive tasks.

Review of Related Literature

Early work by Piaget (1976) using the Tower of Hanoi task revealed poor performance among school-age children, and subsequent research focusing on planning has confirmed that performance on tower tasks follows a protracted developmental course. For example, Klahr and Robinson (1981) modified the original Tower of Hanoi by employing upside-down cans instead of disks, thereby inverting one of the arbitrary rules to “don’t put a smaller can on top of a larger one,” and embodying it as an inviolable task constraint. These investigators also required children simply to describe their plans. Using their modified version, Klahr and Robinson (1981) found that 4-year-olds typically did well on 2- and 3-move problems, whereas 5-year-olds usually did well on 4-move problems, and 6-year-olds did well on 6-move problems. Thus, clear age differences emerged in the length of the problems that children could solve. Analysis of children’s pass/fail patterns in different versions of the task indicates that there are corresponding changes in problem analysis and depth of search (i.e., the number of anticipated moves that must be remembered). More recent work employing the Tower of London has extended these results. For example, Luciana and Nelson (1998) found that on 4- and 5-move problems, even 8-year-old children (the oldest group of children included) performed significantly worse than adults.

Following Luria’s work on children’s rule use (see Zelazo & Jacques, 1996, for review), Zelazo and Reznick (1991) investigated inhibitory control and selective attention in 2.5- to 3-year-olds using a card sort in which children were presented with a pair of ad hoc rules (e.g., “If it’s something found inside the house, then put it here. If it’s something found outside the house, then put it there”) and then asked them to use these rules to separate 10 test cards. Two-and-a-half-year-olds failed to use the rules despite professing knowledge about the cards, whereas 3-year-olds performed well. Subsequent research (Zelazo, Reznick, & Piñon,1995) found that 2.5-year-olds had difficulty even when they were provided with considerable aids and incentives. Analyses of children’s errors revealed a tendency to repeat responses: when they erred, it usually involved putting a card into the box in which they had put a card on the previous trial.

Preschoolers often exhibit an inability to follow verbal instructions. For instance, when told to tap once if an adult taps twice, and twice if an adult taps once, Diamond and Taylor (1996) found that three- and four-year-olds were often unable to follow the rules over an extended series of trials. Their failure occurred in spite of the fact that they demonstrated knowledge of the rules in a pretest. Rather than doing the opposite of what the adult did, preschoolers tended to imitate the adult’s actions, complied with only one of the two rules, or tapped many times regardless of what the adult did. Diamond and Taylor suggested that young children cannot keep two rules in mind and simultaneously inhibit one rule in order to execute the other. Preschoolers may lack an ability to exercise inhibitory control, shift attention, or to selectively attend to the most relevant features of the game.

As mentioned earlier, three- to five-year-olds have been assessed using the Dimensional Change Card Sort, which puts two pairs of rules into opposition. Subsequent studies have revealed that these age-related changes on the Dimensional Change Card

Sort are robust and occur in a wide range of situations with a wide variety of task materials (e.g., Bialystok, 1999; Brooks, Hanauer, Podawska, & Rosen, 2003; Carlson & Moses, 2001; Diamond, Kirkham & Amso, 2002; Kirkham, Cruess, & Diamond, 2003; Munakata & Yerys, 2001). Zelazo and Frye (1997) have interpreted these results as evidence that 3-year-olds have difficulty integrating incompatible pairs of rules into a single system of rules via a higher order rule. Support for this interpretation comes from the finding that 3-year-olds demonstrate knowledge of the post-switch rules, even though they fail to use them (Zelazo et al., 1996), and show predictable patterns of success and failure across different versions of the task (see Zelazo & Frye, 1997; 1998, for a review).

Diamond and her colleagues (Diamond & Taylor, 1996; Gerstadt et al., 1994) have observed that preschoolers often have difficulty following 'opposite' rules (e.g., tap once if I tap twice, tap twice if I tap once; say "day" to a card with a moon and "night" to a card with a sun) when tested over an extended series of trials. They proposed that children's errors are a consequence of a lack of inhibitory control coupled with the demands of keeping multiple rules in mind. Therefore, reducing memory and/or inhibitory demands may aid young children in performing executive function tasks. Recent work by Diamond et al. (2002) suggests that another factor may be important as well, that is, the amount of time taken to formulate one's response. Diamond et al. (2002) played a novel version of the day-night Stroop task of Gerstadt et al. (1994) in which the experimenter sang a "ditty" after presenting each test card, to prevent children from responding to the card as quickly as in the standard condition. The ditty forced children to take more time to formulate their answers and led to less impulsive responding, which greatly improved their performance. Taken together, this set of findings supports the view that both memory for the rules and inhibition of prepotent responses affects children's ability to implement the rules.

Diamond has proposed that preschoolers experience 'attentional inertia' (e.g., Kirkham, Cruess & Diamond, 2003) in that they have difficulty keeping more than one thing in mind and therefore tend to fixate on only one aspect of a multi-dimensional stimulus. For instance, in the DCCS, when asked to sort by a second criterion during the post-switch phase, preschoolers have difficulty inhibiting their focus on the first sorting criterion (e.g. color) to switch to the new criterion (e.g., shape). Diamond has argued that young children are not capable of disengaging from the first set of rules that are no longer relevant, to adopt to the new set of rules. To test the 'attentional inertia' hypothesis, Kirkham et al. (2003) administered variations of the DCCS. One variation involved a labeling condition where the child, not the experimenter, labeled the card. Most three-year-olds were successful in this condition, presumably because the labeling helped draw their attention to the card's currently relevant dimension. In a face-up condition, Kirkham et al. allowed the cards from the previous preswitch trials to remain in view. This manipulation led to a greater numbers of perseverative errors than the standard DCCS task, presumably because it kept the children focused on the no-longer-relevant dimension. These findings led Kirkham et al. to conclude that the problem for children does not involve representing incompatible sets of rules, but in redirecting their attention when looking at a multi-dimensional stimulus.

The development of the ability to override inappropriate responses appears to have a protracted course of development. In children between the ages of 4 to 11years, cognitive control can be measured by negative priming on Stroop-like tasks, go/no-go tasks, incidental learning and directed forgetting (Harnishfeger, 1991; 1997; Luria, 1961; Schiff, & Knopf, 1985; Tipper, Bourque, Anderson, & Brehaut, 1989). In all cases, children, depending on age and complexity of the task, have a more difficult time ignoring or inhibiting irrelevant salient information or prepotent responses in favor of the relevant items or responses. For example, Reed, Pein, & Rothbart (1984) asked preschoolers to respond to instructions by one puppet ("go"), but not by another ("no go"). They found that the ability to inhibit a response showed a marked developmental progression between 39 (22% correct trials) and 47 months (76% correct trials). Additional research by Posner and colleagues also demonstrated that children used physical restraints (e.g., holding their hands or placing them between their knees) to help inhibit their behavior (Posner & Badgaiyan, 1998; Posner, 2001). Similarly, Enns and colleagues (e.g., Enns, Brodeur, & Trick, 1998; Enns & Akhtar, 1989; Enns & Cameron, 1987) have demonstrated comparable developmental changes in attention tasks that include distracting peripheral information as in the case of the flanker task of Eriksen & Eriksen (1974). These studies show a developmental trend in the improved ability to ignore irrelevant flankers over the ages of 4 to 12 years that appears to reach adult levels by age 12, as indexed by mean reaction times and accuracy rates. These age-related differences are not observed on these tasks in the absence of interfering information (Enns, Brodeur, & Trick, 1998).

The Stroop and Stroop-like tasks

The Stroop task (Stroop, 1935) is perhaps the most widely used measure of selective attention and inhibitory control in adults (MacLeod, 1991) and is associated with PFC functioning (from adult neuroimaging studies showing activity in midline frontal areas, e.g., Carter, Braver, Barch, Botvinick, Noll & Cohen, 1998; MacLeod & MacDonald, 2000). In the Stroop task, participants are instructed to identify the print color of a color word (e.g., say 'green' when shown the word *blue* printed in green). This requires participants to inhibit reading the color word, which is difficult because, according to MacLeod (1991), reading tends to be automatized. Hence there is a prepotent tendency to read the word itself rather than name its color. A typical finding with adults in the Stroop task (e.g., Knopler, 1996) is that interference increases (as measured by reaction times) as the semantic relationship between the to-be-ignored word and the correct response increases. This has lead researchers (e.g., Luo, 1999) to argue that semantic competition, as opposed to response competition, is the main source of Stroop interference. Therefore, one possibility is that the color words interfere with identification of print colors simply because the words are semantically related to the correct responses.

On the other hand, in the original Stroop task, the colors *red, blue, green* and *yellow* were used both as print colors and color word stimuli and thus, also made up the response set of correct responses. These four color words became the response set for correct answers, and thus, they were primed as responses relative to other words. Klein (1964) tested the response set hypothesis using color words within the response set (e.g., *green*) and color words that were not part of the response set (e.g., *orange*). He found much greater interference when the written word was a member of the response set as compared to when it was not. This early study demonstrated that response set interference is an important component of the Stroop effect.

To study the development of selective attention and inhibition, the Stroop task has been adapted for use with children in various ways. This work has generated debate as to whether the interference effect shows age-related stability versus developmental change. Comalli, Wapner and Werner (1962) were the first to use the Stroop task with literate school aged children and adolescents and found significant age differences in the magnitude of the interference effect, with the largest effect occurring with the youngest children (i.e., 7-year-olds) and decreasing throughout childhood until the age of 17 to 19 years. In contrast, in related picture-word interference studies where participants were instructed to name pictures on which printed words were superimposed, Rosinski, Golinkoff, and Kukish (1975) and Rosinski (1977) found equivalent semantic interference effects in elementary school children and adults, suggesting continuity as opposed to age-related changes, in semantic processing. On the other hand, Ehri (1976) and Schiller (1966) found that children who were not yet proficient readers failed to show a semantic interference effect at all.

For the purpose of exploring earlier developments of selective attention, a number of researchers have created versions of the Stroop task that do not require reading, and can therefore be administered to very young children. For example, Jerger, Martin, and Pirozzolo (1988) adapted procedures of Green and Barber (1981, 1983) for a study of 3- to 6-year-olds, who were given the incongruous task of pressing a ‘Mommy’ button whenever a male voice was heard and a ‘Daddy’ button whenever a female voice was heard. As compared to both the congruent trials (i.e., hearing *mommy* spoken in a female voice) and neutral trials (i.e., hearing *ice cream* spoken in either voice), they found slower reaction times for incongruent trials (e.g., hearing *daddy* spoken in a female voice). In addition, the magnitude of the interference effect (i.e., the RT difference between incongruent and neutral conditions) decreased significantly between the ages of 3 and 4 years.

The debate concerning the relative contributions of semantic relatedness and response set membership to Stroop interference resurfaced in the developmental literature surrounding the ‘day-night’ Stroop task. In the original study, Gerstadt, Hong and Diamond (1994) created a novel ‘day-night’ Stroop task in which 3 1/2- to 7-year-old children were instructed to say ‘day’ to a black card with a white moon and ‘night’ to a white card with a yellow sun. In the control condition, children were told to say ‘day’ and ‘night’ to abstract geometric designs. Gerstadt et al. found a significant difference between the experimental and control conditions, with children’s ability to produce the correct non-matching response increasing with age. Taking the Gerstadt et al. study a step further, Diamond, Kirkham and Amso (2002) used several variations of the day-night Stroop task with 4-year-olds. Instead of saying ‘day’ to the black-moon card and ‘night’ to the white-sun card, children were told to say ‘pig’ to the moon and ‘dog’ to the sun. Although this task still required children to maintain two rules in working memory, Diamond et al. proposed that the ‘dog-pig’ condition would reduce the inhibitory demands of the task because the pictures and responses were not semantically related. Children’s better performance in the ‘dog-pig’ condition over the ‘day-night’ condition led Diamond et al. to conclude that young children have difficulty inhibiting a word that is semantically related to the target word. They hypothesized that activating the word *night* automatically activated the related word *day*, thus generating conflict.

Simpson and Riggs (2003) proposed an alternate explanation for children's differential performance on the 'day-night' and 'dog-pig' conditions of Diamond et al. (2002). In the 'day-night' condition, children's responses were, in fact, candidate names for the pictures of the sun and the moon, whereas in the 'dog-pig' condition, they were not. Simpson and Riggs hypothesized that response set interference, as opposed to semantic conflict, might be the source of children's difficulty. To test this hypothesis, they removed the confound of semantic-relatedness and response set by setting up four conditions: same response set, semantically-related (see red, say 'blue'; see blue, say 'red'); same response set, semantically-unrelated (see car, say 'book'; see book, say 'car'); different response set, semantically-related (see black, say 'yellow'; see white, say 'green'); and different response set, semantically-unrelated (see sun, say 'pig'; see moon, say 'dog'). Testing 4 to 11-year-olds, Simpson and Riggs (2003) found a significant effect of response set, and no effect of semantic-relatedness, demonstrating that it is very likely response set interference that accounted for children's poorer performance on the day-night Stroop task. Their data indicate that children differentially attended to the stimuli within the response set, but not to specific semantic features of the words.

The cross-modal Stroop task

The same confound of semantic relatedness and response set membership appeared in the work of Cowan and colleagues (Cowan and Barron, 1987; Cowan, 1989; Elliott, Cowan & Valle-Inclan, 1998) who designed a cross-modal Stroop analogue with colors presented in the visual modality and color and non-color words presented over headphones. They found significantly slower color naming reaction times in adults when colors were paired with color word auditory distractors (e.g., seeing purple and hearing *yellow*) as compared with non-color words (e.g., seeing purple and hearing *single*). Cowan and Barron (1987) argued that adults could not fully inhibit processing words in the auditory modality, and, therefore could not limit lexical processing to the visual modality. This claim, however, was challenged as Miles, Madden and Jones (1989) and Miles and Jones (1989) failed to replicate Cowan and Barron (1987)'s findings. Cowan (1989) claimed that the failed replications were due to methodological errors. In subsequent studies, Elliott et al. (1998) and Elliott and Cowan (2001) again demonstrated the cross-modal Stroop effect in adults.

In the Elliott et al. study, adult participants were asked to name patches of color as quickly as possible while ignoring semantically-related or unrelated auditory distractors. The related distractors were color names, all within the response set of the visual stimuli, but never congruent with the visual stimulus presented on a given trial (e.g., the word *red* was never paired with a red color patch). The unrelated distractors were adjectives (e.g., *dry, short, best*). Across trials participants named color patches that were presented without an auditory distractor ('*silent* condition'), with distractor onset preceding the color patch by 500 ms ('*-500 ms* condition'), or with distractor onset simultaneously with the appearance of the color patch ('*0 ms c*ondition'). Elliott et al. (1998) found greater interference with color than with non-color distractors (e.g., seeing a blue color patch and hearing *yellow* versus hearing *single*) only when the distractor occurred simultaneous with the color patch. They suggested that the lack of a Stroop-like effect with the word presented prior to the color patch was due to adults having sufficient time to suppress their representation of the distractor. Therefore, they claimed that the source of the cross-modal Stroop effect resided in inhibitory mechanisms, although they could not rule out other explanations, such as concurrent semantic processing, as the source of interference.

The debate over the existence of the cross-modal Stroop effect is of theoretical importance in constraining the role of working memory in language processing. According to the influential theory of Baddeley (1986, 1997), the phonological loop is a component of verbal working memory responsible for the temporary storage of sound patterns. Miles et al. (1989) argued that when verbal material is being maintained in the phonological loop, interference might occur if an item to be remembered is displaced by another item entering this temporary store. Interference in the phonological loop is most likely to occur if the phonological loop's capacity has been reached and the displacing item is phonologically similar (as opposed to semantically related) to the item to be remembered. Hence, Miles et al. did not expect there to be a cross-modal Stroop effect because first, the task does not require participants to maintain words in the phonological loop over any period of time, and second, on no trial, was the distractor phonologically related to target color name. Cowan and Barron (1987) argued for a broader view of the phonological loop as a temporary speech buffer where words to be spoken may be held prior to articulation. When there are multiple items in this temporary store, selection of the item most relevant to the task at hand must occur, and there may be competition among candidate items. In the cross-modal Stroop task, the auditory distractor automatically enters the temporary speech buffer as it is processed. Because it takes time to trace the origin of each item in the buffer in selecting the name of the color patch as the intended word to be produced, interference occurs in color naming. As the similarity of the words in the buffer increases (i.e., semantic-relatedness), the ease of selecting the correct word decreases, leading to greater interference with color word distractors than non-color word distractors.

In the Elliott et al. (1998) study, the timing of presentation of the color patch to be named and the auditory distractor was varied by presenting the distractor either simultaneous with or 500 ms prior to the presentation of the color. Exposure to a word 500 ms before presentation of a visual stimulus provides sufficient time to allow for complete processing of the word (Baddeley, 1986; Cowan & Saults, 1995). Thus, with the distractor presented 500 ms before the color patch, Elliott et al. (1998) predicted a cross-modal Stroop effect because the auditory representation of the word would still be active in working memory. Surprisingly, they found the predicted interference effect only with simultaneous presentation of the color patch and distractor. Elliott et al. (1998) considered two possible explanations: First, delaying the presentation of the color patch by 500 ms might provide participants with sufficient time to both process and suppress activation of the distractor. Alternatively, the cross-modal Stroop effect might stem from concurrent lexical access of the words presented in the auditory and visual modalities. This last hypothesis derives from a study by Schriefers, Meyer, and Levelt (1990) in which they found semantic interference in a cross-modal picture-word interference task. Schriefers et al. (1990) suggested that semantic interference stems from competition between the distractor and picture names occurring during the semantically-driven stage of lexical access called lemma[1] retrieval. Although Elliott et al. (1998) favored the former "suppression" or inhibition account as an explanation of the time course of the cross-modal Stroop effect, their data do not provide a basis for ruling out the alternative "concurrent processing" explanation.

Examination of the development of the cross-modal Stroop effect would help to resolve the controversies regarding the source and reliability of the interference effect because developmental differences in selective attention may affect the time course and magnitude of the effect. In addition, using pictures in a picture-word interference task, rather than solely colors as in the studies by Cowen and colleagues, would allow for further investigation of these questions related to response set membership versus semantic competition. No previous research has compared the extent to which young children, older children and adults are able to suppress processing of irrelevant spoken words when naming visually presented stimuli. There have been just a few studies using the cross-modal Stroop (e.g., Elliott & Cowan, 2001) and picture-word interference paradigms (e.g., Brooks & MacWhinney, 2000; Jerger, Lai, & Marchman, 2002a, 2002b; Jerger, Martin & Damian, 2002) with children and only one (Jerger, Martin & Damian, 2002) has explored semantic processes involved in picture naming. Typically in the picture-word interference paradigm used with adults (i.e., Cutting & Ferreira, 1999; Damian & Martin, 1999; Schriefers, Meyer, & Levelt, 1990), the target pictures have tended to be selected from different semantic categories, in contrast to Stroop-like tasks where all target stimuli are semantically related (e.g., colors, numbers). In addition, stimulus onset asyncrony (e.g., 0 ms or –500 ms) is usually kept constant, in contrast to cross-modal Stroop experiments (e.g., Elliot et al., 1998) where timing of the distractor varies within each block of trials. It is generally assumed (e.g., Damian & Martin, 1999; Jerger, Martin, & Damian, 2002; Schriefers, et al., 1990) that semantic competition between the visual and auditory stimuli at the stage of lemma[1] retrieval creates interference when participants are asked to name a picture that is semantically related to an auditory distractor. Jerger, Martin & Damian (2002) and Damian and Martin (1999) found statistically equivalent effects of semantic interference in children (i.e., 5 to 7-year-olds), adolescents (i.e., 12 to 14-year-olds), and adults, suggesting continuity in linguistic knowledge and a similar time course of semantic processing during lexical access. Both the adults in the Damian and Martin study (1999) and the children and adolescents in the Jerger, Martin and Damian study (2002) were slower at picture naming when target pictures and auditory distractors shared semantic features, with the interference effect peaking when the distractor onset was slightly (i.e., 150 ms) in advance of the picture (see also Schriefers et al., 1990).

Caramazza and Costa (2000) addressed the issue of response set membership in adults with respect to semantic interference in a purely visual picture-word interference task in which printed words were superimposed over pictures to be named. They found that the magnitude of the semantic interference effect did not vary as a function of whether the distractor words were members of the response set. To our knowledge, the issue of response set membership has not been addressed in experiments using the cross-modal Stroop or Stroop-like picture-word interference paradigm, nor has it been examined from a developmental perspective.

In sum, the existing literature is divided with respect to whether children show developmental change in performing Stroop-like selective attention tasks, and whether the ability to inhibit auditory distractors reflects semantic or response set competition. The present experiments were designed to explore this issue further. We predicted that, due to age differences in selective attention, working memory, and inhibition the pattern of stability in the semantic interference effect found in Jerger et al. (2002) and Martin and

Damian (1999) would disappear when semantically-related distractors in the response set are used. In addition, we predicted that we would observe a marked developmental progression in the magnitude and time course of the cross-modal Stroop effect of Elliott et al. (1998).

Chapter 2 - Experiment 1

In the present study, the development of the cross-modal Stroop effect in 4- to 11-year-old children and adults was examined. Given the inconsistency of reports of the effect, the basic procedures of Elliott et al. (1998, Experiment 1) were used to maximize the likelihood of replicating their results with adults and children. However, the timing of the auditory distractor relative to the picture was varied somewhat differently than in Elliott et al. (1998) to provide a stronger test of the inhibition versus concurrent processing explanations of the effect. There were two timing conditions: The first was an exact replication of the 0 ms (simultaneous) condition of Elliott et al. (1998) in which they found a reliable cross-modal Stroop effect in adults. However, because of age differences in processing speed (Kail, 1991; 1992) and auditory conduction rate (Swingley, Pinto, & Fernald, 1999), for the -500 ms condition, the interval between presentation of the auditory distractor and the color patch was lengthened to provide children with sufficient time to fully process the heard word prior to seeing the patch. That is, the stimulus asynchrony was increased to rule out, or at least reduce, the possibility of concurrent lexical access of the distractor and the color name even in the youngest participants. Thus, the color patch appeared 500 ms after the offset of the word, as opposed to 500 ms after the onset as in Elliott et al. (1998). This manipulation of stimulus asynchrony allows us to evaluate the competing accounts of the cross-modal effect proposed by Elliott et al. (1998).

If the concurrent lexical processing account is correct, one would expect the interference effect to occur only with simultaneous presentation of the color patch and distractor, irrespective of the age of the participant. However, if the inhibition account is correct, one would expect to observe the interference effect at both timing conditions in young children due to their requiring more time to process and inhibit the distracting words. Furthermore, due to a developmental progression in the ability to selectively attend to color naming while inhibiting irrelevant auditory distractors, it was predicted that the cross-modal Stroop effect would be robust in children and become progressively weaker with age. That is, it was expected that the relatively small interference effect observed in previous studies with adults is the end point of a trajectory in the development of selective attention and inhibitory control.

Method

Participants. Fifteen 4- to 5-year-olds (6 boys, 9 girls: mean age = 4 yrs. 11 mos., range = 4 yrs. 1 mo. – 5 yrs. 11 mos.), 15, 6- to 7-year-olds (7 boys, 8 girls: mean age = 4 yrs 11 mos, range = 4 yrs 1 mos – 5 yrs 11 mos), 15, 9- to 11-year-olds (9 boys, 6 girls: mean age = 10 Yrs. 11 mos., range = 9 yrs. 1 mo. – 11 yrs 11 mos), and 30 undergraduates (14 men, 16 women, mean age = 22 yrs., range = 17-34 yrs.) participated in the study. The study was approved by the IRB of the College of Staten Island of the City University of New York and all adult participants and parents of participants under age 18 signed written informed consent forms prior to the start of the experiment. All participants had corrected to normal vision and normal hearing, and were prescreened to ensure no color perception deficiencies. All were native speakers of English. The sample was ethnically diverse and predominantly of middle-class background. The children were recruited using flyers posted at the College of Staten Island of the City University of New York. They were tested in a psychology laboratory and received stickers and t-shirts for their participation. The undergraduates were recruited from Introductory Psychology classes at the College of Staten Island and received course credit for their participation. In the adult group we tested twice the number of participants as in child groups due to the small effect sizes obtained in previous studies of adults (Cowan & Barron, 1987; Elliott et al., 1998).

Materials and Apparatus. The experiment was conducted using a Macintosh Power PC computer equipped with PsyScope experimental software (Cohen, MacWhinney, Flatt, & Provost, 1993) and SoundEdit 16. The visual stimuli consisted of six color patches, measuring 3 x 3 inches, against a black background. The colors were red, white, blue, green, yellow and purple, as in Elliott et al. (1998). Spoken words corresponding to the six colors along with six non-color words (dry, single, real, short, fewer, and best) were presented over headphones in a female voice. The non-color words were matched to the color words in terms of word frequency and syllable structure (Carroll, Davies, & Richman, 1971; Elliott et al., 1998). The duration of the color words ranged from 315 to 512 ms with a mean of 411 ms, and the duration of the non-color words ranged from 308 to 496 ms with a mean of 410 ms. The PsyScope software controlled the presentation of the spoken words and color patches. Each color patch was paired with each stimulus word except its own (e.g., the red color patch was never paired with the word *red*). That is, in each block of trials, items were randomly selected without replacement from a list combining each color patch with each color word (except for the matching color word) and each non-color word. A microphone was set in front of the participant with a voice-key triggering a button box timer that recorded reaction times for color naming. RTs for correct responses were measured from the onset of the color patch to the triggering of the voice key by the participant's response.

Procedure. Each participant was tested individually in a quiet room. Participants were seated in front of the computer monitor, with a microphone placed approximately 1 inch away from their mouth. The experimenter sat approximately one foot to the left of the participant so that she could have sight of the monitor, but not distract the participant. Six color patches (red, blue, white, green, purple and yellow), printed on white paper from a color printer, were shown to the participant as the experimenter read the color names aloud. The participant was then asked to repeat the color words to ensure color recognition. This was considered a pretest and ensured knowledge and correct identification of the color names. Participants were told that they were going to play a computer game and were asked to wear a set of headphones. Participants were told that the object of the game was to "say what you see." The experimenter said, "In this game, color patches are going to appear on the screen and your job is to name the colors as quickly as possible. Sometimes, you are going to hear words over the headphones, but try your best to ignore the word and say only what you see. The words may confuse you sometimes because they may be different from what you see, but you should concentrate and say what you see." Participants were told to name the color of each color patch, as soon as it appeared, and not to talk otherwise. After 36 trials, a smiley face appeared to indicate that the block of trials was finished. At the end of each block, participants were told that they did a great job and the children received stickers for their efforts.

Each trial began with a white fixation cross which remained on the screen for 2500 ms. In the *0 ms* experimental condition, the timing of the onset of the auditory distractor was simultaneous with presentation of the color patch, and coincided with the disappearance of the fixation cross. In the *-500 ms* experimental condition, the timing of the onset of the auditory distractor was simultaneous with the disappearance of the fixation cross, and the color patch appeared 500 ms after the offset of the word. In the *silent* condition, the color patch replaced the fixation cross after 2500 ms, and no auditory distractor was presented. The participant's response activated a voice key that recorded the RT for the trial and triggered the disappearance of the color patch. After 200 ms the fixation cross for the next trial appeared. The experimenter kept a log of the participant's responses as a record of errors and lost trials. Trials were counted as errors when the participant misnamed the color patch (e.g., seeing the color green, but saying "yellow"). If a participant hesitated or stuttered (e.g., by saying "ah" prior to naming the color), failed to make a response within 7 seconds, did not speak loudly enough for the voice key to activate, or if the voice key was triggered prematurely (e.g., by heavy breathing in the direction of the microphone or kicking or hitting the desk) the trial was considered lost and was omitted.

Each participant received five blocks of trials – two practice blocks and three test blocks. The first practice block consisted of 18 trials of the silent condition. This allowed participants to practice naming the color patches as they appeared on the computer monitor and allowed the experimenter to adjust the sensitivity of the voice key. If the participant made any errors during this block (i.e., misnaming a color patch), they were corrected. The second practice block comprised 18 practice trials with auditory distractors to allow the participant to get used to hearing the words in the headphones. If the participant made any errors in this block (e.g., repeating the auditory stimulus instead of naming the color patch), they were corrected. After the two blocks of practice trials, three blocks of 36 test trials (108 total trials) were presented with each block comprising

12 silent trials, 12 color word trials (6 at each stimulus asynchrony [SA]), and 12 non-color word trials (6 at each SA), occurring in random order. Subjects did not receive the same random order. In the test blocks, participants were not corrected for any errors. If, at any point during the experiment, a child became distracted or started a conversation, the experimenter paused the experiment until the child calmed down and trials could be resumed.

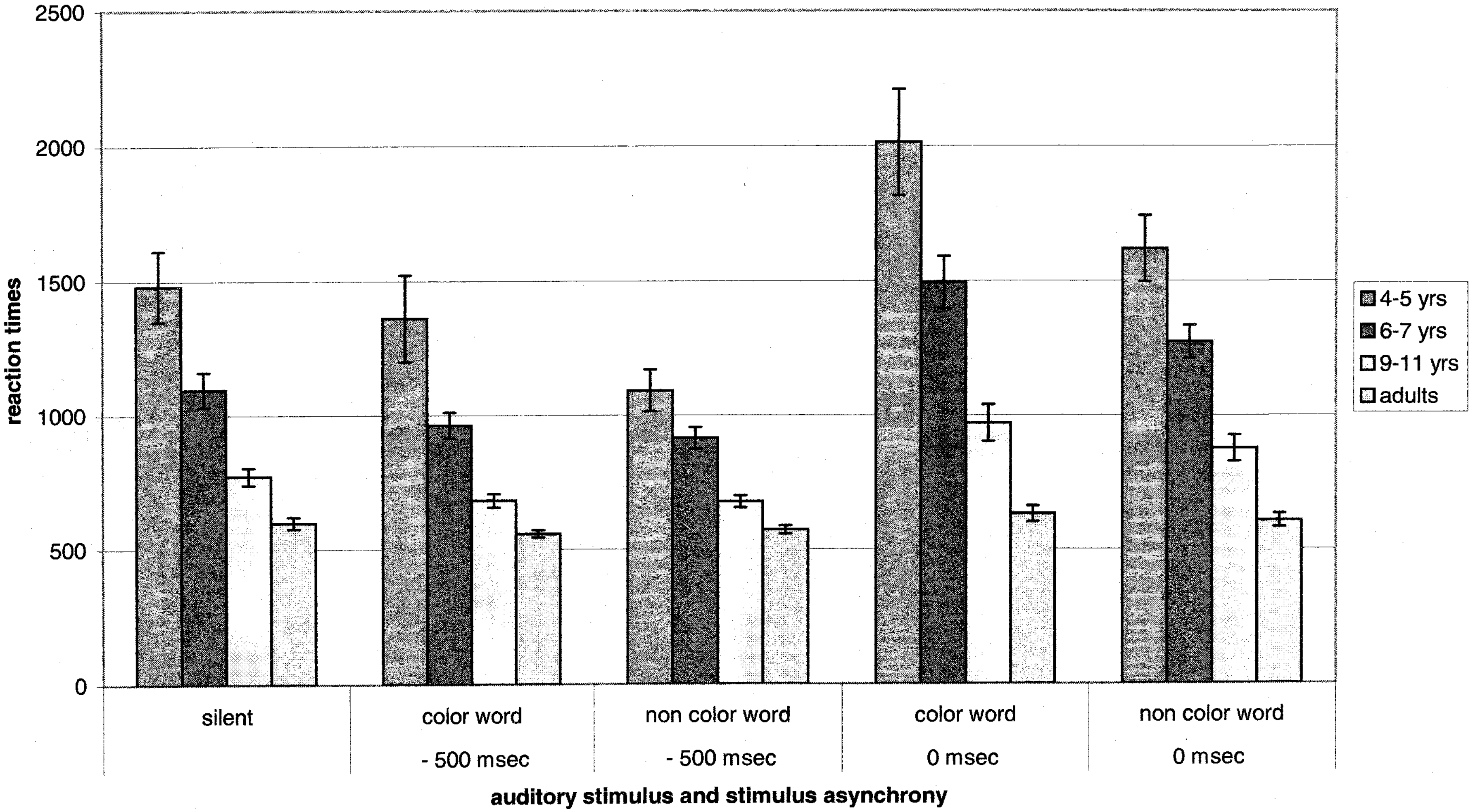
Results

Reaction times. As the distributions of RTs were positively skewed, especially for the youngest children who often took very long to respond, the median RTs for correct trials were used as the dependent measure. Table 1 and Figure A present the median RTs for each age group as a function of distractor type and stimulus asynchrony.

Table 1. Median RTs (ms) for Experiment 1 as a Function of Auditory Stimulus Condition (Stimulus Asynchrony and Distractor Type) and Participant Age, with Standard Errors in Parentheses (N=15 for each child group, N=30 for adults).

	Auditory Stimulus Condition				
	-500 ms SA			0 ms SA	
	Silent	Color word	Non-color word	Color word	Non-color word
4-5 years	1481 (132)	1361 (162)	1092 (78)	2015 (197)	1620 (123)
6-7 years	1096 (65)	962 (49)	913 (41)	1495 (98)	1273 (62)
9-11 years	770 (33)	680 (25)	675 (22)	970 (69)	875 (49)
Adult	597 (22)	557 (13)	571 (15)	630 (29)	606 (25)

Figure A – Median RTs (ms) for Experiment 1 as a Function of Auditory Stimulus Condition (Stimulus Asynchrony and Distractor Type) and Participant Age, with Standard Errors (N=15 for each child group, N=30 for adults).



Overall, color naming was fastest for the -500 ms condition, intermediate for the silent condition, and slowest for the 0 ms condition. This ordering of RTs as a function of distractor condition exactly replicates Elliott et al. (1998), and is likely due to the fact that the timing of the color patch, relative to both the fixation point and the distractor, varied randomly across trials within each block. Thus, because it was impossible to predict for any trial exactly when the color patch would appear, when the distractor preceded the color patch (-500 ms SA), it alerted the participant to prepare a response. In replicating the methodology of Elliott et al., we did not include a baseline condition where we could adequately measure nonverbal auditory interference at both SA's. Therefore, we have determined that the silent condition cannot be included in the statistical analysis and in the following statistical analyses only RTs for trials involving auditory distractors were included. In future research, we would recommend using a baseline condition, such as a tone, that can be applied at both SA's and therefore be considered in the statistical analysis.

RTs were analyzed in a 2x2x4 mixed-design ANOVA with stimulus asynchrony (-500 ms, 0 ms) and distractor type (color word, non-color word) as within-subjects factors, and age (4- to 5-year-olds, 6- to 7-year-olds, 9- to 11-year-olds, and adults) as the between subjects factor. The dependent variable was the median RT for naming the color patches. The ANOVA showed highly significant main effects of age, $F(3,71) = 48.98$, MSE = 265,525, $p < .001$, distractor type, $F(1,71) = 40.30$, MSE = 28,871, $p < .001$, and stimulus asynchrony, $F(1,71) = 184.18$, MSE = 41,516, $p < .001$. Overall RTs for naming colors decreased markedly with age. RTs were faster for non-color word trials than for color word trials, and were faster when the distractor occurred in advance of the color patch (-500 ms SA) than when it was simultaneous with the color (0 ms SA). The main effects were qualified by significant two-way interactions of age with distractor type, $F(3,71) = 13.10$, MSE = 28,871, $p < .001$, age with stimulus asynchrony, $F(3,71) = 27.43$, MSE = 41,516, $p < .001$, and distractor type with stimulus asynchrony, $F(1,71) = 11.80$, MSE = 16, 613, $p < .001$. The three-way interaction of age, distractor type, and stimulus asynchrony was not statistically significant.

To test for the existence of a cross-modal Stroop effect at each age, planned comparisons were conducted, comparing RTs for color word and non-color word trials at each SA condition. For the -500 SA condition, the 4- to 5-year-olds named color patches paired with color words more slowly than color patches paired with non-color words, $F(1,14) = 9.45$, MSE = 57, 335, $p < .01$, accounting for 2% of the total variance. In contrast, for the other age groups, RTs for color word and non-color word trials were not statistically different when the distractor was presented 500 ms before the color patch. Thus, for all groups except the youngest children, delaying presentation of the color patch by 500 ms provided sufficient time for activation of the distractor to be fully suppressed. The lack of a cross-modal Stroop effect in adults with the distractor presented in advance of the color patch replicates the findings of Elliott et al. (1998). For the 0 ms SA condition, the RT difference for color word and non-color word trials was highly significant for the 4- to 5-year-olds $F(1,14) = 20.38$, MSE = 57,335, $p < .001$, and for the 6- to 7-year-olds, $F(1,14) = 33.40$, MSE = 11,098, $p < .001$, and was significant for the 9- to 11-year-olds, $F(1,14) = 5.13$, MSE = 12,982, $p < .05$, and for the adults, $F(1,29) = 6.09$, MSE = 1,369, $p < .05$. Taken together, the planned comparisons show that the cross-modal Stroop effect is much more robust in children than in adults, and occurs at both of the SA conditions in very young children to a greater extent,than in older children and adults.

Finally, proportional RT differences when a color word distractor occurred in comparison to a non-color word distractor were examined. These proportions were computed by dividing RT differences between color and non-color distractor conditions by RTs for the non-color distractor condition. For the -500 ms SA condition, the proportional differences were 24.6% for the 4- to 5-year-olds, 5.4% for the 6- to 7-year-olds, 0% for the 9- to 11-year-olds, and 2.5% (in the opposite direction) for the adults. For the 0 ms SA condition, the proportional differences were 24.4% for the 4- to 5-year-olds, 17.4% for the 6- to 7-year-olds, 10.9% for the 9- to 11-year-olds, and 4.0% for the adults. Thus, there is further evidence of the decline in the size of the interference effect with age.

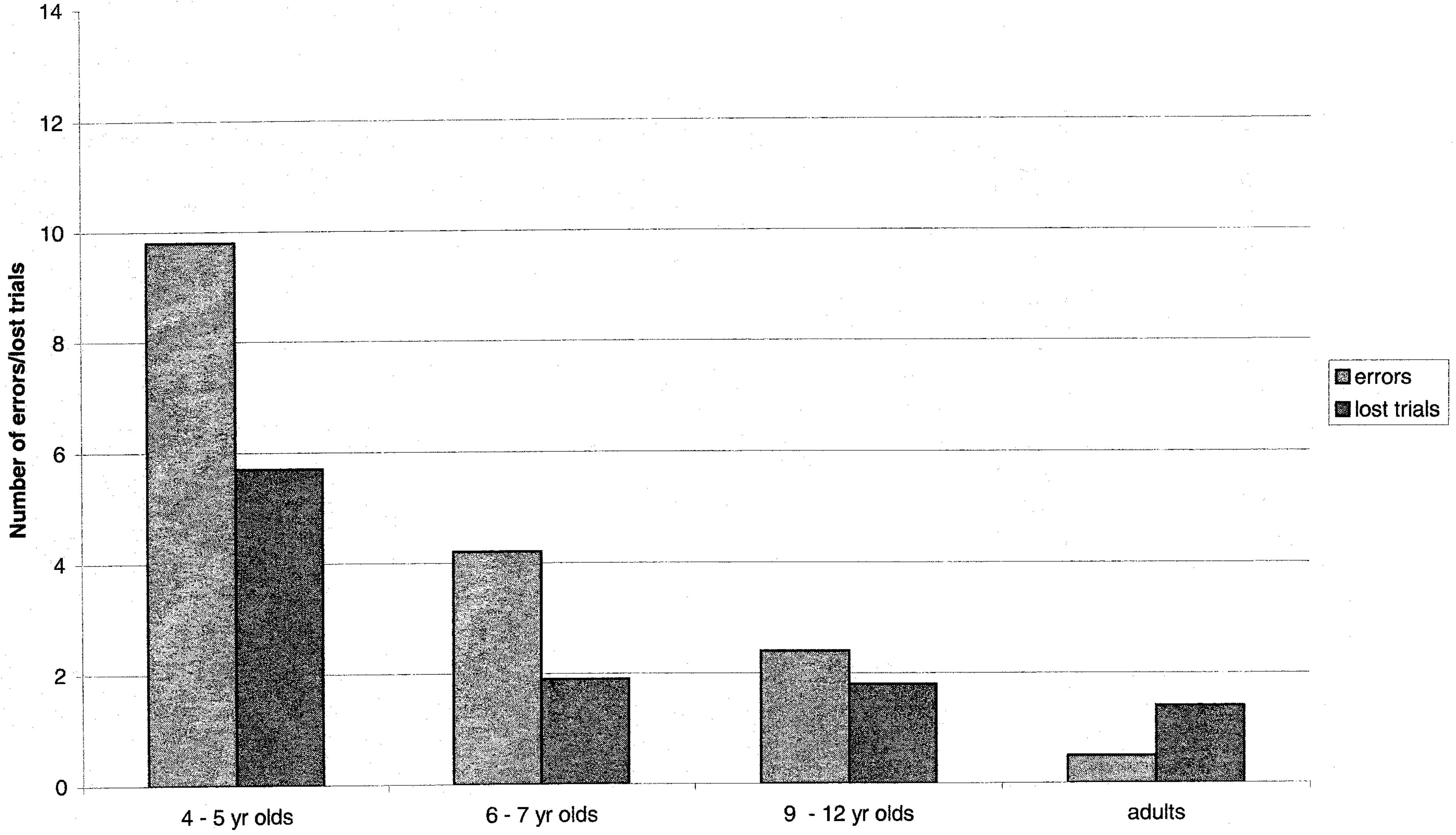
Errors. Error rates for each age group as a function of distractor type and stimulus asynchrony were analyzed. Trials were counted as errors when the participant misnamed the color patch (e.g., seeing the color green, but saying “yellow”). As mentioned earlier, if a participant hesitated or stuttered (e.g., by saying “ah” prior to naming the color), failed to make a response within 7 seconds, did not speak loudly enough for the voice key to activate, or if the voice key was triggered prematurely (e.g., by heavy breathing in the direction of the microphone or kicking or hitting the desk) the trial was considered lost and was omitted. Of the 108 test trials, the 4- to 5-year-olds averaged 9.8 errors and 5.7 lost trials, the 6- to 7-year-olds averaged 4.2 errors and 1.9 lost trials, the 9- to 11-year-olds averaged 2.4 errors and 1.8 lost trials, and the adults averaged 0.5 errors and 1.4 lost trials. Table 2 and Figure B represent the error rates and lost trials for Experiment 1.

Error rates were computed as proportions of completed trials. Errors were analyzed in a mixed-design ANOVA with within-subjects factors of stimulus asynchrony (-500 ms, 0 ms) and distractor type (color word, non-color word), and the between subjects factor of age (4- to 5-year-olds, 6- to 7-year-olds, 9- to 11-year-olds, and adults). Error proportions were arcsine transformed prior to statistical analysis, as is recommended for proportional data (Cohen & Cohen, 1983). Overall, the main effect of age was significant, $F(3,71) = 11.69$, MSE = .10, $p < .001$. While error rates were relatively low at all ages, there was a significant decline in errors with age. The only other significant effect in the ANOVA was a two-way interaction of distractor type and stimulus asynchrony, $F(1,71) = 5.24$, MSE = .05, $p < .05$. When the distractor occurred simultaneously with the color patch (0 ms SA), the error rate for color word trials was significantly higher than for non-color word trials, $F(1,71) = 4.91$, MSE = .05, $p < .05$. At the -500 ms SA, error rates for color word and non-color word trials were not statistically equivalent. Planned comparisons of error rates for color word and non-color word trials were conducted for each age group separately, but revealed no significant differences due to low error rates and low statistical power.

Table 2. Number of errors and lost trials for Experiment 1 as a Function Participant Age, (N=15 for each child group, N=30 for adults).

	Errors	Lost Trials
4-5 years	9.8	5.7
6-7 years	4.2	1.9
9-11 years	2.4	1.8
Adult	0.5	1.4

Figure B – Number of errors and lost trials for Experiment 1 as a Function of Participant Age, (N=15 for each child group, N=30 for adults).



Discussion

When the auditory distractor occurred simultaneous with the color patch, a significant Stroop-like interference effect across child and adult groups was found that decreased markedly in magnitude with age. This pattern of greater interference in children than adults is highly consistent with recent work demonstrating greater salience of the auditory than the visual modality in children (Sloutsky & Napolitano, 2003). More importantly, a Stroop-like interference effect was observed in 4- to 5-year-olds when the distractor was presented 500 ms in advance of the color patch, supporting Elliott et al.'s (1998) inhibition account of this effect.

The finding of a developmental trajectory in performance of the cross-modal Stroop task helps to clarify the literature on the effect. With only adults tested in previous cross-modal Stroop experiments, some researchers have found reliable interference (Cowan & Barron, 1987; Cowan, 1989; Elliott et al., 1998; Elliott & Cowan, 2001) whereas others have not (Miles et al., 1989; Miles & Jones, 1989). What is most pronounced in the current study is the finding that the cross-modal Stroop effect becomes progressively weaker with age, and is a relatively small effect in adults. The fact that a robust cross-modal Stroop effect appears when children are tested runs counter to Miles and his colleagues' assertion that interference from irrelevant spoken words occurs only in tasks involving short-term memory.

By using color-word distractors that named colors in the response set (i.e., the color patches), it could not be determined if the interference effect was due to the semantic relatedness of the distractors to the target colors or to their being members of the response set. Thus, Experiment 1 using the cross-modal Stroop task faces the same experimental confound as was encountered in the day-night Stroop literature. So, although we propose that the lack of a Stroop-like effect with the word presented prior to the color patch is due to adults having sufficient time to inhibit their representation of the distractor and claim that the source of the cross-modal Stroop effect resides in inhibitory mechanisms, we cannot rule out other explanations, such as concurrent semantic processing, as the source of interference. If there is continuity in the psycholinguistic processes involved in picture naming from early childhood to adulthood, as suggested by Jerger, Martin and Damian (2002), then the striking developmental changes observed in the cross-modal Stroop effect in Experiment 1 must stem from another source besides semantic competition. The next sets of experiments sought to resolve this issue using a cross-modal picture-word interference task to systematically examine semantic versus response set components of the interference effect.

Chapter 3 - Experiment 2

In Experiment 2, we examined the existence of a Stroop-like cross-modal picture-word semantic interference effect in children and adults, using a variant of Experiment 1. In contrast to Experiment 1 and other earlier studies (e.g., Elliot et al., 1998) of color naming that used distractors that were adjectives (i.e., color words such as *purple* for the semantically=related condition, and other adjectives such as *fewer* for the semantically-unrelated condition), in Experiment 2, participants named pictures of objects while listening to the names of other semantically related or unrelated objects over headphones. The important difference in procedure here was the use of distractors, for both related and unrelated conditions, that named objects that could easily be rendered as pictures. In each of two tasks, nouns of one semantically-defined, superordinate category (animals or clothing) comprised target pictures and related distractors, and the nouns of the remaining category served as the unrelated distractors. As in Elliott et al. (1998) and our Experiment 1, we varied stimulus asyncrony within each block of trials. Picture naming reaction times for trials with pictures paired with related words were compared with reaction times for trials with pictures paired with unrelated words, to determine the occurrence of semantic interference.

Method

Participants. Nineteen 3- to 5-year-olds (7 boys, 12 girls: mean age = 4 yrs. 11 mos., range = 3 yrs. 2 mos. – 5 yrs. 11 mos.), 19, 6- to 7-year-olds (7 boys, 12 girls: mean age = 7 yrs. 2 mos., range = 6 yrs. 0 mos. – 7 yrs. 11 mos.), 20, 8- to 11-year-olds (9 boys, 11 girls: mean age = 10 yrs. 5 mos., range = 8 yrs. 9 mos. – 11 yrs. 11 mos.), and 30 adults (11 men, 19 women, mean age = 20 years, range = 18 – 39 yrs.)

participated in the study. All participants had corrected to normal vision and normal hearing, and were native speakers of English. The sample was ethnically diverse and predominantly of middle-class background. The participants were recruited from the same sources as in Experiment 1. None had participated in the previous experiment. The study was approved by the IRB of the College of Staten Island of the City University of New York and all adult participants and parents of participants under age 18 signed written informed consent forms prior to the start of the experiment.

Materials and Apparatus. The apparatus was exactly the same as in Experiment 1. The visual stimuli were selected from the Snodgrass and Vanderwart (1980) set of standardized black and white line drawings and consisted of six animal pictures and six clothing pictures, each measuring 3 x 3 inches and surrounded by a black background. We selected stimulus pictures that are easily recognized by children (Cycowicz, Friedman, Snodgrass & Rothstein, 1997). In addition, these stimulus words and pictures have an early age of acquisition (Morrison, Chappelli & Ellis, 1997). In selecting the animal and clothing stimuli, we tried to avoid words with identical onset consonants or consonant clusters, and words with identical rhymes. We also attempted to create animal and clothing sets that were roughly comparable in terms of their acoustic-phonetic onset characteristics. The animal stimuli were *bear, chicken, dog, fish, rabbit* and *snake*. The clothing items were *dress, hat, mitten, pants, shoe* and *sock*. The auditory stimuli, consisting of the words corresponding to the twelve pictures, were presented over headphones in a naturally spoken female voice. The duration of the animal words ranged from 581 to 709 ms with a mean of 657 ms, and the duration of the clothing words ranged from 582 to 756 ms with a mean of 658 ms.

Procedure. The task procedures were the same as in Experiment 1. The PsyScope software controlled the presentation of the spoken words and pictures. Participants performed two tasks comprising five blocks of trials (2 practice blocks and 3 test blocks each task). In one task they were instructed to name animal pictures and in the other task they were instructed to name clothing pictures (with order of tasks counterbalanced across subjects). Across trials, each stimulus picture was paired with each stimulus word except its own (e.g., the picture of a mitten was never paired with the word *mitten*). That is, in each block of trials, items were randomly selected with replacement from lists combining each picture with each clothing word and each animal word (except for the matching word). Three blocks of 36 test trials (108 total trials) were presented with each block comprising 12 silent trials, 12 trials with distractors from the same semantic category (6 at each stimulus asynchrony [SA]), and 12 trials with distractors from the other semantic category (6 at each SA), occurring in a random order. That is, in the animal naming task, for half of the trials with distractors, animal pictures were paired with animal words, and for the other half, animal pictures were paired with clothing words. Likewise, in the clothing task, clothing pictures were paired with clothing words and with animal words in equal numbers of trials. As in Experiment 1, in the test blocks, participants were not corrected for any errors and if, at any point during the experiment, a child became distracted or started a conversation, the experimenter paused the experiment until the child calmed down and trials could be resumed.

Results

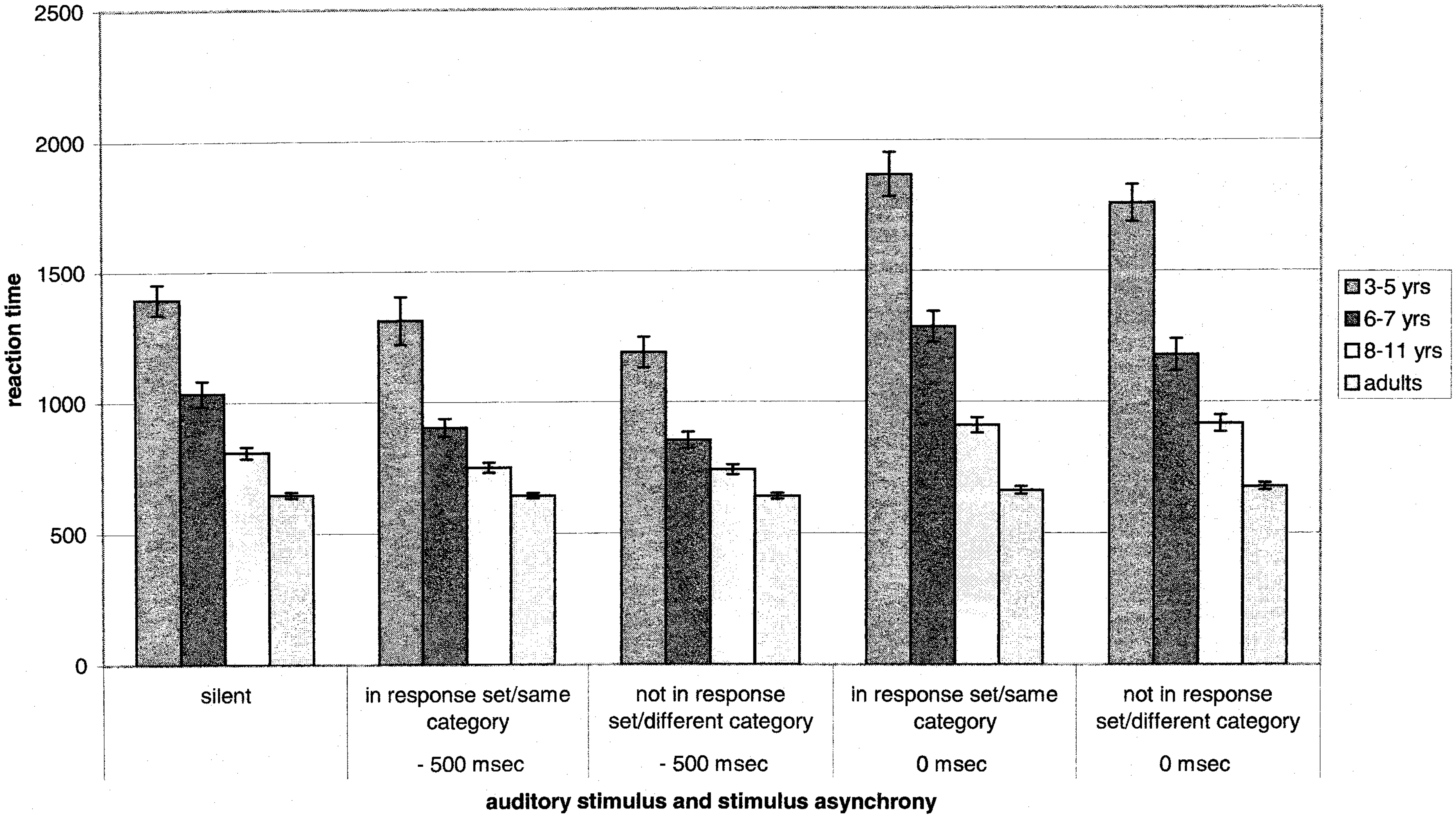
Reaction times. As the distributions of RTs were positively skewed, especially for the youngest children, median RTs for correct trials were used as the dependent measure.

Table 3 and Figure C present RTs for each age group, as a function of distractor type and stimulus asynchrony.

Table 3. Median RTs (ms) for Experiment 2 as a Function of Auditory Stimulus Condition (Stimulus Asynchrony and Distractor Type) and Participant Age, with Standard Errors in Parentheses (N=19 for 3- to 5-year-olds and for 6- to 7-year-olds, N=20 for 8- to 11-year-olds, and N=30 for adults).

	Auditory Stimulus Condition				
	-500 ms SA			0 ms SA	
	Silent	In Response Set / Same Category	Not In Response Set / Different Category	In Response Set / Same Category	Not In Response Set / Different Category
3-5 years	1394 (59)	1311 (92)	1188 (59)	1868 (84)	1758 (71)
6-7 years	1033 (48)	903 (34)	854 (31)	1285 (59)	1178 (61)
8-11 years	809 (22)	751 (19)	742 (19)	910 (29)	918 (32)
Adult	646 (11)	643 (10)	640 (11)	662 (15)	677 (14)

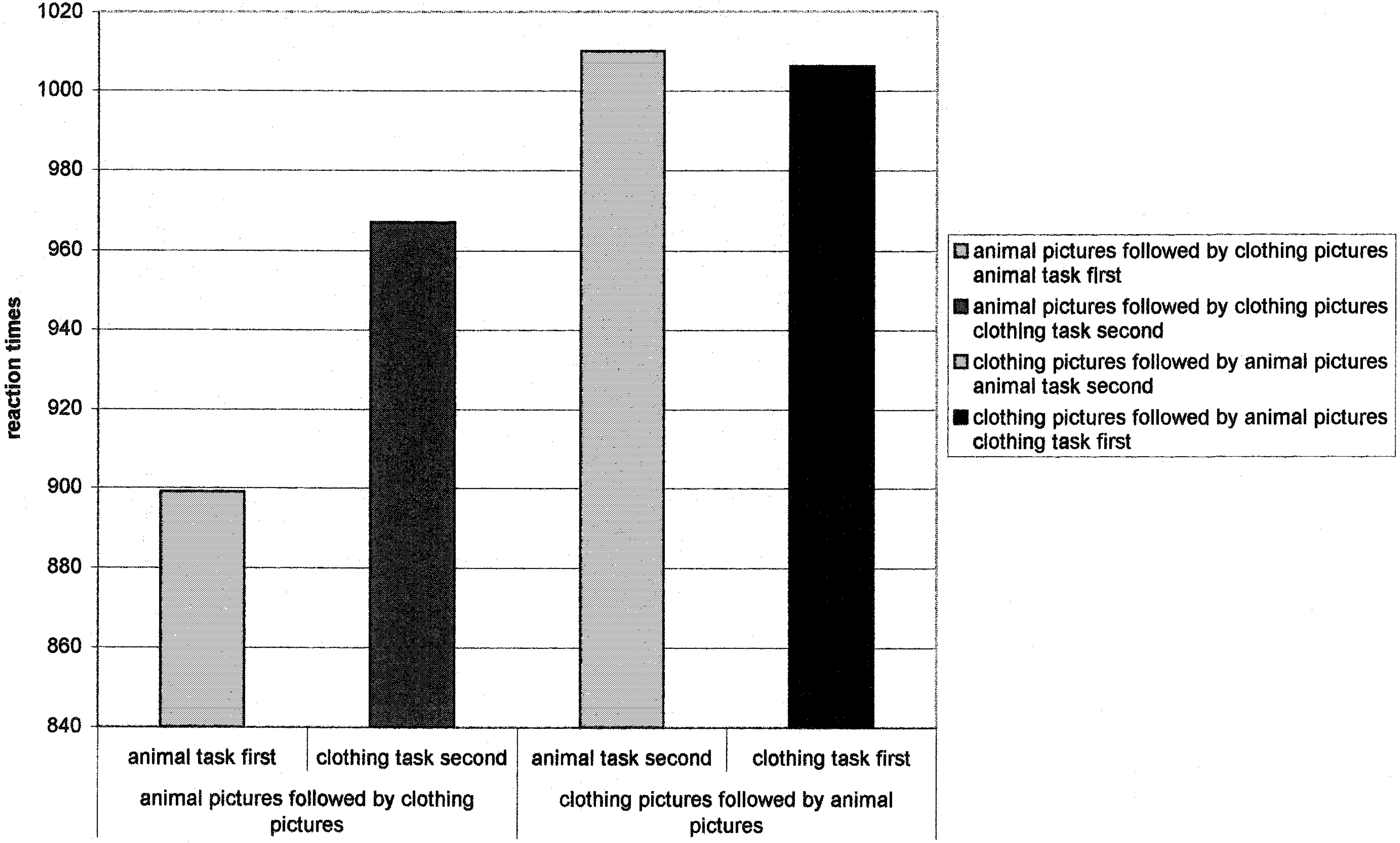
Figure C – Median RTs (ms) for Experiment 2 as a Function of Auditory Stimulus Condition and Participant Age, with Standard Errors (N=19 for 3- to 5-year-olds and for 6- to 7-year-olds, N=20 for 8- to 11-year-olds, and N=30 for adults).



Overall, picture naming was fastest for the -500 ms condition, intermediate for the silent condition, and slowest for the 0 ms condition. This ordering of RTs as a function of distractor condition replicates Elliott et al. (1998) and Experiment 1. It is again likely due to the fact that the timing of onset of the picture, relative to both the fixation point and the distractor, varied randomly across trials within each block. Thus, because it was impossible for the participant to predict for any trial exactly when the picture would appear, when the distractor preceded the picture (–500 ms SA), it alerted them to prepare a response. In replicating the methodology of Experiment 1, we did not include a baseline condition in Experiment 2 where we could adequately measure nonverbal auditory interference at both SA's. Therefore, we have determined that the silent condition cannot be included in the statistical analysis and in the following statistical analyses we examined only picture naming reaction times for trials involving auditory distractors, and did not consider the silent condition further. In future research, we would recommend using a baseline condition, such as a tone, that can be applied at both SA's and therefore factored into the statistical analysis.

Median picture naming reaction times were analyzed in a 2x2x2x2x4 mixed-design ANOVA with distractor type (same semantic category, different semantic category), stimulus asynchrony (-500 ms, 0 ms), and picture type (animal, clothing) as within-subjects factors, and task order (animal naming first, clothing naming second versus clothing naming first, animal naming second) and age (3- to 5-year-olds, 6- to 7-year-olds, 8- to 11-year-olds, and adults) as between-subjects factors. The ANOVA showed highly significant main effects of age, *F*(3, 80) = 69.94, MSE = 24,685,705, *p* < .001, distractor type, *F*(1, 80) = 16.52, MSE = 379,936, *p* < .001, and stimulus asynchrony, $F(1, 80) = 206.71$, MSE = 13,064,446, $p < .001$. Overall, RTs for naming the pictures decreased markedly with age. RTs tended to be slower for trials with distractors from the same semantic category than for trials with unrelated distractors, and were slower when the distractor was simultaneous with the picture (0 ms SA) than when it was in advance of the picture (–500 ms SA). Although the main effects of task order and picture type were not significant, there was a significant two-way interaction of task order and picture type, $F(1, 80) = 4.35$, MSE = 280,409, $p < .05$. As represented in Figure D, when the animal task preceded the clothing task, reaction times were considerably faster for animal trials (899 ms) than clothing trials (967 ms). In contrast, reaction times for animal and clothing trials were virtually identical when the clothing task preceded the animal task (1010 versus 1006 ms, respectively, for animal and clothing trials), suggesting a trade-off between faster naming for the first task, irrespective of semantic category, and faster naming of animals over clothing.

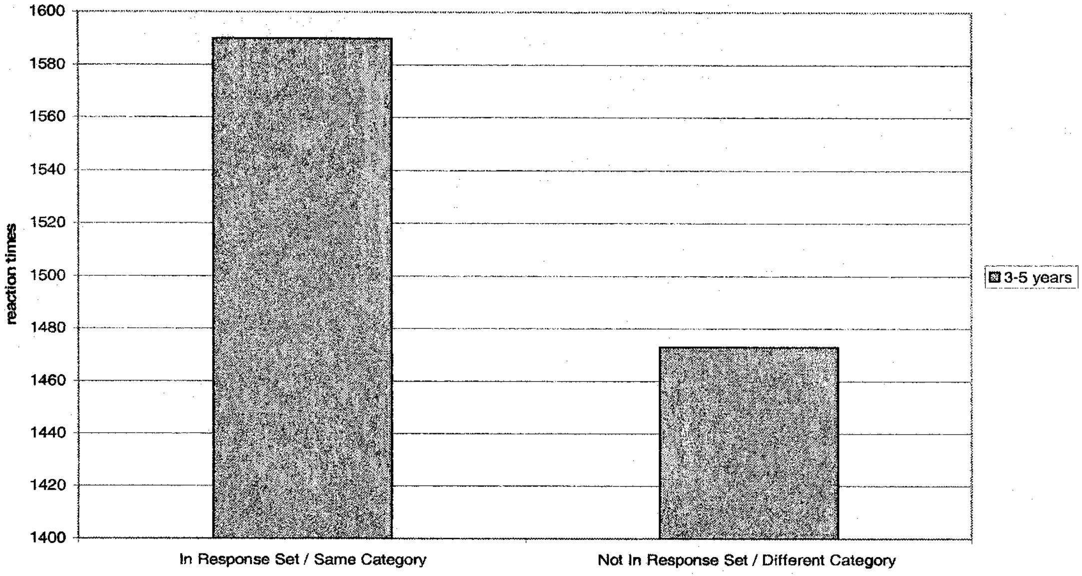
Figure D -- Median RTs (ms) for Exp. 2 as a Function of Task Order and Distractor Type (N=19 for 3- to 5-yr-olds & 6- to 7-yr-olds, N=20 for 8- to 11-yr-olds, and N=30 for adults).



The main effects of age, distractor type, and stimulus asynchrony were qualified by significant two-way interactions of age and distractor type, *F*(3, 80) = 6.77, MSE = 155,661, $p < .001$, age and stimulus asynchrony, *F*(3, 80) = 38.54, MSE = 2,435,685, $p < .001$, and age and task order, *F*(3, 80) = 4.31, MSE = 1,522,470, $p < .01$, a three-way interaction of age, distractor type and picture type, *F*(3, 80) = 2.75, MSE = 33,407, $p < .05$, a four-way interaction of age, distractor type, picture type and task order, *F*(3, 80) = 3.51, MSE = 42,684, $p < .05$, and a five-way interaction of age, distractor type, picture type, task order and stimulus asynchrony, *F*(3, 80) = 3.88, MSE = 30,991, $p < .05$. Therewere no other higher-order interactions.

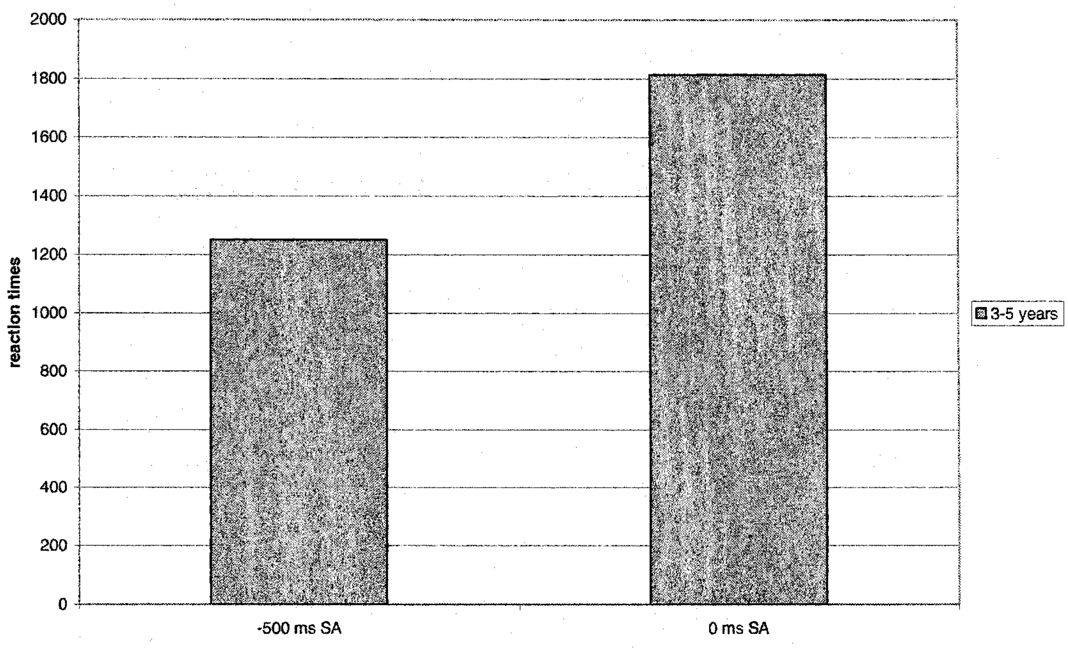
To decompose these interactions and, more importantly, to test for the existence of a semantic interference effect at each age, separate ANOVAs for each age group were conducted, with distractor type, stimulus asynchrony, and picture type as within-subjects factors and task order as a between-subjects factor. For the 3- to 5-year-olds, there were significant main effects of distractor type, *F*(1, 17) = 5.97, MSE = 512,871, $p < .05$, stimulus asynchrony, *F*(1, 17) = 73.90, MSE = 11,915,642, $p < .001$, and task order, *F*(1, 17) = 5.76, MSE = 5,182,260, $p < .05$, with no interactions. In support of a semantic interference effect, RTs were longer for trials with same category distractors than for trials with unrelated distractors (1590 versus 1473 ms, represent in Figure E).

Figure E -- Median RTs (ms) for Experiment 2 as a Function of Distractor Type for 3 to 5 year olds (N=19).



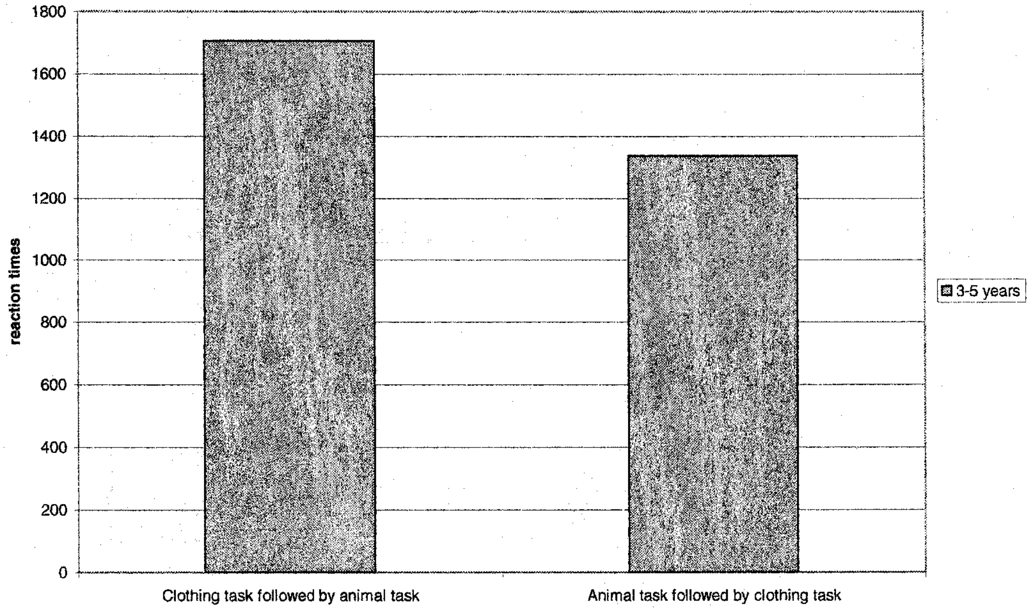
Picture naming was slower (Figure F) when the distractor appeared simultaneous with the picture than when presented before it (1813 versus 1250 ms).

Figure F -- Median RTs (ms) for Experiment 2 as a Function of Stimulus Asynchrony for 3 to 5 year olds (N=19).



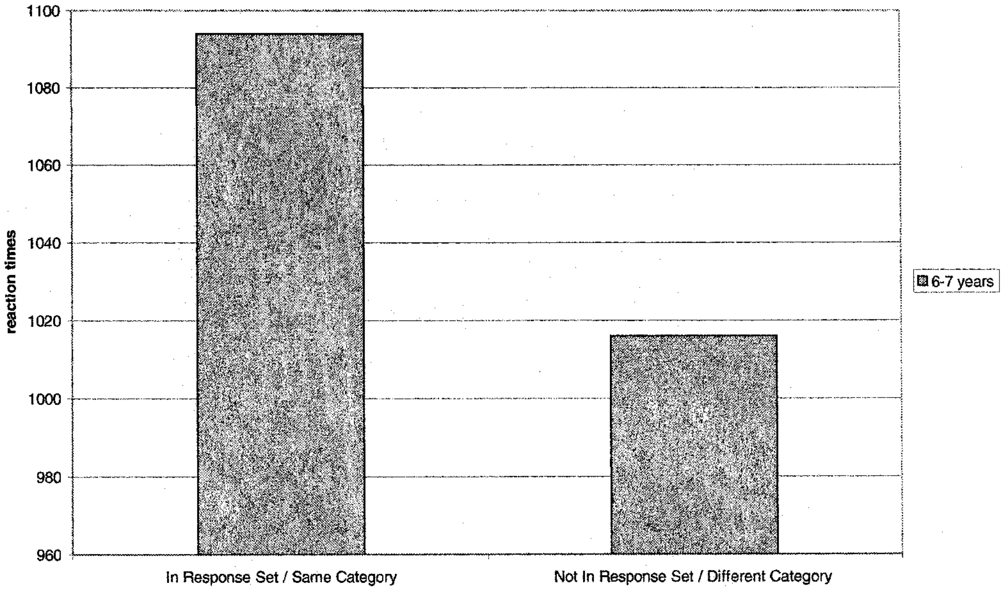
Picture naming was also slower for the youngest children who performed the clothing task before the animal task (overall mean 1707 ms), as opposed to performing the tasks in the opposite order (overall mean 1337 ms), as can be seen in Figure G.

Figure G -- Median RTs (ms) for Experiment 2 as a Function of Task Order for 3 to 5 year olds (N=19).



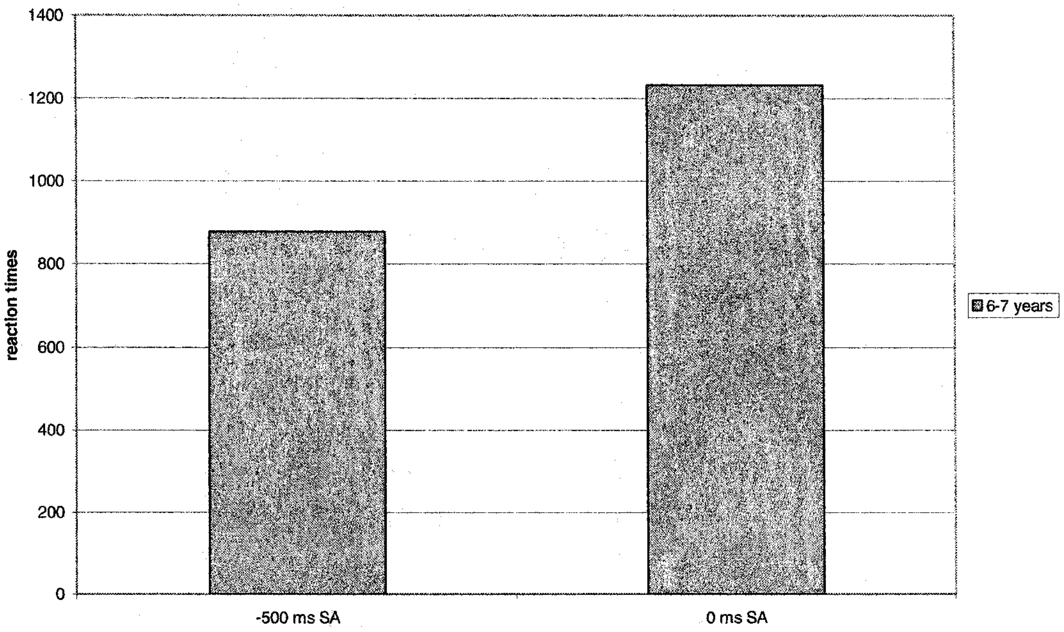
For the 6- to 7-year-olds, there were significant main effects of distractor type, *F*(1, 17) = 14.30, MSE = 234,584, $p < .01$, and stimulus asynchrony, *F*(1, 17) = 57.05, MSE = 4,770,043, $p < .001$, as well as an interaction of distractor type and stimulus asynchrony, *F*(1, 17) = 4.48, MSE = 32,117, $p < .05$. As was the case for the youngest group of children, the 6- to 7-year-olds showed longer reaction times for trials with same category distractors than for different category distractors (1094 versus 1016 ms, Figure H).

Figure H -- Median RTs (ms) for Experiment 2 as a Function of Distractor Type for 6 to 7 year olds (N=20).



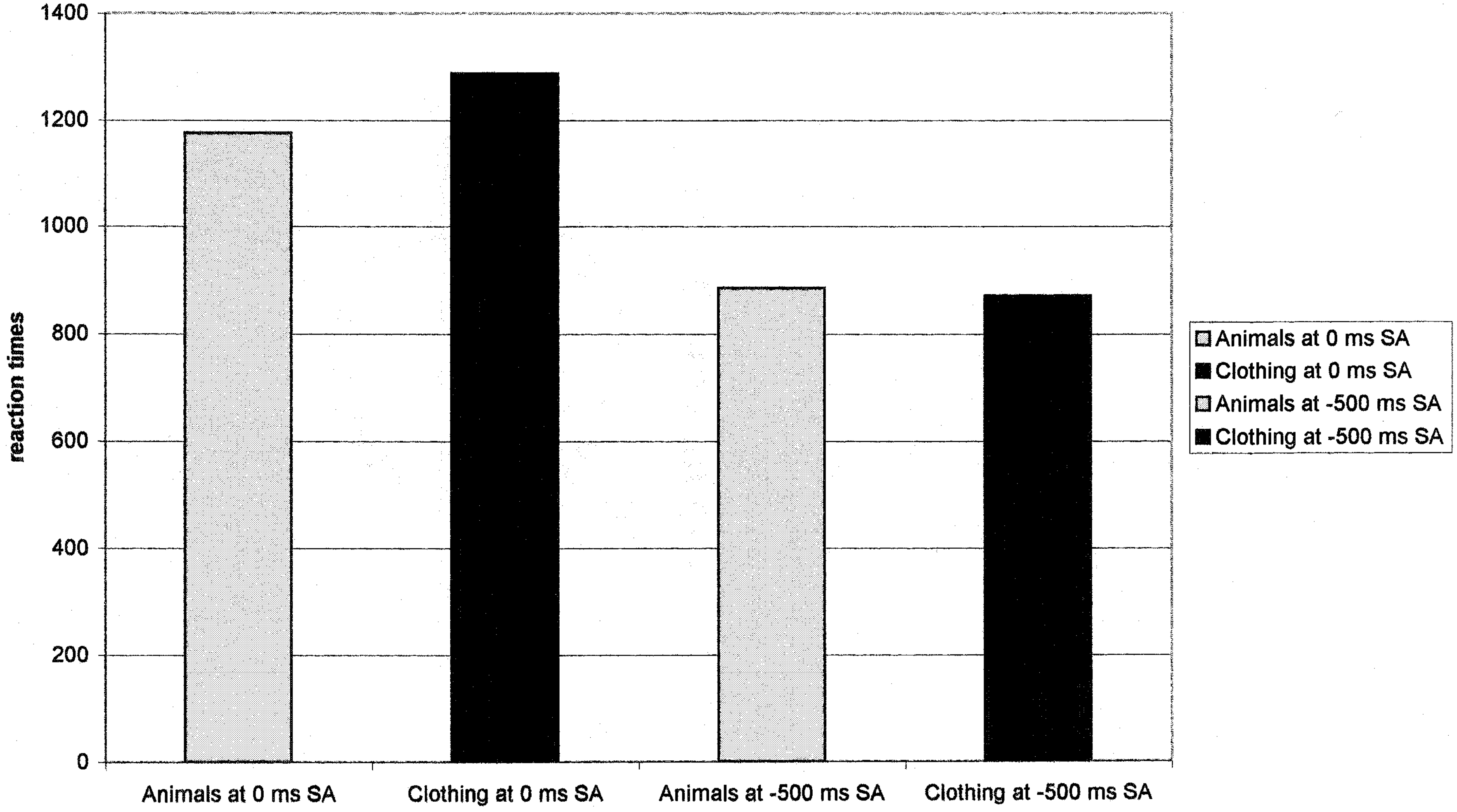
The 6- to 7-year-olds also showed longer reaction times for trials with simultaneous presentation of picture and distractor than for trials with asynchronous presentation (1232 versus 878 ms, Figure I). While the effect of distractor type was stronger when the picture and the distractor occurred simultaneously, the semantic interference effect was nonetheless significant at both SA conditions, F(1, 17) = 30.72, MSE = 32,117, $p < .001$ for the 0 ms SA condition, and F(1, 17) = 6.50, MSE = 32,117, $p < .05$ for the –500 ms condition.

Figure I - Median RTs (ms) for Experiment 2 as a Function of Stimulus Asynchrony for 6 to 7 year olds (N=20).



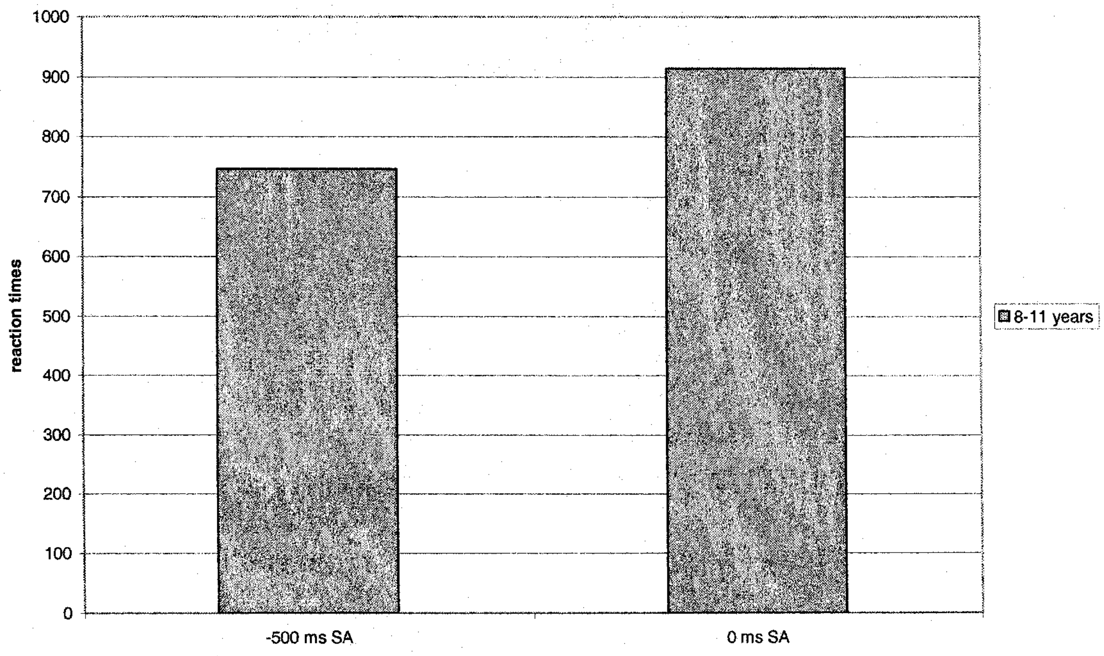
In addition to these effects involving distractor type and stimulus asynchrony, the 6- to 7-year-olds showed an unexpected interaction of picture type and stimulus asynchrony, F(1, 17) = 8.33, MSE = 151,767, $p < .05$. As can be seen in Figure J, with simultaneous presentation of target picture and distractor, animals were named faster than clothing (1176 ms versus 1287 ms), F(1, 17) = 12.08, MSE = 151,767, $p < .01$. However, with the distractor occurring before the picture, reaction times for animal and clothing trials were not statistically significant (885 and 871 ms, respectively).

Figure J - Median RTs (ms) for Experiment 2 as a Function of Stimulus Asynchrony and Distractor Type for 6 to 7 year olds (N=20).



The ANOVA conducted for the 8- to 11-year-olds revealed only a significant main effect of stimulus asynchrony, *F*(1, 18) = 27.31, MSE = 1,122,418, *p* < .001, with longer RTs for trials with simultaneous presentation of picture and distractor than for those with asynchronous presentation (914 versus 746 ms, Figure K).

Figure K - Median RTs (ms) for Experiment 2 as a Function of Stimulus Asynchrony for 8 to 11 year olds (N=20).



For the adults, there was a main effect of stimulus asynchrony, *F*(1, 28) = 8.40, MSE = 46,176, *p* < .01, and an interaction of distractor type and stimulus asynchrony, *F*(1, 28) = 5.23, MSE = 4,463, *p* < .05. Counter to predictions regarding semantic interference, RTs for the 0 ms SA condition were faster for trials with same category distractors than for trials with unrelated distractors, *F*(1, 28) = 7.45, MSE = 4,463, *p* <

.05. For the –500 ms SA condition the effect of distractor type was not significant, *F*(1, 28) ns.

Taken together, these analyses indicate that the effect of distractor type varied dramatically as a function of participant age. The youngest two groups of children showed the predicted semantic interference effect, with slower picture naming reaction times for trials with same category distractors than for trials with different category distractors. In contrast, the oldest children showed no effect of distractor type, and the adults showed the opposite effect, with faster reaction times for trials with same category distractors than for those with different category distractors. While the semantic interference effect was observed at both SA conditions in the youngest two groups of children, the opposite semantic 'priming' effect in adults was present only when the distractor and picture occurred simultaneously. The analyses further indicated that the effect of stimulus asynchrony was highly significant in each age group, but varied in its magnitude with age. The effects of task order and picture type tended to vary with age in idiosyncratic ways. Importantly, task order did not interact with the effect of distractor type at any age.

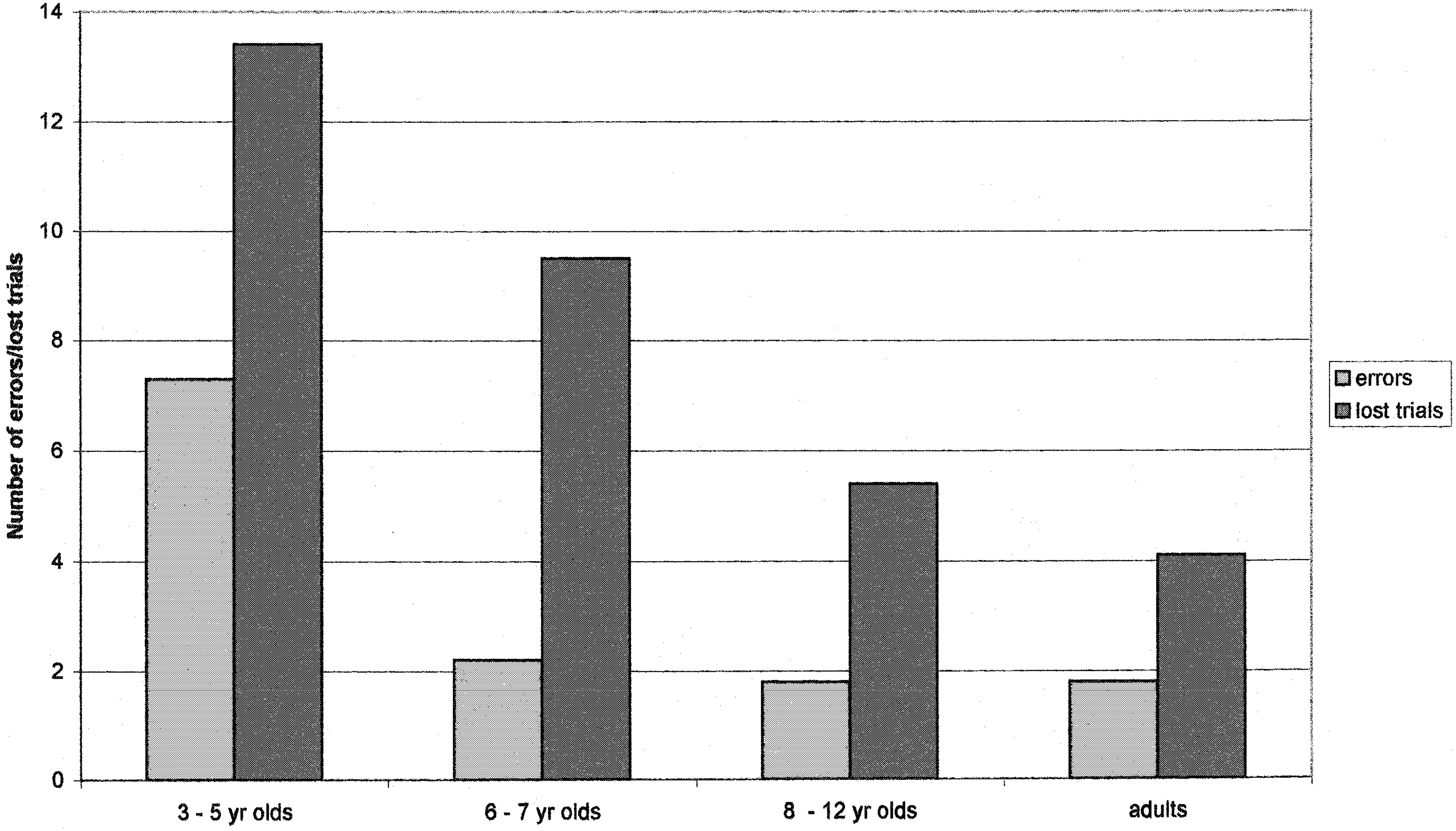
Errors. Trials were counted as errors when the participant misnamed the picture (e.g., seeing the picture of a bear, but saying 'dog'). If a participant hesitated (e.g., by saying 'ah' prior to naming the picture), failed to make any response within 6 seconds, did not speak loudly enough for the voice key to activate, or if the voice key was triggered prematurely (e.g., by heavy breathing in the direction of the microphone or kicking or hitting the desk) the trial was considered lost. Overall, both children and adults were highly accurate in performing the task. Results are presented in Table 4 and Figure

L. Given 216 total test trials (i.e., 108 in each task), the 3- to 5-year olds averaged only 7.3 errors and 13.4 lost trials, the 6- to 7-year-olds averaged 2.2 errors and 9.5 lost trials, the 8- to 11-year-olds averaged 1.8 errors and 5.4 lost trials and adults averaged 1.8 errors and 4.1 lost trials. One-way ANOVAs indicated that number of errors, *F*(3, 84) = 7.58, MSE = 19.0, $p < .001$, and of lost trials, *F*(3, 84) = 7.33, MSE = 53.4, $p < .001$, decreased significantly with age. To further examine error rates for trials involving auditory distractors, error proportions (corrected for numbers of lost trials) were subjected to a mixed-design ANOVA with distractor type, stimulus asynchrony, and picture type as within-subjects factors, and task order and age as between-subjects factors. This ANOVA yielded no significant effects.

Table 4. Number of errors and lost trials for Experiment 2 as a Function Participant Age, (N=19 for 3- to 5-year-olds, N=20 for 6- to 7-year-olds and 8- to 11-year-olds, N=30 for adults).

	Errors	Lost Trials
4-5 years	7.3	13.4
6-7 years	2.2	9.5
9-11 years	1.8	5.4
Adult	1.8	4.1

Figure L – Number of errors and lost trials for Experiment 2 as a Function of Participant Age, (N=19 for 3- to 5-year-olds, N=20 for 6- to 7-year-olds and 8- to 11-year-olds, N=30 for adults).



Discussion

The youngest groups of children (3- to 5-year-olds and 6- to 7-year-olds) showed a cross-modal semantic interference effect in picture naming that resembled the cross-modal Stroop effect found in Experiment 1. Pictures that were paired with auditory distractors from the same semantic category were named more slowly than those paired with semantically unrelated auditory distractors. This interference effect was present at both SA conditions, with simultaneous presentation of target picture and distractor, and with the picture occurring 500 ms after the offset of the distractor. In Experiment 1, it was proposed that the basis of the interference effect was inefficient suppression of the distractor lemma, providing evidence that the effect decreased in magnitude with age and was observed at both of the stimulus asynchronies in children but not in adults. The findings of Experiment 2 are supportive of this account. In Experiment 1 it appeared that the basis of the interference effect was inefficient inhibition of the distractors in working memory, provided by evidence that the effect decreased in magnitude with increasing age and was observed at both of the stimulus asynchronies in children than adults.

In Experiment 2, the oldest children (8- to 11-year-olds) and adults failed to show a semantic interference effect, and the adults showed the opposite effect with significantly faster reaction times for semantically-related trials. The priming effect in adults was observed only with simultaneous presentation of picture and distractor. Delaying the picture by 500 ms provided sufficient time for adults, but not young children, to fully inhibit the distractor. The absence of a semantic interference effect in the oldest children and the adults was surprising. We suspect that several factors may have contributed to this null effect. One such factor is the small set size used in the present study. La Heij and van den Hof (1995) showed, in the purely visual picture-word interference task, that the magnitude of the semantic interference effect in adults was greatly reduced when the response set size was decreased (e.g., from 16 to 4 pictures), and the stimulus pictures were repeated often. Previous cross-modal picture-word interference experiments with adults (Cutting & Ferreira, 1999; Damian & Martin, 1999; Schriefers et al., 1990) have used much larger numbers of stimulus items, with lists comprising items selected from many different superordinate categories. A second factor may be the use of a categorized stimulus list (e.g., all pictures selected from the one or two superordinate categories). Kroll and Stewart (1994) observed that picture naming reaction times were longer for semantically categorized lists as compared to randomized lists of items. They suggested that categorized lists create inter-trial interference at the conceptual level, leading to slower lemma selection of the target picture name. In the context of the present experiment, the use of categorized lists may have increased the amount of time required to access the names of the target pictures. If the time course of lexical access for the target picture name was delayed in our task, then the timing of the distractor word relative to the picture may not have been ideal for generating an interference effect.

The fact that we observed a priming effect in the adults was even more puzzling. The literature on semantic relatedness effects does, however, cite examples of both semantic interference and priming in picture naming (see Glaser, 1992). In the picture-word translation task, a ‘semantic relatedness paradox’ was reported by Bloem and La Heij (2003). They observed that the occurrence of semantic interference versus facilitation in word translation was dependent on whether the distractor was a picture or a word. Adults were instructed to translate English words (e.g., *spoon* into Dutch *lepel*) which were accompanied by a semantically related context picture (a fork) or printed word (*vork,* which is the Dutch for fork). Word translation reaction times were facilitated by a picture of a fork, but inhibited by the word *vork*. Bloem and La Heij explained this pattern through a lemma competition model in which activated concepts do not automatically launch their corresponding lemmas. They argued that a distractor picture creates facilitation because it generates activation only at the conceptual level, and is never put into words. A visually presented distractor word, on the other hand, creates interference because it continually accesses its corresponding lemma, thus competing with the target lemma (e.g., *lepel*) during lexical access.

That study provided us with important insights regarding our results. The use of categorized lists would be expected to increase activation at the conceptual level. Related distractor words could enhance this activation, in the same manner as the related picture primes in the Bloem and La Heij (2003) experiments. The use of auditory rather than visual distractors would lead to relatively short-term activation of the lemma corresponding to the distractor (especially if adults are quick to suppress an irrelevant auditory stimulus). In order for the auditory distractor to produce interference, activation of its corresponding lemma would have to be coincidental with access to the lemma of the target picture name. In cases in which the timing of the distractor did not coincide with access to the lemma for the picture name, a related distractor could nonetheless still increase activation at the conceptual level that would lead to conceptual priming of the picture name.

If this post-hoc explanation for the priming effect in adults is correct, we would expect this effect to be replicated in Experiment 3, in which we held constant the stimulus materials and timing of the auditory distractors. In addition, as in Experiment 1, Experiment 2 confounded response set membership with semantic relatedness of targets and distractors, thus precluding precise determination of the executive components of the effect. In Experiment 3 the animal naming and clothing naming tasks of Experiment 2 were combined into a single task, such that across trials participants randomly viewed 12 different pictures (6 animals and 6 clothing pictures) paired with semantically related and unrelated distractors that were always members of the response set. If the interference effect observed in the youngest children in Experiments 1 and 2 was due to response set interference rather than semantic competition, then the effect should disappear in Experiment 3. If the priming effect observed in the adults in Experiment 2 is due to semantic association, then this effect should be replicated in Experiment 3.

Chapter 4 - Experiment 3

To examine how the establishment of a response set affects the cross-modal picture-word interference effect, in Experiment 3, trials with animal pictures and those with clothing pictures were no longer segregated into separate tasks, but were combined into a single task, such that across trials, the pictures and distractors varied randomly between animal and clothing categories, with equal numbers of trials from each category. As in Experiments 1 and 2, RTs for trials with semantically related distractors (i.e., an animal picture paired with an animal distractor, a clothing picture with a clothing distractor) were compared with RTs for trials with semantically unrelated distractors (i.e., an animal picture paired with a clothing distractor, a clothing picture with an animal distractor) to determine the occurrence of interference and/or priming due to semantic relatedness.

Method

Participants. Nineteen 3- to 5-year-olds (7 boys, 12 girls: mean age = 5 yrs. 0 mos., range = 3 yrs. 10 mos. – 5 yrs 11mos), 20, 6- to 7-year-olds (8 boys, 12 girls: mean age = 7yrs. 2 mos. range = 6 yrs. 5 mos – 7 yrs. 11 mos.), 20, 8- to 11-year-olds (10 boys, 10 girls: mean age = 10 yrs. 2 mos., range = 8 yrs. 4 mos. – 11 yrs. 11 mos.) and 30 adults (9 men, 21 women: mean age 25 yrs., range = 18 – 47 yrs.) participated in the study. The participants were recruited from the same sources as in Experiments 1 and 2. All participants had corrected to normal vision and normal hearing, and were native speakers of English. None had participated in the previous experiments. The study was approved by the IRB of the College of Staten Island of the City University of New York and all adult participants and parents of participants under age 18 signed written informed consent forms prior to the start of the experiment.

Materials and Apparatus. The materials and apparatus were exactly the same as in Experiment 2.

Procedure. The task was essentially the same as in Experiment 2: Participants were instructed to name pictures while listening to distractor words over headphones. However, in each block of trials, half of the pictures were clothing and half were animals (in contrast to Experiment 2 where participants named only clothing pictures in one task, and only animal pictures in the other). As in Experiment 2, for animal naming trials with auditory distractors, the distractor was an animal word for half of the trials, and a clothing word for the other half. Likewise, for clothing naming trials, distractors were equally often animal and clothing words.

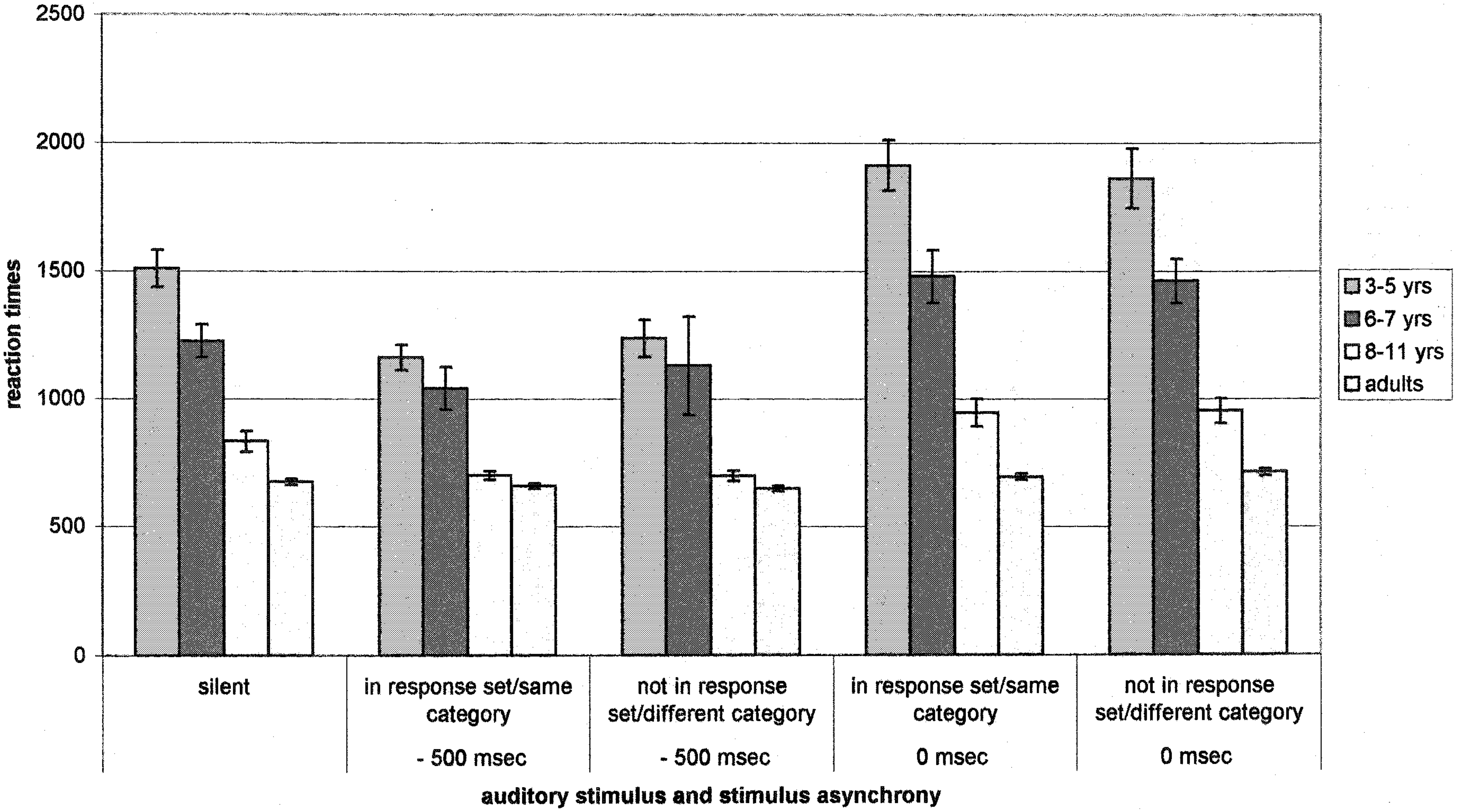
Results

Reaction times. Median RTs for correct trials were used as the dependent measure due to the positive skew of the RT distributions. Table 3 and Figure M present RTs for each age group, as a function of distractor type and stimulus asynchrony. Overall, picture naming was again fastest for the -500 ms condition, intermediate for the silent condition, and slowest for the 0 ms condition, replicating the results of Experiments 1 and 2. In replicating the methodology of Experiments 1 and 2, we did not include a baseline condition in Experiment 3 where we could adequately measure nonverbal auditory interference at both SA's. Therefore, we have determined that the silent condition not be included in the statistical analysis and in the following statistical analyses we examined only picture naming reaction times for trials involving auditory distractors, and did not consider the silent condition further. Again, in future research, we would recommend using a baseline condition, such as a tone, that can be applied at both SA's and therefore considered in the statistical analysis.

Table 5. Median RTs (ms) for Experiment 3 as a Function of Auditory Stimulus Condition (Stimulus Asynchrony and Distractor Type) and Participant Age, with Standard Errors in Parentheses (N=19 for 3- to 5-year-olds, N=20 for 6- to 7-year-olds and 8- to 11-year-olds, N=30 for adults).

	Auditory Stimulus Condition				
		-500 ms SA		0 ms SA	
	Silent	In Response Set / Same Category	In Response Set / Different Category	In Response Set / Same Category	In Response Set / Different Category
3-5 years	1510 (72)	1163 (50)	1239 (74)	1914 (98)	1892 (117)
6-7 years	1228 (65)	1042 (84)	1132 (193)	1481 (102)	1462 (86)
8-11 years	834 (40)	700 (17)	699 (19)	947 (54)	954 (49)
Adult	675 (11)	659 (10)	649 (10)	695 (12)	714 (13)

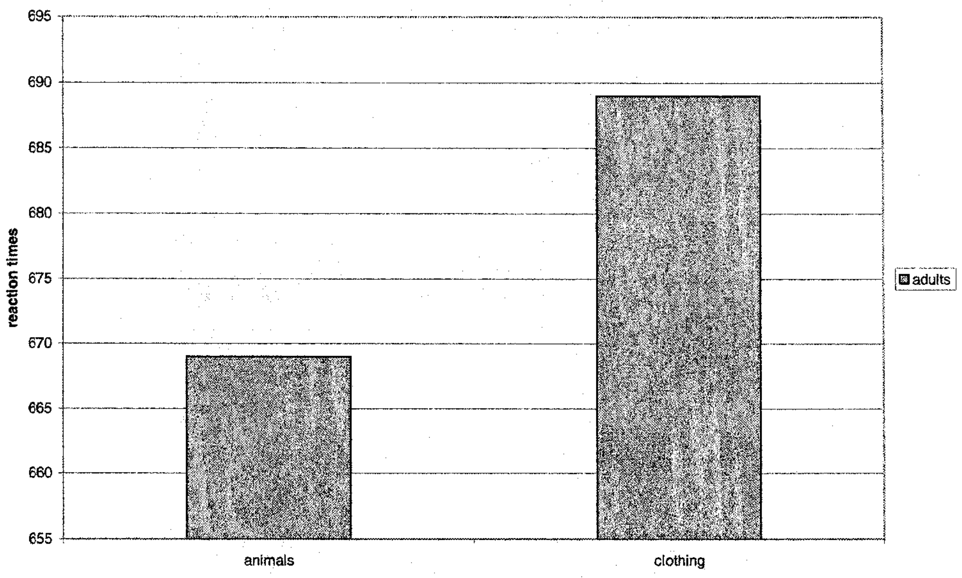
Figure M – Median RTs (ms) for Experiment 3 as a Function of Auditory Stimulus Condition and Participant Age, with Standard Errors (N=19 for 3- to 5-year-olds, N=20 for 6- to 7-year-olds and 8- to 11-year-olds, N=30 for adults).



Median picture naming reaction times for trials with distractors were analyzed in a 2x2x2x4 mixed-design ANOVA with distractor type (same semantic category, different semantic category), stimulus asynchrony (-500 ms, 0 ms), and picture type (animal, clothing) as within-subjects factors, and age (3- to 5-year-olds, 6- to 7-year-olds, 8- to 11-year-olds, and adults) as a between-subjects factor. The ANOVA showed highly significant main effects of age, *F*(3, 85) = 36.58, MSE = 797,851, $p < .001$, and stimulus asynchrony, *F*(1, 85) = 109.03, MSE = 190,006, $p < .001$, and a significant two-way interaction of age and stimulus asynchrony, *F*(3, 85) = 17.94, MSE = 190,006, $p < .001$. No other main effects or interactions were significant.

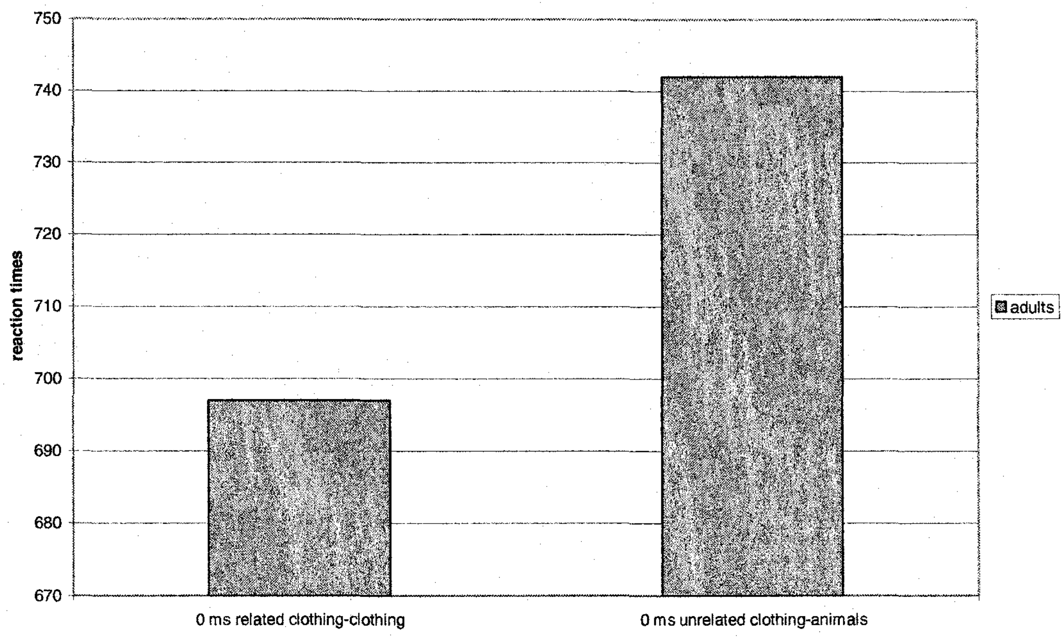
To decompose the interaction of age and stimulus asynchrony, and to confirm the absence of a semantic interference effect at any age, a separate ANOVA for each age group was conducted, with distractor type, stimulus asynchrony, and picture type as within-subjects factors. For each child group, only the main effect of stimulus asynchrony was significant, *F*(1, 18) = 119.71, MSE = 156,319, $p < .001$ for the 3- to 5-year-olds, *F*(1, 19) = 10.32, MSE = 572,715, $p < .01$ for the 6- to 7-year-olds, and *F*(1, 19) = 20.34, MSE = 123,844, $p < .001$ for the 8- to 11-year-olds. In contrast, for the adults, the ANOVA revealed significant main effects of stimulus asynchrony, *F*(1, 29) = 43.95, MSE = 3,522, $p < .001$, and picture type, *F*(1, 29) = 14.13, MSE = 1,671, $p < .001$, with faster RTs for animal pictures than for clothing pictures (669 versus 689 ms, Figure N).

Figure N - Median RTs (ms) for Experiment 3 as a Function of Distractor Type for adults (N=30)



In addition to these main effects in adults, there was a significant two-way interaction of distractor type and stimulus asynchrony, $F(1, 29) = 10.38$, MSE = 1,256, $p < .01$, and a three-way interaction of distractor type, picture type, and stimulus asynchrony, $F(1, 29) = 9.40$, MSE = 1,206, $p < .01$. Replicating Experiment 2, and counter to predictions regarding a semantic interference effect, for trials in the 0 ms condition, RTs were faster for trials with same category distractors than for trials with unrelated distractors, $F(1, 29) = 9.05$, MSE = 1,256, $p < .01$. Further analysis, however, revealed that this semantic priming effect was significant only for clothing naming, $F(1, 29) = 25.00$, MSE = 1,206, $p < .001$ (with means of 697 and 742 ms, respectively, for clothing trials with same category versus unrelated distractors, as represented in Figure O), and not significant for animal naming, $F(1, 29)$ ns.

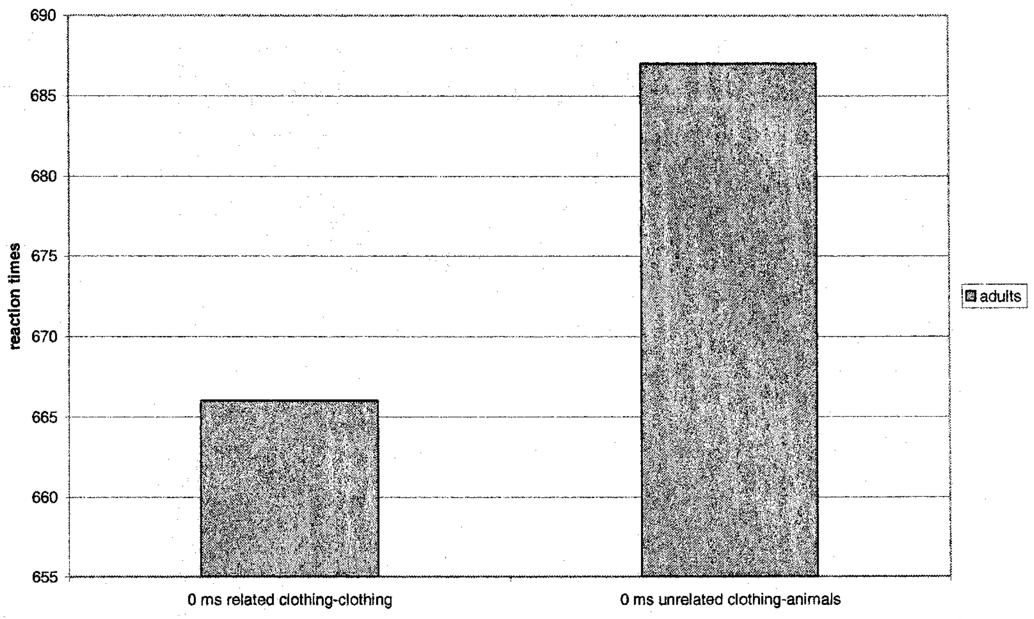
Figure O - Median RTs (ms) for Experiment 3 as a Function of simultaneous SA and clothing distractor type for adults (N=30)



As in Experiment 2, there was no significant effect of distractor type in the –500 ms condition in adults.

Given the absence of a semantic priming effect for animal naming trials in Experiment 3, the data from the adults in Experiment 2 were reexamined to determine whether the same pattern was obtained. For clothing naming trials, with simultaneous presentation of picture and distractor, the semantic priming effect was indeed significant, $F(1, 28) = 12.71$, MSE = 605, $p < .01$ (with means of 666 and 687 ms, respectively, for clothing trials with same category and unrelated distractors, as represented in Figure P) whereas for animal naming trials, the priming effect was not significant, $F(1, 28) = 1.61$, ns. Thus, the results of the two experiments are entirely consistent with each other with respect to the semantic priming effect in adults.

Figure P - Median RTs (ms) for Experiment 2 as a Function of simultaneous SA and clothing distractor type for adults (N=30)

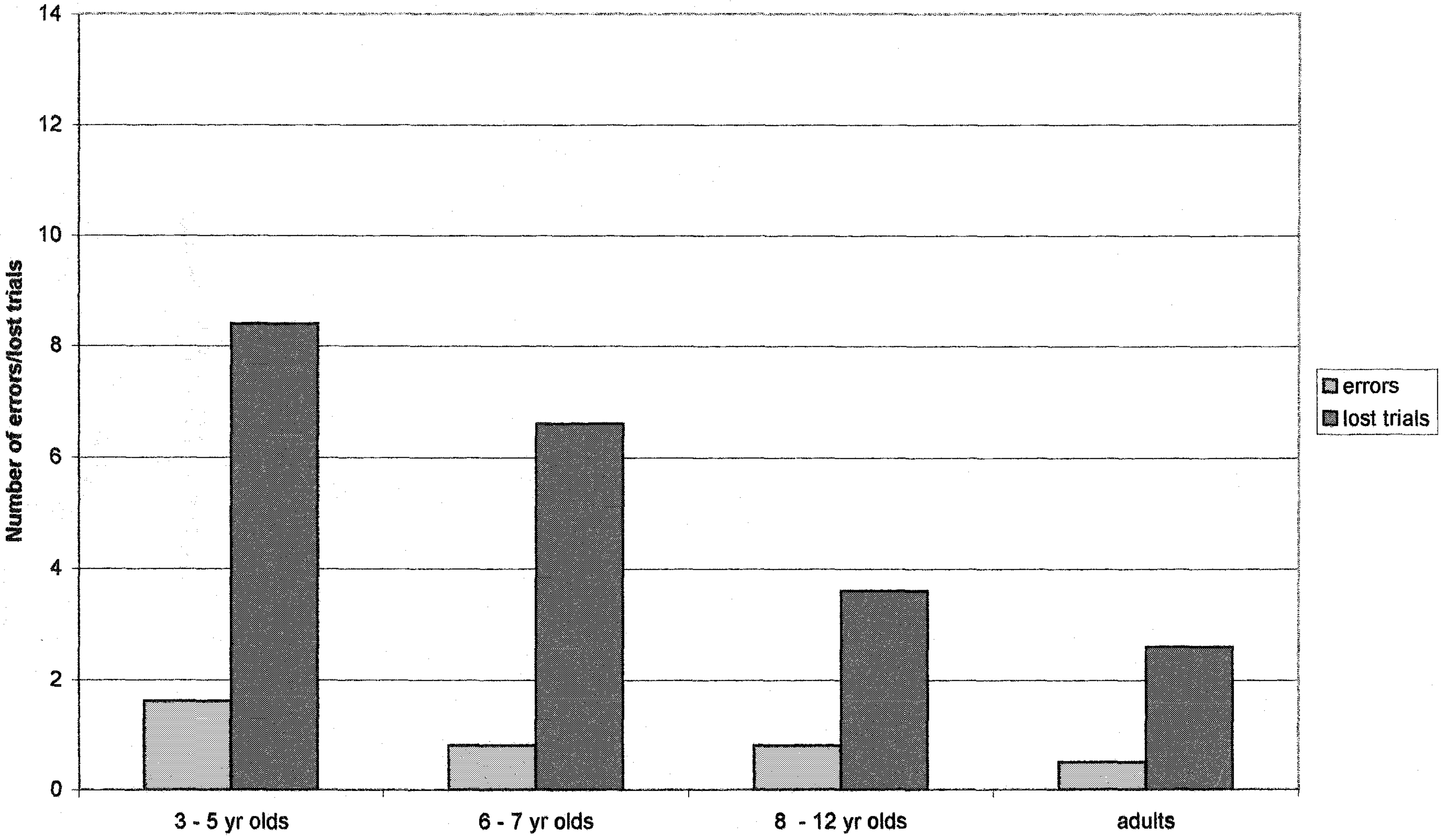


Errors. As in Experiments 1 and 2, children and adults were highly accurate in performing the naming task. Error rates and lost trials are represented in Table 6 and Figure Q. Of the 108 total test trials, the 3- to 5-year olds averaged 1.6 errors and 8.4 lost trials, the 6- to 7-year-olds averaged 0.8 errors and 6.6 lost trials, the 8- to 11-year-olds averaged 0.8 errors and 3.6 lost trials and adults averaged 0.5 errors and 2.6 lost trials. One-way ANOVAs indicated that number of lost trials decreased significantly as a function of age, $F(3, 85) = 5.49$, MSE = 29.1 , $p < .01$, whereas numbers of errors did not, $F(3, 85) = 1.87$, ns.

Table 6. Number of errors and lost trials for Experiment 3 as a Function Participant Age, (N=19 for 3- to 5-year-olds, N=20 for 6- to 7-year-olds and 8- to 11-year-olds, N=30 for adults).

	Errors	Lost Trials
4-5 years	1.6	8.4
6-7 years	0.8	6.6
9-11 years	0.8	3.6
Adult	0.5	2.6

Figure Q – Number of errors and lost trials for Experiment 3 as a Function Participant Age (N=19 for 3- to 5-year-olds, N=20 for 6- to 7-year-olds and 8- to 11-year-olds, N=30 for adults).



Discussion

With animal and clothing trials combined into a single task, no semantic interference was observed in children or adults, suggesting that the interference effects observed in Experiments 1 and 2 were produced by the combination of semantic relatedness and response set membership. For all groups of children, RTs for related trials (e.g., an animal word paired with an animal picture) and unrelated trials (e.g., a clothing word paired with an animal picture) were not found to be statistically different. While the change in methodology greatly affected the magnitude of the semantic interference effect, it had very little impact on the semantic priming effect (i.e., faster RTs for trials with semantically related distractors than for trials with unrelated distractors) that was observed in the adult sample. As in Experiment 2, the priming effect was observed only with simultaneous presentation of target picture and distractor word, indicating that early presentation of the distractor provided adults with sufficient time to suppress it in working memory. In Experiment 3, unlike Experiment 2, there was an overall difference in adult performance in naming animals versus clothing, with slower reaction times for the latter. Furthermore, the priming effect was reliable for clothing naming trials, but not for animal naming trials, possibly because the clothing items tended to be more closely associated with each other than was the case for the animals (e.g., *shoe-sock* versus *fish-bear*). In addition, it is also possible that animal distractors might have produced greater interference than clothing distractors in clothing naming trials in Experiment 3 in part because the animal names tended to be accessed more quickly.

While combining animal and clothing pictures into a single task was sufficient to eliminate the semantic interference observed in Experiments 1and 2, it has not yet been determined whether semantic relatedness among pictures in the response set is required for children to construct a response set in the first place. In Experiment 4, we examined whether response set membership, in and of itself, affects the magnitude of interference from auditory distractors, in the case where target pictures were not members of the same semantic category. The selection of unrelated pictures in the response set eliminates the possibility of priming at the conceptual level. Hence adults should no longer show faster picture naming reaction times for trials with distractors in the response set.

Chapter 5 - Experiment 4

Experiment 4 sought to determine the existence of a cross-modal picture-word interference effect due solely to response set membership. Two sets of unrelated pictures were constructed, with participants naming pictures from only one set. To test for a response set interference effect, RTs for trials with distractors from the participant's response set were compared with RTs for trials with distractors that were not in the participant's response set.

Method

Participants. Twenty 4- to 7-year-olds (7 boys, 13 girls: mean age = 6 yrs. 5 mos., range = 4 yrs. 9 mos. – 7 yrs. 10 mos.) 18 9- to 12-year-olds (12 boys, 6 girls: mean age = 10 yrs. 7 mos., range = 9 yrs. 0 mos. – 12 yrs. 5 mos.)[2], and 30 adults (13 men, 17 women, mean age = 22 yrs., range = 17-37 yrs.) participated in the study. The participants were recruited from the same sources as in Experiments 1, 2 and 3. All participants had corrected to normal vision and normal hearing, and were native speakers of English. None had participated in the previous experiments. The study was approved by the IRB of the College of Staten Island of the City University of New York and all adult participants and parents of participants under age 18 signed written informed consent forms prior to the start of the experiment.

Materials and Apparatus. The apparatus was the same as in Experiments 1, 2 and 3. The stimulus items were 12 black and white line drawings selected from the Snodgrass and Vanderwart (1980) set of standardized pictures. The specific pictures selected were those that were easily recognized by children (Cycowicz, Friedman, Snodgrass & Rothstein, 1997) and were members of different superordinate categories, with the further criterion that the names of the 12 pictures have distinct initial phonemes and rhymes. Pictures were arranged in two sets with six pictures in each. Each group of pictures comprised a response set. Half of the participants in each age group were shown pictures from set A and the other half were shown pictures from set B. Stimulus pictures for set A were *book, chair, flower, house, pig* and *window*. Stimulus pictures for set B were *apple, cup, doll, moon, scissors* and *train*.

Spoken words corresponding to the names of the twelve pictures were presented over headphones in a naturally spoken female voice. The auditory distractors were the names of the pictures from both sets A and B. The auditory stimulus durations ranged from 767 to 1092 ms with a mean of 952 ms for words corresponding to pictures in Set A and 790 to 1069 ms with a mean of 957 ms for words corresponding to pictures in Set B. As in the prior experiments, in each block of trials, items were randomly selected with replacement from a list combining each stimulus picture with each word, except for the matching word. Thus, pictures were paired with auditory distractors that were both in and out of the participant's response set. For example, the word *doll* paired with a picture of a moon would comprise an 'in response set' trial, because both *doll* and *moon* were members of response set B. In contrast, the word *flower* paired with a picture of a moon would comprise a 'not in response set' trial, because *flower* was not a member of response set B. In each block of trials, pictures were paired with distractors corresponding to items in their response set, and items not in their response set equally often.

Procedure. The procedures were the same as in the previous experiments.

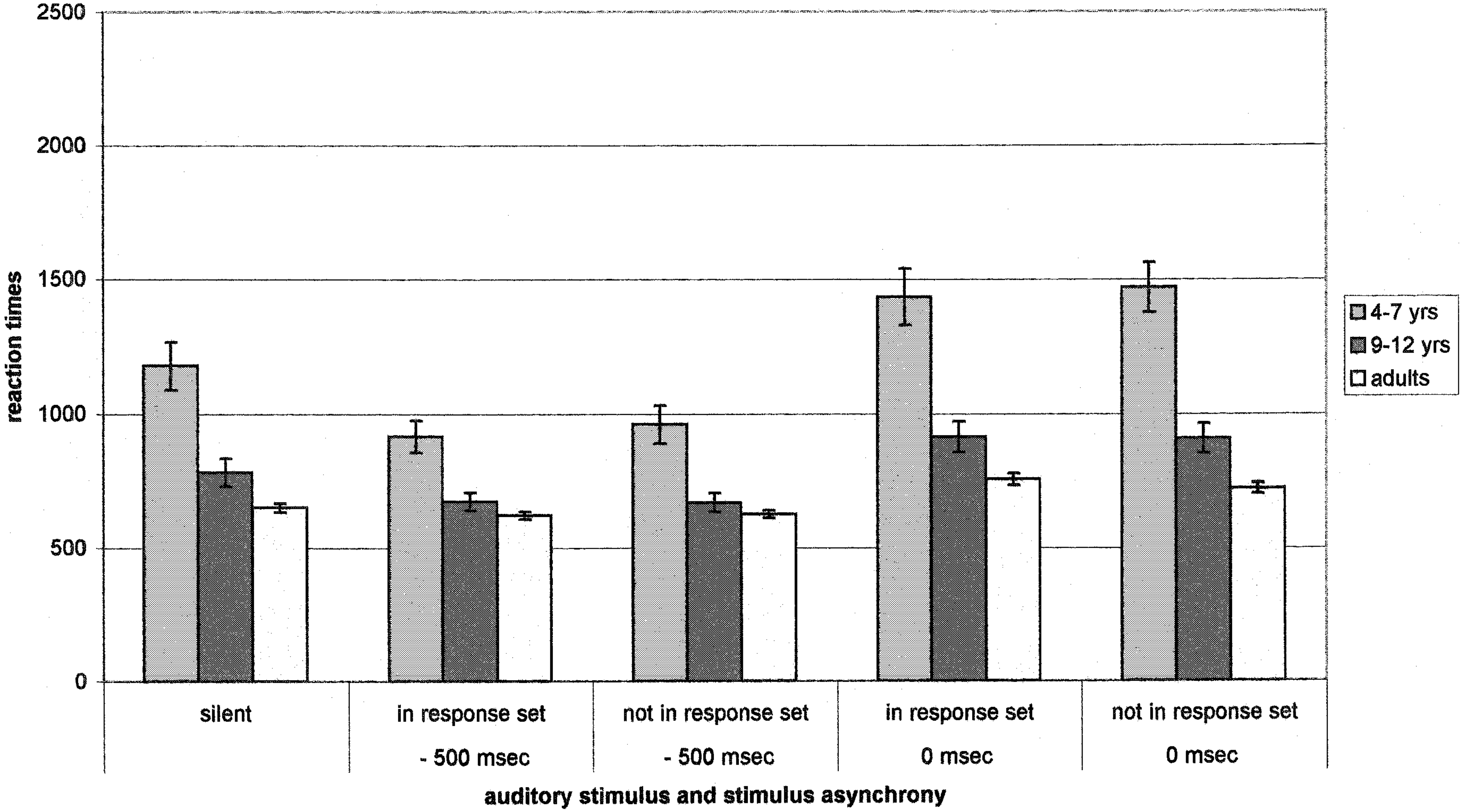
Results

Reaction times. Table 7 and Figure R present the mean RTs as a function of distractor type and stimulus asynchrony.[3] As in the previous experiments, picture naming was fastest for the -500 ms condition, intermediate for the silent condition, and slowest for the 0 ms condition. In replicating the methodology of Experiment 1, 2 and 3, we did not include a baseline condition in Experiment 4 which could adequately measure nonverbal auditory interference at both SA's. Therefore, we have determined that the silent condition not be included in the statistical analyses and in the following statistical analyses, we examined only picture naming reaction times for trials involving auditory distractors, and did not consider the silent condition further. Again, in future research, we would recommend using a baseline condition, such as a tone, that can be applied at both SA's and therefore considered into the statistical analysis.

Table 7. Median RTs (ms) for Experiment 4 as a Function of Auditory Stimulus Condition (Stimulus Asynchrony and Distractor Type) and Participant Age, with Standard Errors in Parentheses (N=20 for 4- to 7-year-olds, N=18 for 9- to 12-year-olds, N=30 for adults).

	Auditory Stimulus Condition				
	-500 ms SA			0 ms SA	
	Silent	In Response Set	Not In Response Set	In Response Set	Not In Response Set
4-7 years	1171 (88)	917 (60)	962 (71)	1435 (105)	1469 (92)
9-12 years	783 (52)	674 (34)	669 (36)	915 (58)	909 (55)
Adult	651 (17)	622 (14)	626 (14)	756 (22)	723 (20)

Figure R – Median RTs (ms) for Experiment 4 as a Function of Auditory Stimulus Conditionand Participant Age, with Standard Errors (N=20 for 4- to 7-year-olds, N=18 for 9- to 12-year-olds, N=30 for adults).



Median picture naming reaction times for trials with distractors were analyzed using a 2x2x2x3 mixed-design ANOVA with stimulus asynchrony (-500 ms, 0 ms) and distractor type (in response set, not in response set) as within-subjects factors and task version (response set A as target pictures, response set B as target pictures) and age (4- to 7-year-olds, 9- to 12-year-olds, adults) as between-subjects factors. The ANOVA showed significant main effects of age, $F(2, 62) = 33.68$, MSE = 196,671, $p < .001$, and stimulus asynchrony, $F(1, 62) = 309.39$, MSE = 17,279, $p < .001$, qualified by a two-way interaction of age and stimulus asynchrony, $F(2, 62) = 55.37$, MSE = 17,279, $p < .001$. The only other effect to approach significance was a marginal interaction of distractor type and age, $F(2, 62) = 2.77$, MSE = 6,723, $p = .07$.

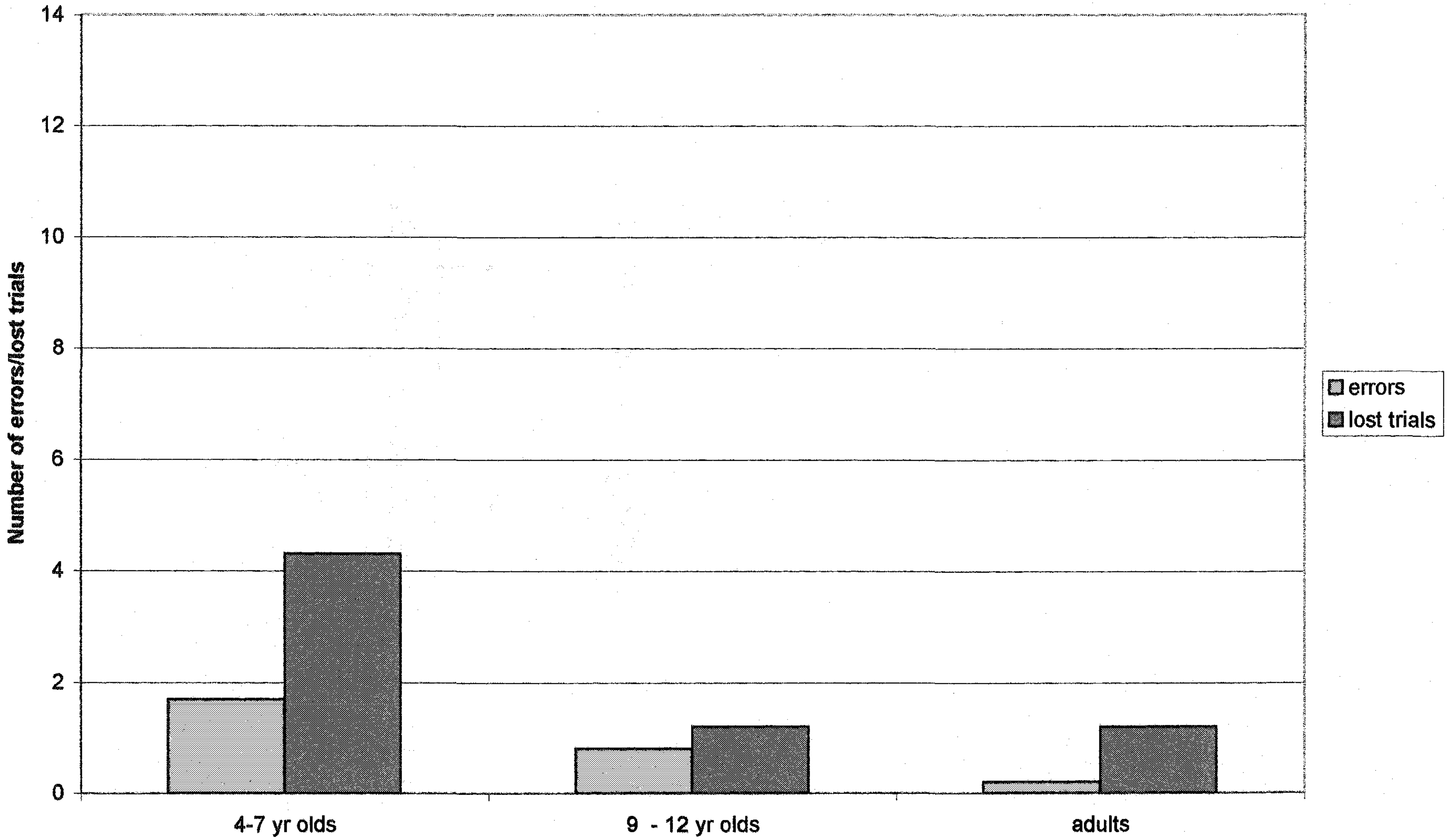
As in Experiment 3, separate ANOVAs for each age group were conducted to confirm the lack of an effect of distractor type, and to break down the interaction of age and stimulus asynchrony. In these ANOVAs, stimulus asynchrony and distractor type were within-subjects factors, and task version was a between-subjects factor. For both groups of children, only the main effect of stimulus asynchrony was significant, $F(1, 18) = 120.83$, MSE = 43,565, $p < .001$ for the 4- to 7-year-olds, and $F(1, 16) = 77.74$, MSE = 12,621, $p < .001$ for the 9- to 12-year-olds. In contrast, for the adults, both the main effects of stimulus asynchrony, $F(1, 28) = 132.42$, MSE = 3,042, $p < .001$, and distractor type, $F(1, 28) = 8.46$, MSE = 763, $p < .01$, were significant, qualified by a significant two-way interaction of stimulus asynchrony and distractor type, $F(1, 28) = 16.18$, MSE = 609, $p < .001$. Adults named pictures paired with distractors in their response set more slowly than pictures paired with distractors not in their response set. This 'response set' interference effect was observed when the picture and distractor occurred at the same time, $F(1, 28) = 26.48$, MSE = 609, $p < .001$, but was not significant when the distractor preceded the picture by 500 ms, $F(1, 28) < 1$.

Errors. Of the 108 total test trials, the 4- to 7-year olds averaged 1.7 errors and 4.3 lost trials, the 9- to 12-year-olds averaged 0.8 errors and 1.2 lost trials and adults averaged 0.2 errors and 1.2 lost trials. One-way ANOVAs indicated that both errors, $F(2, 65) = 8.92$, MSE = 1.4, $p < .001$, and lost trials, $F(2, 65) = 5.39$, MSE = 12.5, $p < .01$, decreased significantly with age. Due to the low numbers of errors produced, no additional analyses were conducted. Table 8 and Figure S represent the number of errors and lost trials.

Table 8. Number of errors and lost trials for Experiment 4 as a Function Participant Age, (N=20 for 4- to 7-year-olds, N=18 for 9- to 12-year-olds, N=30 for adults).

	Errors	Lost Trials
4 -7 years	1.7	4.3
9-12 years	0.8	1.2
Adult	0.2	1.2

Figure S – Number of errors and lost trials for Experiment 4 as a Function Participant Age, (N=20 for 4- to 7-year-olds, N=18 for 9- to 12-year-olds, N=30 for adults).



Discussion

To examine whether response set membership by itself would affect the magnitude of the cross-modal picture-word interference effect, in Experiment 4, sets of pictures containing items that were members of different superordinate categories were constructed. The use of lists comprising unrelated pictures eliminated the conceptual basis for the priming effect observed in adults in the previous experiments. Adults, but not children, named pictures more slowly when paired with unrelated distractors from their response set, than when paired with unrelated distractors that were not in their response set. This suggests that adults, but not children, spontaneously constructed an ad hoc response set in working memory even when the pictures comprising the set were unrelated to each other. Activation of a response set allowed the adults to respond differentially to distractors as a function of whether they were candidate names for the pictures. The response set interference effect in adults was present only with simultaneous presentation of the picture and distractor, indicating that presenting the distractor 500 ms in advance of the picture enabled adults to fully suppress it.

Chapter 6 - General Discussion

In this series of studies, we examined the development of selective attention and resistance to interference using both an auditory-visual cross-modal Stroop and an auditory-visual cross-modal Stroop-like picture-interference task. Children of ages 3 to 12 years as well as adults participated. Prior studies of selective attention (e.g., Dempster, 1992; 1993; Lane & Pearson, 1982; Zelazo, Carter, Reznick, & Frye, 1997) have demonstrated that the ability to selectively inhibit distracting information and suppress inappropriate action develops throughout childhood and adolescence. However, these prior studies did not specifically address the issue of whether irrelevant spoken language can be ignored while selectively attending to a visual stimulus. The specific tasks utilized here have shown to be appropriate measures for this purpose in that they enabled us to test individuals of a wide range of ages using identical procedures.

In Experiment 1, an auditory distractor word was either simultaneously presented with a color patch (e.g., purple) or was presented 500 ms prior to the presentation of the color patch. The auditory distractors were either the names of the color patches, (e.g., yellow) or were an unrelated adjective (e.g., fewer). When the auditory distractor occurred simultaneously with the presentation of the color patch, a significant Stroop-like interference effect was found across both child and adult groups that decreased markedly in effect size with age. This pattern of greater interference from auditory distractors in children than adults is highly consistent with recent work demonstrating greater salience of the auditory versus the visual modality in children (Sloutsky & Napolitano, 2003). We also observed a Stroop-like interference effect in 4- to 5-year-olds (the youngest children) when the distractor was presented 500 ms in advance of the color patch which confirms the inefficiency in children's inhibitory mechanisms. However, because the color-word distractors named colors in the response set (i.e., the color patches), we could not determine whether the interference effect was due to the semantic relatedness of the distractors to the target colors or to their being members of the same response set.

Consequently, in Experiment 2, we attempted to replicate the results of Experiment 1 and to explore the relative contributions of response set competition and semantic competition to age related differences in a cross-modal picture-word interference task. Using the same procedure as Experiment 1, in Experiment 2 we used visual stimuli and auditory distractors which could easily be rendered as pictures (i.e., animals and clothing) rather than using colors. As in Experiment 1, response set membership and semantic relatedness of distractors were intentionally confounded. Both of the youngest groups of children (3- to 5-year-olds and 6- to 7-year-olds), but not the oldest children (8- to 11-year-olds) nor the adults, showed a cross-modal semantic interference effect in picture naming. Pictures paired with distractors from the same semantic category (i.e., animal pictures paired with animal distractors) were named more slowly than pictures paired with unrelated distractors (i.e., animal pictures paired with clothing distractors). In the two youngest groups of children, this interference effect was observed both with simultaneous presentation of the distractor and the picture, and with the distractor occurring 500 ms in advance of the picture. The extended time course of the interference effect in the youngest children matches that of the cross-modal Stroop effect of Experiment 1 and again demonstrates the inefficiency of children's inhibitory mechanisms. These findings are important in demonstrating age-related change in children's ability to distinguish relevant and irrelevant information, and in showing developmental improvement in the efficiency of response selection procedures.

In Experiment 3, the simple act of combining the pictures of animals and clothing into a single task completely eliminated the semantic interference effect for all age groups. RTs for semantically-related trials were not found to be statistically different in any of the groups of children. The combination of semantic categories into a single response set had a dramatic effect on results. Thus it appears that the Stroop-like effect observed in Experiments 1 and 2 depended on the categorization of semantically related distractors into members of the same response set (e.g. only animals or only clothing). It is difficult to relate this pattern of results to the findings of Caramazza and Costa (2000), who used a visual picture-word interference task and found that response set membership did not affect the magnitude of the semantic interference effect in adults. In contrast to the present study, the Caramazza and Costa experiments tested only adults, and used a large set of stimulus pictures sampled from many different superordinate categories, with few repetitions of either pictures or distractors. Further research is needed to directly examine the effect of response set membership across auditory-visual cross-modal and purely visual picture-word interference paradigms, holding constant these additional factors. An important consideration here is that a visually presented distractor will continually activate its corresponding lemma (i.e., with each visual fixation), whereas an auditory distractor will have a more transient effect in terms of activation of its lemma.

To further distinguish the contributions of semantic relatedness and response set interference in the cross-modal picture-word interference task, in Experiment 4, we eliminated the possibility of conceptual priming by presenting participants with unrelated pictures selected from different superordinate categories. The auditory distractors were either members of the visual stimuli's response set or other auditory distractors which were not a part of the response set. None of the auditory distractors were semantically related to the pictures. Interestingly, only adults showed a pure response set interference effect, naming pictures more slowly when paired with unrelated distractors within their response set as compared to unrelated distractors that were not in their response set. This response set interference effect in adults occurred only with simultaneous presentation of picture and distractor, providing further support for the inhibition account. The finding that the children's reaction times were not affected by response set membership in the absence of semantic coherence among pictures in the response set suggests that the working memory component involved in categorizing and holding each picture in mind was overtaxed. The ability to construct an ad hoc response set in working memory (Barsalou, 1983) may be a manifestation of the maturation of executive functions.

It is of interest that, in our pilot work using the cross-modal Stroop task of Experiment 1 with eight 3-year-olds (aged 3 years, 4 months – 3 years, 11 months), we found that the majority of children at this age could not perform the cross-modal Stroop task at all. In the practice condition, when asked to name the color patches in the absence of auditory distractors, the 3-year-olds performed accurately. However, when the distractors were presented along with the color patches, all but 2 of the children consistently repeated the words they had heard, even though they knew that the rules were to "say what you see." Only 2 children were able to complete a single block of 36 test trials and produced only 28% and 40% correct responses for this block. Attempts to train the 3-year-olds to ignore the spoken words while naming the color patches led to child frustration and forced us to abandon testing younger children. Clearly, the auditory modality was highly salient and nearly impossible for our youngest participants to ignore while visualizing color patches. In comparison with the 3-year-olds, none of the 4- to 5-year-olds produced errors in over 20% of the trials with distractors, and only 3 children had error rates over 10%. Interestingly, 3-years-olds did not encounter such difficulties in Experiments 2 and 3. These results are in line with the research of Braisby and Dockrell (1999) and Pitchford, and Mullen (2002) who found that preschoolers (ranging in age from two to five-years-old) had the ability to recognize objects, such as animals, much earlier and with less constraint than color names. The earlier acquisition and comprehension of the animal and clothing names in Experiments 2, 3 & 4 may have led to easier lexical access and less confusion than was the case for the children in Experiment 1 in which color names and color patches were used.

Our finding of a developmental trajectory in performance on the auditory-visual cross-modal Stroop and the Stroop-like picture-word interference tasks helps to clarify the literature on the effect. With only adults being tested in previous cross-modal Stroop experiments, some researchers have found reliable interference (Cowan, 1989; Cowan & Barron, 1987; Elliott & Cowan, 2001; Elliott et al., 1998), whereas others have not (Miles & Jones, 1989; Miles et al., 1989). What is most pronounced in our data is the finding that the cross-modal Stroop effect becomes progressively weaker with age and is a relatively small effect in adults. In addition, the construction of a response set in working memory is a major factor in this effect. The fact that a robust cross-modal Stroop effect appeared when children were tested in Experiments 1 and 2 runs counter to Miles and his colleagues' assertion that interference from irrelevant spoken words occurs only in tasks involving short-term memory.

Elliott et al. (1998) considered two explanations of the cross-modal Stroop effect: They argued that semantic interference might occur in a temporary speech buffer unless there is sufficient time for the spoken word to be suppressed. Consistent with this hypothesis was their observation that the cross-modal Stroop effect fully disappeared in adults if the auditory distractor was presented 500 ms in advance of the color patch. Elliott et al., however, could not rule out an alternative hypothesis, namely that the cross-modal Stroop effect stems from concurrent lexical processing in the auditory and visual modalities (Schriefers et al., 1990). According to this concurrent processing account, the interference effect occurs when there is temporal overlap in accessing the lemmas for the spoken word and name of the color patch, and stems from competition among lemmas during lexical access.

To test these two accounts, we varied the timing of presentation of the auditory distractor relative to presentation of the color patch or the picture. It was hypothesized that the cross-modal Stroop effect would be seen at both stimulus asynchronies in children while only being seen in the simultaneous condition in the adults due to age differences in information processing speed (Kail, 1991; 1992) coupled with less efficient inhibition mechanisms in children (Bjorklund & Harnishfeger, 1990; Livesey & Morgan, 1991; Tipper, Bourque, Anderson & Brehaut, 1989). In one condition the color patch or picture occurred simultaneously with the distractor. With simultaneous presentation, both inhibition and concurrent processing accounts would predict a cross-modal Stroop effect to occur, replicating Elliott et al. (1998). In the other condition the color patch or picture was delayed and appeared 500 ms after the offset of the distractor. It was suspected that a -500 ms stimulus offset interval would be sufficient to prevent temporal overlap in lexical access for the auditory distractor and the color patch/picture. Thus, the occurrence of a cross-modal Stroop effect, even in the youngest children, would be inconsistent with the concurrent processing account. The results favored the inhibition account: In Experiments 1 and 2, the youngest participants showed a large interference effect at both stimulus asynchronies, whereas older participants showed interference only with simultaneous presentation of the distractor and color patch/picture. Thus, delaying presentation of the color patch/picture by 500 ms provided older children and adults, but not younger children, with sufficient time to fully suppress the irrelevant stimulus.

One possible challenge to this interpretation of the results is that, given the relative inefficiency of word retrieval processes in children, a -500 ms stimulus asynchrony might not be sufficiently long to prevent simultaneous lexical activation of the distractor and color patch names in very young children. Under normal listening conditions, lexical access occurs rapidly, even in young children. This has been shown in recent on-line studies of the development of word recognition, indicating that children as young as 24 months of age access the meanings of familiar spoken words prior to their offsets (Fernald, Pinto, Swingley, Weinberg & McRoberts, 1998; Swingley et al., 1999). Indeed, word recognition based on only partial input has been observed in 24-month-olds even when the words in the response set share initial consonants, as in *doll* and *doggie* (Swingley et al., 1999). In gating studies examining word recognition for the larger vocabularies characteristic of school-aged children, Elliott, Hammer and Evan (1987) and Walley, Michela, and Wood (1995) demonstrated that 5- to 7-year-olds readily identify words based on partial input. For example, Walley et al. (1995) estimated that kindergarteners (mean age 6;0) isolated target words after only hearing 66% of the sound pattern (i.e., for words of average length 617 ms, words were identified at 406 ms). While informative, these research findings unfortunately do not indicate how long lexical activation lingers in the developing system. Thus, it is impossible to guarantee that in the cross-modal Stroop and picture-word interference tasks, where participants could use the distractor as a cue to anticipate the onset of the color patch or picture, there would be no temporal overlap in lexical activation of the target and distractor names.

The inhibition account of the cross-modal Stroop effect is consistent with related findings in the developmental literature on the phenomenon of negative priming. Negative priming occurs when a participant must respond to a stimulus that was to be ignored on the preceding trial. Suppose, for example, in the original Stroop task, that on trial 1 a participant saw the word *blue* printed in green and on trial 2, saw the word *red* printed in blue. Identifying blue as the print color on trial 2 would take longer than if it had not been the to-be-ignored stimulus in the previous trial. It has been argued (e.g., Neill, 1977; Neill & Westberry, 1987; Tipper et al., 1989; Driver & Baylis, 1993) that the magnitude of the negative priming effect is a direct reflection of the efficiency of inhibition mechanisms, and is negatively correlated with susceptibility to distraction. Tipper et al. (1989) proposed that the developmental differences seen in studies of selective attention (e.g., Doyle, 1973; Gerstadt et al., 1994; Jerger, Martin & Damian, 1988; Zuckier & Hagan, 1978) are due to children's underutilization of the inhibition mechanism. In support of this idea, Tipper et al. (1989) observed that 7- to 8-year-olds showed greater Stroop interference than adults, and that adults showed greater negative priming than 7- to 8-year-olds. Driver and Baylis (1993) found similar trade-offs in adults between the magnitude of the interference effect and the size of the negative priming effect in a cross-modal Stroop-like paradigm. It is noteworthy in this regard that Gernsbacher and her colleagues (e.g., Gernsbacher, Varner, & Faust, 1990; Gernsbacher & Faust, 1991) have observed that the efficiency of inhibition mechanisms varies considerably among adults, and is a strong predictor of individual differences in general comprehension skill (Gernsbacher, 1997). For example, less skilled comprehenders have been shown to less efficiently suppress inappropriate meanings of homophones (e.g., reject CALM after reading *He had a lot of patients*), as well as information across pictorial and printed word modalities (i.e., ignore words superimposed on pictures or pictures superimposed on words). These findings lead us to predict that less skilled comprehenders would experience greater interference in the cross-modal Stroop task, at a wider range of stimulus asynchronies, than more skilled comprehenders.

In both Experiments 2 and 3, and contrary to both our predictions and the findings in Experiment 1, adults not only failed to show a semantic interference effect, but rather showed an opposite 'priming' effect with faster reaction times for pictures paired with related distractors. Consistent with the inhibition account, the priming effect occurred only with simultaneous presentation of picture and distractor. In addition, the priming effect was significant only for clothing naming trials, and not for animal naming. Although the explanation of why semantic priming rather than interference occurred in adults is, of necessity, post hoc, one can speculate that the effect arose at the conceptual level from semantic or associative links among pictures in each category. Levelt (1989) has proposed that words become associatively linked by co-occurrence and therefore may take on additional relationships, beyond semantic relatedness. Due to the constraints of selecting pictures that children could easily recognize, we did not attempt to equate items for their degree of association or semantic relatedness. In the mental lexicon, the animal domain, relative to the clothing domain, has many more members. In our experiments we used animals that tended to be visually dissimilar, and less closely associated with each other. We suspect that stronger conceptual links among the clothing items (*hat, mitten, shoe, sock, dress, pants*) in comparison to the animals (*dog, snake, fish, bear, rabbit, chicken*) may have differentially primed response times. This effect of semantic category points to the need for balancing a number of factors in creating stimulus materials. Further work using sets of animals that vary in terms of their degree of association, visual similarity, and conceptual relatedness (e.g., mammals versus animals in general) would allow us to examine whether the priming effect is mitigated by these factors. In addition, the use of a greater number of semantic categories and items would help in assessing the generalizability of the present results.

It is also important to note that recent studies (Brooks & MacWhinney, 2000; Brooks, MacWhinney, & Evans,1995), using a similar cross-modal picture–word interference paradigm have demonstrated, in both children and adults, that related words presented in the auditory modality can prime, as well as inhibit, picture-naming reaction times. Brooks et al. examined associative priming at a range of SAs, and found that picture-naming reaction times for pictures paired with associated words (e.g., hearing *cat* when shown a picture of a dog) were significantly faster than reaction times for pictures paired with unrelated words. This effect was robust in children and adults, even when the auditory stimulus was presented 550 ms in advance of the picture. Thus, participants did not suppress activation of auditory stimuli that were potentially relevant to the task at hand. Together with the present study, Brooks et al.'s results indicate that suppression is a flexible, nonobligatory process that may be invoked under conditions in which it is beneficial, with developmental change occurring in the efficiency and flexibility of the underlying mechanisms.

The findings of developmental change in cross-modal Stroop and Stroop-like picture-word interference effects contrast greatly with the recent work of Jerger, Martin, and Damian (2002) and Damian and Martin (1999) who used a similar interference paradigm. They argued that semantic conflict plays a critical role in generating interference in the cross-modal picture-word interference task, and noted that the semantic components of picture naming are developmentally stable from early childhood to adulthood. Although they found significant semantic effects comparing trials with related and unrelated distractors that were never members of the response set, there may be alternative explanations of their results besides semantic competition between related words. In particular, Damian and Martin used unrelated distractors (e.g., *bulk, louse, fate, germ, rank, mist, threat, hunch*) that seem to be more abstract than the related distractors (e.g., *cow, elbow, gong, zebra, fox, radish, whale, skunk*) paired with the same target pictures. This difference in concreteness may have contributed to faster reaction times for naming pictures paired with unrelated as compared to related words. More generally, in Cutting and Ferreira (1999), Damian & Martin (1999), Jerger, Martin & Damian (2002), and Schriefers et al. (1990), different sets of words were used for related and unrelated distractor conditions, with the two sets potentially differing in many possible ways (e.g., concreteness, length, frequency, lexical ambiguity). Furthermore, all of these studies blocked stimulus asynchrony, used larger sets of stimuli, uncategorized lists, and few repetitions of either target pictures or distractors, in comparison to our Stroop-like experiments. Blocking stimulus asynchrony creates predictability in the timing of distractor presentation, and can lead to strategic effects that differ from unblocked presentation of stimulus asynchrony conditions. It would be worthwhile to test whether the interference effects might differ if the related picture-word pairs (e.g., dog-bear, pickle-lemon) were simply reshuffled to create the unrelated picture-word pairs (e.g., dog-lemon, pickle-bear). If semantically related picture-word pairs still showed longer reaction times relative to unrelated pairs, this would provide strong evidence that semantic competition underlies task performance.

In addition, cross-modal Stroop-like tasks may show larger contributions of response set membership to the interference effect on account of greater repetitions of a small number of stimulus items. The day-night Stroop task (Gerstadt et al. 1994; Simpson & Riggs, 2003) is similar to our task, in that a very small response set (i.e, 2) is used across many repeated trials. Simpson and Riggs (2003) observed that response set was a stronger predictor of interference effect size than semantic relatedness in children's performance of this closely related task. As shown by La Heij and van den Hof (1995), semantic interference decreases with smaller set sizes. Repetitions of stimulus items may also produce sequential dependencies in the data, which may have impacted our results. Due to the random selection of trials for each participant, it is not feasible to systematically track such dependencies in the current study. In future work, we will systematically manipulate spacing of stimulus repetitions in order to explore negative priming and related sequential phenomena. Additional experimental work is also needed to clarify the contributions of response set size, use of categorized versus uncategorized lists, and item repetition to the cross-modal interference effect.

The developmental changes we observed in picture-word interference can parsimoniously be explained as reflecting maturation of the systems underlying selective attention, working memory, resistance to interference, and inhibition. Research has pointed to the role of the anterior cingulate and the dorsolateral prefrontal cortex (DLPFC) in these cognitive functions (MacLeod & MacDonald, 2000), but the exact nature of their roles is not well understood. The DLPFC is thought to be the center of goal directed activities, working memory, inhibition and categorization (Miller & Asaad, 2002), playing a critical role in reducing perseveration, selectively attending to stimuli, and in supporting flexible behavior (Becker, Isaac, & Hynd, 1987; Miller and Cohen; 2001; O'Reilly, Braver, & Cohen, 1999; Stuss & Benson, 1984). All of these operations are implicated in the cross-modal Stroop and cross-modal Stroop-like picture-word interference effect. The PFC sends and receives projections from almost all cortical areas within the brain, suggesting that it is the seat of integration and coordination of numerous neural operations. The PFC is the last area of the brain to mature, as indicated by late myelination and synaptic pruning (Anderson, 1998; Bell & Fox, 1992; Chugani, Mazziotta &, Phelps, 1993).

Miller and his colleagues (e.g., Freedman, Riesenhuber, Poggio and Miller, 2001; Miller & Cohen, 2001) have further emphasized the involvement of the prefrontal cortex in categorization, which they define as the ability to 'react similarly to stimuli when they are physically distinct, and to react differently to stimuli that may be physically similar' (Freedman et al., 2001, p. 312). For example, one should react similarly toward an orange and a banana even though they are dissimilar in appearance and act differently towards an orange and a ball even though they may be similar in appearance. Establishment of an ad hoc category of task-relevant items that are neither similar in appearance nor related by superordinate category membership underlies the response set interference effect in our Experiment 4. In contrast to adults, children did not appear to spontaneously generate task-relevant categories in working memory in the absence of preexisting semantic coherence among category members.

The ability to resist interference plays a pivotal role in enabling one to scan, absorb, and attend to the environment. The cross modal Stroop and the Stroop-like cross-modal picture-word interference tasks have proven to be powerful techniques for uncovering developmental changes in these abilities. It has become apparent that children and adults differ in their ability to selectively attend to visual target information while resisting auditory interference (e.g., Elliott, 2002). This developmental progression may be mediated by age-related changes in the salience of the auditory modality (Sloutsky & Napolitano, 2003) or in the speed of response activation (Band, van der Molen, Overtoon, & Verbaton, 2000), or even by increased experience in tuning out background noises such as television or conversation while working (Banbury & Berry, 1998). The present series of experiments are important in separating the semantic and response set components of auditory interference in picture naming. Unlike previous studies focused on the linguistic aspects of speech production in children and adults (Jerger, Martin & Damian, 2000; Martin & Damian, 1999), we have found semantic interference in picture naming to be affected by response set membership. Our results complement the recent work of Simpson and Riggs (2003), who found response set membership to overshadow semantic effects in the day-night Stroop task. The present set of cross modal Stroop and picture-word interference experiments illustrates the need to analyze the executive demands of tasks and the importance of inhibitory mechanisms in the development of selective attention. Our work identifies response set membership as an important, but frequently overlooked, factor in explicating developmental change in resistance to interference from irrelevant auditory stimuli.

Footnotes

1. In the Levelt (1989) speech production model, the term 'lemma' refers to the nonphonological part of an item's lexical information (i.e., 'those aspects of a word's stored information that are relevant for the construction of the word's syntactic environment' Levelt, 1989, pp. 6).

2. Due to difficulties in recruiting young participants for this study, we tested only two groups of children of ages 4- to 7-year-olds and 9- to 12-year-olds in Experiment 4, rather than three age groups as in Experiments 1, 2 and 3.

3. Unfortunately, in Experiment 4, not every pairing of target picture and distracter was fully unrelated. Therefore, we eliminated trials where the target and distracter were somewhat related. It should be noted, however, that the results of statistical analyses with these items included yielded essentially identical results. Due to the association between *doll* and *house* in the compound noun *dollhouse*, we eliminated trials where the picture of a doll was paired with the word *house* or the picture of a house was paired with the word *doll.* Due to a part-whole relationship, we eliminated trials with the picture of a window paired with the word *train* or the word *house,* and trials with the picture of a train or a picture of a house paired with the word *window.*

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