ABSTRACT  Studies of temperament from early childhood to adulthood have demonstrated inverse relationships between negative affectivity and effortful control. Effortful control is also positively related to the development of conscience and appears as a protective factor in the development of behavior disorders. In this study, the development of attentional mechanisms underlying effortful control was investigated in 2- to 3-year-old children, as indexed by their performance in a) making anticipatory eye movements to ambiguous locations and b) resolving conflict between location and identity in a spatial conflict task. The ability to make anticipatory eye movements to ambiguous locations within a sequence was clearly present at 24 months. By 30 months, children could also successfully perform a spatial conflict task that introduced conflict between identity and location, and at that age, children’s success on ambiguous anticipatory eye movements was related to lower interference from conflict in the spatial conflict task. Children’s performance on the eye-movement task was correlated with performance

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and reaction time on spatial tasks, and both were related to aspects of
effortful control and negative affect as measured in children’s parent-
reported temperament.

Recent years have seen a burgeoning of research and theory on
individual differences in temperament. Temperament can be
observed in infants and nonhuman animals, and temperamental
dispositions form the basis for the developing personality (Rothbart,
Ahadi, & Evans, 2000). We have defined temperament as individual
differences in emotional, motor, and attentional reactivity and self-
regulation (Rothbart & Derryberry, 1981; 2002). Within our
developmental framework, more reactive temperament character-
istics such as emotionality become increasingly regulated by
temperamental control mechanisms such as fearful inhibition and
attentional self-regulation. In our laboratory, we have studied the
stability of emotional reactivity over the early years of life
(Rothbart, Derryberry, & Hershey, 2000), and we have also studied
in detail the development of attentional mechanisms, including those
related to orienting and executive attention (Posner & Rothbart,
1998). This paper investigates developments in executive attention
that may underlie temperamental effortful control.

In factor analytic studies of temperament, broad factors of
Negative Affectivity, Surgency/Extraversion, and Effortful Control
have been extracted in childhood (Rothbart & Bates, 1998). Of
these, the factor of Effortful Control, including attentional focusing,
inhibitory control, perceptual sensitivity, and low intensity pleasure,
is of special interest to the study of temperament and development
(Kochanska, Murray, & Harlan, 2000; Posner & Rothbart, 1998).
We have defined effortful control as the ability to suppress a
dominant response in order to perform a subdominant response.
More generally, we view effortful control as an outcome of the
development of executive attention, including the ability to inhibit a
dominant response in order to activate a subdominant response, to
plan, and to detect errors (Jones, Rothbart, & Posner, 2002).

Effortful control plays a critical theoretical role in our view of
temperament and development. Whereas most theories of tempera-
ment stress the extent to which our motivation and behavior is
driven by positive affect and approach systems versus negative affect
and avoidance/inhibition systems (e.g., Eysenck, 1967, Thomas &
Chess, 1977), effortful control allows the child to suppress these tendencies and to program behavior in conflict situations, giving some freedom from affectively driven behavior.

Research on individual differences in effortful control has linked it to the development of empathy and conscience and to lower levels of psychopathology and maladjustment (Eisenberg, 2000; Kochanska, 1997; Kochanska et al., 2000; Krueger, Caspi, Moffitt, White, & Stouthamer-Loeber, 1996; White, Moffitt, Caspi, & Bartusch, 1994). Low self-control, as measured by poor delay of gratification, has also been identified as a risk factor for aggressive and delinquent behaviors, and successful delay of gratification has been linked to adaptive behaviors (Krueger et al., 1996). Lack of control, as defined by emotional lability, restlessness, short attention span, and negativism has been implicated in the development of externalizing behaviors in adolescents (Caspi, Henry, McGee, Moffitt, & Silva, 1995). Behavioral undercontrol, as characterized by insufficient control of impulse, motivation, and affect, has also been linked to substance use (Stice & Gonzales, 1998). Wills, DuHamel, and Vaccaro (1995) identified lack of self-regulation as a particularly strong factor in adolescent substance use and deviant peer associations, suggesting that “difficulties in self-regulation may precede or co-occur with manifestations of aggressive and antisocial behavior…” (p. 325).

We see the mechanisms of executive attention, developing rapidly during the toddler and preschool years, as supporting the broad temperamental dimension of effortful control (Posner & Rothbart, 1998). One of the most basic questions in current research on temperament and development thus addresses the origin and development of attentional mechanisms underlying the effortful control of action and emotion. The importance of this question is further underlined by Denckla (1996), who has argued that “the difference between the child and adult resides in the unfolding of executive functions” (p. 264).

One of the most exciting aspects of effortful control as a temperament construct is its links to nervous system function via executive attention (Posner & Rothbart, 1998; Rothbart, Derryberry, & Posner, 1994). Recent studies of attention have identified separable networks of neural areas that carry out the functions of achieving and maintaining the alert state, orienting to sensory input, and voluntary control of thoughts and emotions (Posner & Raichle,
A network involving areas of the prefrontal cortex, anterior cingulate, and basal ganglia is thought to be most closely related to executive functions. Recently, the resolution of conflict has been hypothesized to be the central function of this executive network (Botvinick, Braver, Barch, Carter, & Cohen, 2001). Conflict tasks as diverse as the color-word Stroop task (Bush, Luu, & Posner, 2000), the numerical Stroop task (Bush et al., 1998), the use of congruent and incongruent flankers (Botvinick et al., 2001), and spatial conflict between location and identity (Fan, Flombaum, McCandliss, Thomas, & Posner, 2003) have all been shown to activate common and unique areas of the anterior cingulate as well as areas of the prefrontal cortex.

Botvinick argues that this prefrontal network monitors and resolves conflict between the many separate brain areas involved in domain specific computations of stimulus and response dimensions (Botvinick et al., 2001). The development of the prefrontal network in children would then be linked to the ability to exercise voluntary control by choosing among competing cognitive and emotional computations those that will be dominant at a given moment. Of course, no child or adult will be completely successful in maintaining coherence of behavior in the face of conflict, but success in doing so would be central to the transition to maturity and the capacity for self-regulation. For this reason, it is important to develop model tasks that can assay the basic function of the executive attention network in resolving conflict at all ages.

To adapt conflict tasks to young children, it is helpful to avoid the use of language or learned symbolic relationships. One task in which a natural conflict occurs is when a response must be made that competes with the location of a stimulus (Simon, 1969). Gerardi-Caulton (2000) introduced conflict between the location of an event and its identity, two of the earliest developing systems for analyzing visual stimuli. She required children to respond with the one of two keys that matched the identity of a stimulus presented on the left or right of a computer screen. In this situation, there is a strong tendency to respond on the same side of space as the stimulus. When the correct key is on the opposite side of the target stimulus, a conflict emerges, and even adults show longer reaction times (RTs) and higher error rates on these conflict trials. Gerardi-Caulton (2000) found that children of 2 years were almost always able to make the correct response on nonconflict trials, but were almost
always incorrect on conflict trials. Three-year-olds made many fewer errors, although like adults, they had longer RTs on incongruent trials.

Gerardi-Caulton (2000) also found that performance on the spatial conflict task was positively related to temperamental effortful control, as measured in the laboratory and via parent-report scales (The Children’s Behavior Questionnaire, or CBQ; Rothbart, Ahadi, Hershey, & Fisher, 2001). Temperamental effortful control also has been shown to be related to a wide variety of daily behaviors, including the ability to delay gratification and the development of conscience (Kochanska et al., 2000). Thus, the ability to resolve conflict in Stroop-like tasks seems to mark the development of neural networks that play an important role in self-regulation.

To study conflict in young infants and toddlers who have great difficulty in pressing keys or touching screens to indicate their response, one can study anticipatory eye movements. Previous studies have shown that eye movements anticipating the location of predictable visual events occur in the early months of life (Clohessy, Posner, & Rothbart, 2001; Haith, Hazan, & Goodman, 1988). However, when ambiguity is introduced into a sequence, learning is not found before about 18 months (Clohessy et al., 2001). Consider, for example, the sequence 1213, where each of the numbers refers to a stimulus location. In these sequences, occurrence of a stimulus at position one is sometimes followed by a stimulus at position 2 and sometimes at position 3. In anticipating these events, there is conflict in generating the appropriate response that must be resolved by information about the event that had previously followed location 1. One element of the ability to anticipate correctly in such ambiguous sequences is the resolution of conflicting tendencies to go to 2 versus 3 following a stimulus at location 1.

The ability to resolve conflict during sequences of anticipatory eye movements can be studied at any age (Clohessy et al., 2001). However, most adult-sequence learning studies have involved pressing keys (Nissen & Bullemer, 1987), rather than the anticipatory eye movement used for infants. For key press tasks, ambiguity resolution requires higher level control, which is present only when the subjects are able to give full attention to the task (Curran & Keele, 1993). Thus, adults may fail to learn ambiguous sequences when distracted. If the same type of executive attention is needed for resolving ambiguity in sequence learning as is needed for
resolving conflict in Stroop tasks, one might predict a correlation between performances on the two tasks.

If the two are related, it would then be possible to trace the emergence of this network during infancy and childhood by using anticipatory looking for the youngest subjects and Stroop-type interference later in childhood. Exploring this possibility, we examined both anticipatory eye movement in the learning of sequences and Stroop interference in children from 18 to 36 months of age. Our goal was to see whether the two forms of conflict resolution would emerge at roughly the same time and whether performance on the two tasks was positively related across a sample of children.

The current study had several important goals. First, we sought to replicate our finding about the ability of toddlers to use context to resolve spatial conflict in anticipatory eye movements, and to study the development of that skill between 18 and 36 months. Second, we sought to determine the ability of these same infants to resolve conflict in a touch screen version of the spatial conflict task developed by Gerardi-Caulton (2000), replicating and extending her work. Third, we examined whether these skills are correlated in a sample of children who could perform both tasks. Finally, we examined the correlation of performance in resolving conflict to parent reports of the control of action and emotion in the child’s temperament.

**METHOD**

**Participants**

Data on 192 children were collected: 64 children (35 female) at 24–25 months of age (mean age = 24.90 months), 46 children (21 female) at 30–31 months (mean age = 30.75 months), and 40 children (20 female) at 36–37 months (mean age = 36.80 months). Additionally, 42 children (20 female) at 18–19 months (mean age = 18.97 months) participated in the Visual Sequence task. Parents of participants were identified through local birth announcements and recruited by telephone. Subjects were offered a $5 gift certificate or a “Junior Scientist” T-shirt for their participation. The children came from predominantly, but not exclusively, white, middle-class backgrounds. Only children with severe birth complications were excluded from the study due to possible developmental delays.
Some participants fussed during the tasks and refused to finish all trials. To be included in the final analyses, participants in the three older age groups were required to have completed at least 50% of the trials in each task. The 18–19-month old participants were required to complete at least 50% of trials in the Visual Sequence task. One male in the 18–19-month-old group, 8 males and 14 females in the 24–25-month-old group, and 4 males and 2 females in the 30–31-month-old group did not complete sufficient trials to be included in the final analyses. In addition, one male participant in the 18–19-month-old group, and 1 female and 1 male participant in the 30–31-month-old group were eliminated from analysis due to equipment malfunction. However, temperament questionnaire data from 24–25-month–old participants who failed to complete tasks due to fussiness and refusal to participate were retained and analyzed separately.

Procedure: General
Eighteen-month-old participants visited the laboratory one time for approximately one hour. After a short warm-up period playing with the experimenter and assistant, the children completed the Visual Sequence Task, followed by two problem-solving tasks that were not analyzed for this study. Participants in the three older age groups visited the laboratory for two 1-hour sessions approximately 1 week apart. Session one consisted of warm-up time, the Visual Sequence Task, the Spatial Conflict Task, an attentional-alerting task, also not analyzed here, and one of the two problem-solving tasks. Session 2 was identical, with the exception of substitution of the other problem-solving task. All participants performed tasks in the same order.

Apparatus and Stimuli-Visual Sequence Task
The experimental apparatus consisted of three Apple computer monitors arranged in an inverted triangular configuration. These monitors were contained within a 1.2 m × 0.9 m × 1.8 m wooden enclosure (see Figure 1). The experimenter and additional equipment were blocked from the child’s view by the enclosure. A video camera located above the central monitor focused on the participant’s eyes.

Behind the enclosure, the experimenter viewed the subject on a monitor and controlled with key presses the presentation of stimuli, generated by an Apple Power Macintosh computer. The video signal and stimuli appearing on peripheral monitors were mixed through a Panasonic digital mixer so that images of the stimuli were superimposed on the image of the child’s face. Both were displayed on the experimenter’s monitor, allowing on-line simultaneous monitoring of
stimulus presentation and subject eye movements. The display, as well as a time code, was recorded on a Panasonic video recorder for later frame-by-frame coding.

A single stimulus was presented on one of the three monitors until the child oriented to it. Stimuli consisted of colorful, flashing cartoon characters. The inter-stimulus interval was 750 ms. Each stimulus was accompanied by high- and low-pitched computer-generated tones, played in random order at 300 ms intervals. Stimuli appeared on the different monitors according to one of two predetermined sequences, described below.

**Visual Sequence Task**

Children sat in a high chair, centered approximately 0.7 m in front of the three monitors. A trial consisted of the presentation of a single, flashing stimulus, and lasted until the child oriented to the stimulus. The experimenter then pressed a key that removed the stimulus and initiated a delay. This event marked the end of one trial and the beginning of the next. The next stimulus occurred automatically after the 750 ms delay. Participants in the three older age groups were presented with two blocks of 24 test trials and one block of 24 random trials in each of two sessions spaced approximately 1 week apart. Eighteen-month-old participants were presented with four blocks of 24 test trials and one block of 24 random trials in one session.
Stimuli in the test trials were presented in a repeating pattern, in which some stimuli reliably predicted the next target location (unambiguous) while other associations were context-dependent (ambiguous). The basic sequence was “1-2-1-3-1-2-1-3-…,” where 2 or 3 were always followed by 1 (unambiguous). However, 1 could be followed by either 2 or 3 (ambiguous) depending upon stimuli location prior to 1. The sequence “3-2-3-1-3-2-3-1-…” served as a counterbalancing condition. Subjects were randomly assigned to view either the 1213 sequence, or the 3231 sequence.

Videotapes were coded for target onset time, direction, and time of onset of eye movements. Only the first look to a location within a trial was coded. To assess reliability, two coders independently coded one-third of participants’ sessions. Agreement between coders averaged 96%. On trials where coding of eye direction differed or onset times differed by more than two frames, a third coder determined the correct location and/or time from review of the videotape.

Spatial Conflict Task

Children sat in a high chair or booster seat located approximately .33 m from a 39.33 cm × 29.21 cm Sony touch-screen monitor. The touch-screen rested on a table. Two 20 cm × 20 cm square block wedges were affixed to the table in front of the monitor. The wedges were covered with yellow felt and had green, felt, child-sized, hand-shaped cutouts attached to them. The wedges were spaced about 7.5 cm apart and tilted at approximately 25 degrees, enabling the children to see the top surface. Participants were instructed to place their hands on the felt “hands” between trials.

A curtain framing the monitor and a camera lens was draped between the experimenter and the participant. Two cameras were used to film the procedure. One, located directly above the touch-screen monitor, filmed the child’s face. The other, located behind and above the child, filmed the touch-screen monitor. The experimenter watched both views on a split-screen monitor located behind the curtain. Parents sat in a cubicle in the center of the room and watched the child’s session on a television monitor. Children were not able to see the parent, but were aware of the parental presence nearby.

Two “houses,” outlined in black, were located at the lower left and right corners of the touch-screen monitor. During each trial, a picture appeared inside each house. These houses served as locations where the child touched to make a response. During practice trials, a target stimulus, matching a picture from one of the houses, appeared in the upper-center of the screen. During test trials, a target stimulus appeared
in either the upper-left, or right-hand corner of the screen, directly above one of the houses. Stimuli consisted of brightly colored cartoon figures.

At the beginning of each session, children were seated in the booster chair and asked to place their hands on the felt hands. A pair of pictures (e.g., a bear and a lion) appeared inside the black houses. A central, looming square was then presented in the center of the screen to capture the child’s attention. Once the child’s attention was focused on the screen and his or her hands were in place, the experimenter touched a computer key and the target stimulus, matching one of the pair of pictures in the houses, appeared on the screen. The experimenter instructed the participant to help the target stimulus (e.g., the “lion”) find its home. If the child touched the correct house, the stimulus became animated (e.g., the lion’s tail wagged) and a tone sounded. If the child touched the incorrect house, a buzzing sound was presented, and the stimulus disappeared from the screen.

Each session began with a block of four practice trials, in which the stimulus appeared in a neutral position (central-upper position), followed by two blocks of eight test trials. Half the target pictures within each test block appeared above the correct house (spatially compatible trial), while in the other half, the target picture appeared opposite the correct house (spatially incompatible trial). Children were required to ignore the spatial location of the picture and respond based on picture identity. The order of compatible versus incompatible stimulus appearance was randomized within each block, and a different picture pair was used in each block. The target stayed on until the child responded, or for a maximum of 15 seconds.

The computer recorded a number of measures, including response location and accuracy, spatial compatibility of trial, and reaction time in milliseconds for each trial. Occasionally, the child’s touch was too weak to be detected by the touch-screen monitor, and the child had to touch the screen a second time to get a response. These trials resulted in inaccurate Reaction Times (RTs). Additionally, children would sometimes touch both sides of the screen, resulting in an invalid trial. Therefore, videotapes of all sessions were screened frame-by-frame. RTs for inaccurate trials were corrected as needed, and data from invalid trials were discarded prior to analysis. Finally, difference measures between scores for trial types for both accuracy and RT were calculated, as were scores for number of trials completed.

Temperament Questionnaires

Parents of participants were asked to complete questionnaires designed to evaluate children’s temperament. A supplemented version of the Toddler
Behavior Assessment Questionnaire (TBAQ; Goldsmith, 1996) was used to assess temperament in children 18- and 24-months-old. The Children’s Behavior Questionnaire (Rothbart et al., 2001) was used to assess temperament in children 30 and 36 months old. The scales for the supplemented TBAQ included, from Goldsmith’s original version: Activity Level, Anger/Frustration, Positive Anticipation, Pleasure, and Social Fear. These scales were supplemented by scales developed at the Oregon laboratory for: Attentional Shifting, Discomfort, High Intensity Pleasure, Low Intensity Pleasure, Inhibitory Control, Perceptual Sensitivity, Sadness, and Soothability/Falling Reactivity. Scales for the CBQ included these as well as additional scales for Fear, Impulsivity, Shyness, and Smiling and Laughter.

Scale scores for each participant were calculated and, based upon prior factor analytic work (Putnam, Gartstein, Rothbart, & Jones, 2002; Rothbart et al., 2001), combined to form three composite scales: Effortful Control, Surgency, and Negative Affect. The TBAQ Effortful Control composite contained the mean of scores for the Attentional Focusing, Attentional Shifting, Inhibitory Control, Low Intensity Pleasure, and Perceptual Sensitivity scales, while the CBQ Effortful Control composite contained the mean of scores for the equivalent scales along with scores from the Smiling and Laughter scale. Both the TBAQ and CBQ Surgency composites contained mean scores for the High Intensity Pleasure and Activity Level scales, while the TBAQ composite also contained a contribution from the Positive Anticipation scale. The CBQ Surgency composite included scores from the Impulsivity scale and a reverse-scored contribution from the Shyness scale. The TBAQ Negative Affect composite included scores from the Anger/Frustration, Sadness, and Social Fear scales, along with a reverse-scored contribution from Soothability/Falling Reactivity, while the CBQ Negative Affect composite contained scores from the Anger/Frustration, Sadness, and Fear scales, with reverse-scored contributions from Soothability/Falling Reactivity and Positive Anticipation.

RESULTS

Visual Sequence

Two measures assessed children’s learning of the sequence. First, the percent of trials in which looks to a target were anticipatory rather than reactive (Percent Anticipation) was calculated by subtracting target onset times from onset of eye movement. In our previous work (Clohessy, 1994), we looked at the probability of a correct eye movement in anticipation of a visual event that occurred at one of
two locations. We found that, depending upon age, it took between 100 and 264 ms for the looks to a location to be significantly above chance (.5), indicating that a look was reactive rather than anticipatory. To be certain that we included only genuine anticipations that did not reflect information gathered from the visual event, we excluded all responses occurring beyond 100 ms after target onset. Percent Anticipation figures were calculated by dividing the total number of anticipations (both correct and incorrect) by the total number of trials completed.

Additionally, calculations were made to determine the percent of anticipatory trials in which the child looked to the correct location (Percent Correct). This was determined by dividing the total number of correct anticipations by the total number of anticipations. Given three locations, it was expected that anticipatory looks would be correct at least 50% of the time. That is, when a child is fixated at a location, there are only two potential target locations for the next trial, thus yielding a 50–50 chance of correctly anticipating the next location in the absence of learning. Mean scores within age group were calculated for each measure and each trial type.

18-month performance
Results for the 18- to 19-month-old participants are summarized in Table 1. This age group participated in one session of the Visual Sequence task, consisting of 96 trials, and results presented include 22 children completing the full session. Eighteen-month data were analyzed separately because participants in this age group, although completing an equal number of trials, did so in one session rather than two.

Percent anticipation. Each measure was calculated separately within the first and second halves of the session (Block 1 and Block 2). This allowed comparison of performance from early to late in the session. Table 1 shows 18-month percent anticipation by trial type and block. A $2 \times 2 \times 2$ (Gender $\times$ Block $\times$ Trial Type) repeated measures analysis of variance showed a significant main effect of block ($F(1, 20) = 6.70$, $p < .05$), indicating that the children anticipated less during the second half of the session. There was an additional main effect of type ($F(1, 20) = 7.66$, $p < .05$), such that children anticipated significantly more often during ambiguous trials than during nonambiguous trials. There was no significant effect of
gender, nor were there any significant interactions. Random trials were not included in the analysis, as they were included only at the end of the session.

Percent correct. Eighteen-month-old percent correct figures are listed in Table 1 by block and trial type. A $2 \times 2 \times 2$ (Gender $\times$ Block $\times$ Trial Type) repeated measures analysis of variance revealed no significant main effects of block, trial type, or gender or significant interactions. Cell means of percent correct values were compared to values expected by chance (50%). Accuracy levels were not significantly greater than could be expected by chance for ambiguous, nonambiguous, or random trials. A paired samples $t$ test revealed that in block 2, percent correct during ambiguous trials was higher than in block 1, but only at trend level ($t(1, 21) = 1.84, p = .08$).

24-, 30-, and 36-month-old performance
Results for 24-, 30-, and 36-month-old participants are presented in Table 2. Children in these age groups participated in two separate Visual Sequence sessions, consisting of 48 sequenced trials and 24 random trials each, taking place approximately 1 week apart. Measures were calculated separately within each session to assess differences in performance from one session to the next. Results are presented for children completing both sessions of the task and include 31, 25, and 33 children in the 24- to 25-month, 30- to 31-month, and 36- to 37-month-old age groups, respectively.

<table>
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<tbody>
<tr>
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<td>.46 (15)</td>
<td>.40 (14)</td>
</tr>
<tr>
<td>Block 2</td>
<td>.36 (17)</td>
<td>.40 (14)</td>
<td>.30 (17)</td>
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<tr>
<td>Percent Anticipation Mean (SD)</td>
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</tr>
<tr>
<td>Block 1</td>
<td>.42 (21)</td>
<td>.46 (23)</td>
<td>.45 (15)</td>
</tr>
<tr>
<td>Block 2</td>
<td>.46 (23)</td>
<td>.52* (20)</td>
<td>.52 (14)</td>
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*Block 2 > Block 1, $p = .10$.
**Percent anticipation.** Mean percent anticipation by age, session, and trial type are summarized in Table 2. Random percent anticipation is collapsed across session. Sequenced trials were subjected to a $3 \times 2 \times 2 \times 2$ (Age Group $\times$ Gender $\times$ Session $\times$ Trial Type) repeated measures analysis of variance, with percent anticipation entered as the dependent measure. Results indicated a significant main effect of session ($F(1, 81) = 7.55, p < .01$), such that children made more anticipations in session 2 than session 1. There was also a significant main effect of trial type ($F(1, 81) = 32.84, p < .001$), such that children were more likely to anticipate during ambiguous trials than nonambiguous trials. No other significant main effects or interactions were present.

**Percent correct.** Results for 24-, 30-, and 36-month-olds are summarized in Table 2. Sequenced trials were subjected to a $3 \times 2 \times 2 \times 2$ (Age Group $\times$ Gender $\times$ Session $\times$ Trial Type) repeated measures analysis of variance, with percent correct entered as the dependent measure. Results revealed a significant main effect of trial type ($F(1, 81) = 107.87, p < .001$), such that children were correct

<table>
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<tbody>
<tr>
<td>Age</td>
<td>Session 1</td>
<td>Session 2</td>
</tr>
<tr>
<td>24 Mean (SD)</td>
<td>.41 (.16)</td>
<td>.45 (.15)</td>
</tr>
<tr>
<td>30 Mean (SD)</td>
<td>.40 (.15)</td>
<td>.43 (.16)</td>
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<tr>
<td>36 Mean (SD)</td>
<td>.43 (.14)</td>
<td>.45 (.17)</td>
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*Percent Anticipation*

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<tr>
<th>Trial Type</th>
<th>Nonambigous</th>
<th>Ambigious</th>
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<tbody>
<tr>
<td>Age</td>
<td>Session 1</td>
<td>Session 2</td>
</tr>
<tr>
<td>24 Mean (SD)</td>
<td>.35* (.20)</td>
<td>.42* (.17)</td>
</tr>
<tr>
<td>30 Mean (SD)</td>
<td>.45 (.21)</td>
<td>.40* (.21)</td>
</tr>
<tr>
<td>36 Mean (SD)</td>
<td>.38* (.17)</td>
<td>.39* (.18)</td>
</tr>
</tbody>
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*Significantly lower than percent correct expected by chance, $p < .01$.
**Significantly higher than percent correct expected by chance, $p < .05$.
***Significantly higher than percent correct expected by chance, $p < .001$. 

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more often for ambiguous than nonambiguous trials. No main effects of age or session were observed. However, a significant age × trial type interaction was present \((F(1, 81) = 4.31, p < .01)\), such that percent correct increased across age for ambiguous, but not nonambiguous, trials. No other significant main effects or interactions were observed. Additionally, cell means for percent correct were compared to the value expected by chance (50%). During each session and at each age percent correct during ambiguous trials significantly exceeded 50%. Unambiguous trial performance for children in the 24-month and 36-month age groups was at levels significantly lower than those expected by chance during both sessions, as well as during session 2 for 30-month-old children (see Figure 2 for significance levels).

**Spatial conflict.** Data from both sessions were combined to obtain sufficient trials for analysis. Data are presented for children having at least 16 valid trials and include 41 children in the 24- to 25-month age group, 40 children in the 30- to 31-month age group, and 40 children in the 36- to 37-month age group.

**Percent correct.** Percent correct was calculated by dividing the total number of correct trials over the total number of usable trials, and is presented in Figure 2. Trials from both sessions were combined to obtain sufficient trials for analysis, eliminating the ability to examine possible learning across sessions. A \(3 \times 2 \times 2\) (Age Group × Gender × Trial Type) repeated measures analysis of variance revealed a significant main effect of trial type \((F(1, 115) = 53.35, p < .001)\), such that children were significantly more accurate for compatible than for incompatible trials. Additionally, a significant main effect of age \((F(2, 115) = 21.30, p < .001)\) was found, indicating that older children performed with greater accuracy than did younger children.

**Reaction Time (RT).** RT data are presented in Figure 3. A \(3 \times 2 \times 2\) (Age Group × Gender × Trial Type) repeated measures analysis of variance revealed a significant main effect of age \((F(2, 115) = 3.60, p < .05)\), such that older children had faster reaction times than did younger children. A significant age × gender interaction was present \((F(2, 115) = 5.77, p < .01)\), indicating that females were slower than males at 24 months and faster than males.
at the older ages. There was also a significant main effect of trial type \((F(1, 115) = 11.66, p < .01)\), with RTs slower for compatible than for incompatible trials, as well as a significant trial type \(\times \) age interaction \((F(2, 115) = 4.78, p < .05)\), indicating that the difference in RTs was not present in 24-month-old children. Two interference measures were also calculated for each child: (1) A score indexing differences in accuracy for compatible versus incompatible trials, and (2) a score indexing differences in RTs for compatible versus incompatible trials. Figures 4 and 5 illustrate the results. For the reaction time measure \((F(2, 115) = 4.78, p < .05)\), did \(3 \times 2\) (Age Group \(\times \) Gender) univariate analyses of variance revealed a significant main effect of age. However, children in the 24-month-old age group actually had slightly shorter RTs for incompatible versus compatible trials. While no significant main effect of age was present for the accuracy measure, post-hoc tests

Figure 2
Spatial Conflict percent correct by age group and trial type.
revealed that 30-month-old children experienced significantly more accuracy interference than did 36-month-old children ($p < .05$).

Percentage of trials completed was also calculated for each age group. As noted earlier, children completing fewer than 50% of overall trials were not included in main analyses. For the remaining children, a $3 \times 2$ (Age Group $\times$ Gender) univariate analysis of variance revealed a significant main effect of age ($F(2, 115) = 3.75$, $p < .05$), such that older children completed significantly more trials than did younger children. An examination of cell means revealed
that 24-month-old children completed fewer trials ($M = .747$, $SD = .202$) than did 30-month-old children ($M = .853$, $SD = .177$) or 36-month-old children ($M = .824$, $SD = .198$). Post-hoc Tukey tests revealed a significant difference between trials completed for 24-month versus 30-month-old children ($p < .05$). No other comparisons were statistically significant.

**Correlational Analyses**

For each age group, correlations were calculated to examine the relationship between task performance variables. Children completing at least one-half of possible trials for each task were included in correlational analyses. Results are presented for 38 children in the 18- to 19-month-old group and 40 children in each of the three older groups. Although performance at 18 and 24 months was approximately normally distributed, at 30 and particularly 36 months, ceiling effects were evident for accuracy in the spatial conflict task.

**Figure 4**

Spatial Conflict percent correct interference by age group.
To compensate for nonnormality, Spearman rank-order correlations were calculated for task performance measures.

**Correlations Between Visual and Spatial Conflict Task Measures**

Children below 24 months did not participate in the spatial conflict task, so only data for the three older ages are presented in Table 3. However, for children 24–25 months, the percent anticipations during nonambiguous trials in the visual sequence task was inversely related to the percent correct interference effect in spatial conflict ($r_s = - .31, p < .05$). In addition, percent anticipations on ambiguous trials in the visual sequence task was positively related to spatial conflict performance on incompatible trials ($r_s = .35, p < .05$). These findings suggest that, at this age, the effort to anticipate in eye movements is related to effortful control.

At 30–31 months, performance on visual sequence ambiguous trials was inversely related to interference effects in percentage correct in the spatial conflict task ($r_s = - .35, p < .05$). This suggests that children who could use context in the eye movement task also had lower interference in the key press task. At this age, success in using context during eye movements seems to indicate better effortful control. In addition, percent anticipations during non-ambiguous trials was positively related to Spatial Conflict RT interference ($r_s = .40, p < .05$), suggesting that the effort to anticipate
Table 3
Spearman’s Correlations between Task Measures at 24, 30, and 36 months

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Spatial Conflict Task</th>
<th>Percent Correct</th>
<th>Reaction Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Compatible</td>
<td>Incompatible</td>
</tr>
<tr>
<td>24 mos.</td>
<td>Visual Sequence:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percent Anticipation Nonambiguous</td>
<td>.11</td>
<td>.35*</td>
</tr>
<tr>
<td></td>
<td>Percent Anticipation Ambiguous</td>
<td>.14</td>
<td>.35**</td>
</tr>
<tr>
<td></td>
<td>Percent Correct Nonambiguous</td>
<td>.27*</td>
<td>.10</td>
</tr>
<tr>
<td></td>
<td>Percent Correct Ambiguous</td>
<td>.20</td>
<td>.08</td>
</tr>
<tr>
<td>30 mos.</td>
<td>Visual Sequence:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percent Anticipation Nonambiguous</td>
<td>.14</td>
<td>.31*</td>
</tr>
<tr>
<td></td>
<td>Percent Anticipation Ambiguous</td>
<td>.01</td>
<td>.14</td>
</tr>
<tr>
<td></td>
<td>Percent Correct Nonambiguous</td>
<td>−.20</td>
<td>−.01</td>
</tr>
<tr>
<td></td>
<td>Percent Correct Ambiguous</td>
<td>−.19</td>
<td>.16</td>
</tr>
<tr>
<td>36 mos.</td>
<td>Visual Sequence:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percent Anticipation Nonambiguous</td>
<td>.18</td>
<td>.09</td>
</tr>
<tr>
<td></td>
<td>Percent Anticipation Ambiguous</td>
<td>.18</td>
<td>.17</td>
</tr>
<tr>
<td></td>
<td>Percent Correct Nonambiguous</td>
<td>−.33**</td>
<td>−.36**</td>
</tr>
<tr>
<td></td>
<td>Percent Correct Ambiguous</td>
<td>−.09</td>
<td>−.03</td>
</tr>
</tbody>
</table>

*p < .10; **p < .05.
in the eye movements trials was no longer predicting good effortful control. For participants in the 36–37 month age group, performance on Visual Sequence nonambiguous trials was negatively related to performance on both compatible ($r_s = -.33, p < .05$), and incompatible trials ($r_s = -.36, p < .05$). No other significant relationships were present between tasks in this age group.

**Correlations With Temperament Measures**

For all age groups, correlations were calculated between Visual Sequence performance scores and temperament questionnaire composite scale scores. Additionally, for the three older age groups, correlations were calculated between measures of Spatial Conflict completion and interference, and temperament questionnaire composite scores.

Analyses for 18-month-old participants revealed no significant correlations between temperament measures and performance on the Visual Sequence task. However, percent anticipation during nonambiguous trials was negatively related to Surgency scores ($r_s = .41, p < .01$). Spearman’s correlation coefficients for the three older ages are presented in Table 4.

Analyses of data from 24-month-old children revealed a modest negative relationship between Spatial Conflict accuracy interference scores and the Effortful Control composite scale ($r_s = -.27, p = .09$). The direction of this relationship indicated that children experiencing greater interference with accuracy due to spatial conflict scored relatively lower on the measure of Effortful Control. Accuracy interference was positively related to scores on the Negative Affect composite ($r_s = .31, p = .05$). Additionally, the percent of Spatial Conflict trials completed was positively related to Effortful Control ($r_s = .33, p < .05$). Percent anticipation during nonambiguous Visual Sequence trials was negatively related to Surgency in this age group ($r_s = -.43, p < .01$), indicating that more Surgent children made fewer anticipations during nonambiguous trials. The same relationship was evident for ambiguous trials ($r_s = -.33, p < .05$).

Spearman’s correlations for 30-month-old children revealed a significant relationship between performance on Visual Sequence nonambiguous trials and Effortful Control ($r_s = .40, p < .05$). No other significant correlations were found in this age group.
<table>
<thead>
<tr>
<th>Age Group</th>
<th>Scale</th>
<th>Spatial Conflict Task</th>
<th>Visual Sequence Task</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Interference Effects</td>
<td>Completion % of Trials</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Accuracy</td>
<td>RT</td>
</tr>
<tr>
<td>24 mo</td>
<td>TBAQ-R:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Effortful Control</td>
<td>-.27*</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Negative Affect</td>
<td>.31*</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Surgency</td>
<td>.07</td>
<td>-</td>
</tr>
<tr>
<td>30 mo</td>
<td>CBQ:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Effortful Control</td>
<td>-.15</td>
<td>.15</td>
</tr>
<tr>
<td></td>
<td>Negative Affect</td>
<td>.09</td>
<td>-.02</td>
</tr>
<tr>
<td></td>
<td>Surgency</td>
<td>-.08</td>
<td>-.07</td>
</tr>
<tr>
<td>36 mo</td>
<td>CBQ:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Effortful Control</td>
<td>.01</td>
<td>-.34**</td>
</tr>
<tr>
<td></td>
<td>Negative Affect</td>
<td>-.22</td>
<td>.08</td>
</tr>
<tr>
<td></td>
<td>Surgency</td>
<td>.22</td>
<td>-.11</td>
</tr>
</tbody>
</table>

*p < .10; **p < .05; ***p < .01.
For children in the 36- to 37-month-old age group, higher scores on Spatial Conflict reaction time interference, indicative of difficulty due to spatial conflict, were related to lower CBQ Effortful Control composite scores ($r_s = .40, \ p < .05$). Additionally, Negative Affect scores showed a negative relation to Visual Sequence Percent Correct for ambiguous trials ($r_s = −.26, \ p = .10$), although only at the level of a trend.

**Questionnaire Data for 24-Month Old Children Not Completing the Spatial Conflict Task**

A subgroup of 24-month-old participants, including 8 males and 14 females, failed to complete the spatial conflict task due to excessive fussing, crying, or refusal to participate. Temperament questionnaire data for these children were compiled, and composite scores were compared with composite scale scores for children in this age group who did complete the Spatial Conflict task. We found that 24-month-old children who would not or could not perform the spatial conflict task were significantly lower in Effortful Control ($M = 4.40, \ SD = .48$) and higher in Negative Affect ($M = 3.59, \ SD = .58$) than those completing sufficient trials for analysis (Effortful Control: $M = 4.74, \ SD = .51$; Negative Affect: $M = 3.10, \ SD = .41$). These differences were significant for both parent-reported Effortful Control ($t = 2.24, \ p < .05$) and Negative Affect ($t = −.349, \ p < .001$). Additionally, children completing the task were somewhat lower in Surgency than children not completing the task, but only at the level of a trend.

**DISCUSSION**

In our work we have been studying the development of attention networks in infants and young children in order to better understand the development of mechanisms underlying temperamental effortful control (Posner & Rothbart, 2000) and to make connections to the underlying anatomy (Bush et al., 2000). We also related individual differences in these measures to measures of children’s temperament. Previous research explored two marker tasks that we believe to activate the executive attention network. The first task involved anticipatory eye movements in infants (Clohessy et al., 2001). We found that at 18 months, but not before, children could use context
to anticipate locations that were ambiguous. The second task involved a Stroop-like conflict task (Gerardi-Caulton, 2000). The current research sought to replicate both of these effects in a cross-sectional sample of children from 18 months to 3 years, to determine whether performance in the two tasks were related and to understand implications of the children’s performance for their ability to control emotion and cognition in daily life.

We generally replicated both of the previous results. In this study, however, infants of 18 months showed only a marginal tendency to anticipate the correct ambiguous location in the sequence 1213 (reaching 52% in the final block). Beginning at 24 months, however, there was a clear above-chance choice of the correct ambiguous association (60%). Improvements beyond 24 months were modest, but 36-month-olds showed a somewhat higher tendency to select the correct location on ambiguous trials (66%). What was most surprising about these data was the 2- to 3-year-olds’ below-chance performance on the more frequently presented unambiguous association. We had previously shown that 4- and 10-month-olds did very well on the unambiguous association (86% correct at 4 months). The infants clearly performed better on the unambiguous location than the 3-year-olds, but the same infants never showed above-chance performance on the ambiguous association.

In an effort to clarify this developmental shift, we ran 19 adults in exactly the same procedure as applied to infants, with the exception that we asked them to move their eyes to the new stimulus as quickly as possible, even if they moved prior to the target. Overall, the adults performed almost exactly like the 2- to 3-year-olds. They correctly anticipated the ambiguous event with greater than chance probability (.68), but were below chance in the percentage of time they anticipated the unambiguous return movement (.36), despite the fact that the return movement was twice as frequent as movement to either of the ambiguous locations.

How then can we account for both the poor performance of older children and adults on the unambiguous association and the finding that infants of 4 months, who showed no signs of learning the ambiguous association, performed the unambiguous one quite well? One possible explanation is that a general preference for novelty works against toddlers and adults moving back to the unambiguous location (e.g., position 1 in the sequence 1213) following a movement to locations 2 or 3. If so, this preference must differ
somewhat from inhibition of return, which is defined by the use of a visual cue followed by a pair of targets. With the inhibition of return cueing method, we found that infants of 6 months showed about the same preference for novelty as adults (Clohessy, Posner, Rothbart, & Vecera, 1991). Another explanation is that children of 24 months and beyond are implementing a strategy of avoiding the most recent alternative and choosing the one attended longest ago. This strategy would allow them to show good performance on the context-dependent association, but would interfere with anticipation of the ambiguous association.

The second task we studied was the spatial conflict task used first by Gerardi-Caulton (2000). We found a clear improvement in accuracy on this task between 24 and 36 months, replicating the previous study. At 24 months, performance on the incompatible trials was at chance (.5), while performance on both compatible and incompatible trials was highly accurate at 36 months. Reaction time improved between 24 and 30 months and then remained level until 36 months. A longitudinal study would be needed to precisely track the development of this skill, but major improvements in this task appear to occur slightly later (between 24 and 30 months) than is true for the ambiguous looks described above, which show their major improvement between 18 and 24 months.

The first age at which children perform both tasks at levels above chance is at 30 months. At this age, both compatible and incompatible accuracy is above-chance, and anticipatory eye movements to the ambiguous sequence are much better than chance. At 30 months, there is a significant correlation of $-0.35$ between accuracy on ambiguous trials in the eye movement task and accuracy interference in the spatial conflict task. This correlation indicates that accuracy in the ambiguous association for eye movements is related to more efficient conflict resolution in the spatial conflict task.

Performance in the eye movement task appears to be quite similar from 3 years to adults, at least when the adults are under instruction to move rapidly and appear to be less aware of the sequence. Of course, these implicit skills are supplemented by new processes that emerge later in development, such as the ability to learn explicitly from verbal instructions (Thomas & Nelson, 2001).

At 2 to 3 years of age, children anticipate the context-dependent association at above-chance levels in the eye movement task. We believe that this marks development of the executive attention
system that plays an important role in dealing with conflicting response tendencies, for example, in the spatial conflict task. In support of this, at 30 months, we find performance on the ambiguous trials of the visual sequence task correlated with performance on incompatible spatial conflict trials.

These cognitive skills may also underlie the more general ability to acquire and use rules found to develop at about age 3 (Zelazo & Jacques, 1996). Ruff and Rothbart (1996) have also reviewed studies indicating increases in voluntary control of attention over the preschool years. In Kopp’s (1982) review of the development of self-control and self-regulation, she argued that children 3 and above can cease physical acts, delay upon request, and increasingly show flexibility of control processes depending on the task demands. She also indicates that this is a period when children begin to produce strategies in task performance.

At 24 months, the spatial conflict task is so poorly performed that any correlation with anticipatory eye movements is unlikely. However, there is evidence at this age that how often children anticipate during visual sequence trials is related to how well they do on incompatible trials, perhaps suggesting that the effort to anticipate is a precursor of the emergence of effortful control in the two tasks. At 36 months, the spatial conflict tasks are so well learned that there is little evidence of an interference effect. However, at this age there is a tendency for poor performance on nonambiguous trials in the eye movement task to be related to good performance in both compatible and incompatible trials in the spatial conflict task. This suggests that subjects who show better overall skill in the spatial conflict task may also be using a strategy of not going back to the most recently oriented location, producing poor performance on the unambiguous eye movement trials. Here, children showing the most adult-like performance in the eye movements are performing better on spatial conflict.

Finding a correlation between performance in anticipatory eye movements to ambiguous locations and interference in the spatial conflict task suggests that we may be able to measure the emergence of effortful control from 4 months through adulthood in common eye movement and key press tasks. Given the importance of effortful control in cognitive and emotional development, this is likely to be a very useful methodology (Posner & Rothbart, 2000). We have now obtained fMRI results showing that the spatial conflict task
activates areas of the anterior cingulate and frontal lobes (Fan et al., 2003) involved in cognitive and emotional control (Bush et al., 2000). While there is evidence that sequence learning tasks in adults activate some of the same frontal areas found active in spatial conflict (Grafton, Hazeltine, & Ivry, 1995), it is not known whether anticipatory eye movements have an effect upon this circuit, although there are speculations along this line (Curran & Keele, 1993).

How does children’s performance on these tasks relate to their temperament as measured from parental reports? In our previous work (Gerardi-Caulton, 2000), we found that aspects of the spatial conflict task were positively correlated with caregiver reports of effortful control and negatively related to their reports of the child’s negative affect. The current data suggest the emergence of effortful control at 24 months in both interference and completion effects, with those 24-month-olds who show smaller interference effects in spatial conflict showing higher effortful control on the temperament scale and lower reported negative affect. It should be noted that many children with relatively lower effortful control and higher negative affect scores were not represented in the correlational analysis, as indicated by the differences found between children who completed the procedure and those who did not. Yet, even within the somewhat restricted range of children included, we found modest but significant correlations between trials completed and effortful control, and between interference effects and both effortful control and negative affect. We also found that the 24-month-old children who did not complete the Spatial Conflict task were lower in effortful control than those who completed the task. Kochanska et al. (2000) also found that 22- and 33-month-old children’s performance on an effortful control battery predicted better modulation of emotion. These findings suggest that individual differences in the ability to inhibit prepotent responses may play a particularly important role in temperamental regulation in the age at which the executive attention skills are first appearing.

We found no relation between task performance in spatial conflict and temperament at 30 months, but at 36 months, the RT interference effect showed a significant negative correlation with effortful control. Negative affect was also inversely related to children’s percent correct on ambiguous Visual Sequence trials, but at the level of a trend. The negative relation between effortful
control and negative affect has been found at many ages using laboratory measures and temperament scales (Derryberry & Rothbart, 1988; Kochanska et al., 2000; Rothbart et al., 2001). The ability to use effortful control as a means of reducing negative emotion may be an important link between cognition and emotion that arises in early childhood.

In summary, this study provides further evidence for the view that the substrate for effortful control develops significantly over the toddler and preschool years. In recent work, we (Rueda et al., in press) have shown that the executive attention network as marked by a flanker task continues to show development up to age 7–8, but is surprisingly stable from then until adulthood. As executive attention develops, increasing capacities for self-control can provide a basis for continuing socialization. Because some young children will have greater capacities for this kind of influence from parents, teachers, and others, it will be important to disseminate knowledge of the developing basis of effortful control in order to provide the best introduction for young children into contexts and situations that require the exercise of self-regulation. In addition, the motivation for the child’s cooperation with parents and teachers is likely to involve other individual differences that will in turn be influenced by the child’s developing temperament. The nature of the links between attention and control of the emotions will require further study. Finally, the plasticity of the executive attention system over the early years may allow for early interventions to promote the development of executive attention in at-risk populations.

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