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Effortful Control of Attention and Executive Function in Preschool Children

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Abstract

Attention is widely considered a core process of Executive Function (EF), but it is not clear if it is a separable or integral component of EF in preschool children. Preschool children (n=137) completed a battery of tasks which included EF (i.e., response inhibition, working memory) and attentional control (AC) processes (i.e., sustained attention, selective attention). Confirmatory Factor Analyses (CFA) indicated that a two-factor model with EF and AC as separate factors fit the data better than a unitary one-factor model. These findings are consistent with the view that EF and AC are developing at different rates during the preschool years, and thus are not yet fully integrated in the processing of information. The implications of how EF and AC should be conceptualized in early childhood are discussed.

Keywords: Executive Function, Attentional Control, Latent Structure, Confirmatory Factor Analysis, Preschool Children

Introduction

Executive Function (EF) refers to self-regulation processes which underlie our ability to plan, coordinate, and complete goal-directed actions in our daily lives. EF emerges during infancy and undergoes substantial development during the preschool years (Diamond, 2013; Griffin, McCardle, & Freund, 2016). EF is considered foundational to development since early individual differences are predictive of later cognitive/academic performance (e.g., Fitzpatrick & Pagani, 2012) as well as successful social interactions (e.g., de Wilde, Koot, & van Lier, 2016). There has been an explosion of research in the past two decades examining how EF quantitatively and qualitatively changes, with much consideration given to how best to conceptualize the structure of EF throughout childhood. While EF consists of multiple related processes in older children and adults (Lehto et al., 2003; Miyake et al., 2000), it is still not clear if EF is best conceptualized as a multi-dimensional or a unitary construct during the preschool years (Lerner & Lonigan, 2014; Nelson et al., 2016).

Attention or Attentional Control (AC) is widely considered the process common to all EF processes, regardless of how the EF structure itself is conceptualized (Awh, Vogel, & Oh, 2006; Garon, Bryson, & Smith, 2008; Kane & Engle, 2003; Miyake et al., 2000; Posner & Rothbart, 2007). It is well established that AC plays a central role in EF development during the preschool years (Garon et al., 2008). Consistent with this idea, previous studies demonstrate that facilitating children's attention by increasing the number of stimulus cues or their duration improves children's performance on EF tasks (e.g. Bertrand & Camos, 2015; Kirkham, Cruess, & Diamond, 2003). Yet, studying how attention relates to EF in this manner does not directly address if children's AC is separable or integral to EF. One of the main limitations in previous studies of AC is that authors often overlook the fact that AC is not a monolithic construct (e.g., Awh et al., 2006). AC can be conceptualized and measured as a number of different processes, such as sustained and selective attention (Posner, 2012). *The principal aim of this study is to examine the underlying latent structure of EF with the inclusion of tasks directly assessing AC in preschool children.*

Executive Function

Executive function consists of three related but distinct processes: response inhibition (i.e., inhibition of a prepotent or automatic response in order to make a target response), working memory (i.e., maintenance and manipulation of information for a short period of time), and set shifting (i.e., flexible shifting from one task to another) in adults and older children (Garon et al., 2008; Lehto et al., 2003; Miyake et al., 2000). It is not clear if this pattern extends to preschool children. The prevailing view is that EF is an undifferentiated construct during the preschool years which only differentiates into separable processes later in childhood (Nelson et al., 2016). Consistent with this view, response inhibition and working memory are often highly correlated and load onto a single factor (e.g., Hughes et al., 2010; Wiebe et al., 2011). Still, some studies challenge these findings and suggest that EF processes are related but already distinguishable in preschool children and exhibit different developmental trajectories throughout childhood (Zelazo & Carlson, 2012). Consistent with this view, response inhibition and working memory load onto separate factors (e.g., Lerner & Lonigan, 2014; Miller et al., 2012).

One of the main explanations for these contradictory findings is related to "task impurity" and task selection differences between studies (Miller et al., 2012; Miyake et al., 2000; Wiebe et al., 2011). "Task impurity" refers to the fact that performance on EF tasks is rarely based on only one EF process, and it is also influenced by other task factors as well (Nelson et al., 2016). In studies which use only one

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task/measure to assess an EF process, it is especially difficult to know if the resulting associations truly reflect the underlying structure or are idiosyncratic to the task, such as stimulus salience (Miyake et al., 2000). One solution is to include multiple tasks/measures to assess each process, and then pool the common variance among the tasks/measures via composite scores or factor analysis for a "purer" assessment of the process (Miyake et al., 2000; Wiebe et al., 2011).

Attentional Control and Executive Function

Attention is widely viewed as pivotal to a central executive (Baddeley, 2002; Kane & Engle, 2003), and it is considered foundational to the development of EF processes (Garon et al., 2008). For example, selecting and sustaining attention toward relevant information and inhibiting irrelevant information narrows focus and creates an "attentional spotlight," as well as enhances processing and maintenance of relevant information in working memory, which has a limited capacity (Gathercole et al., 2008; Posner & Fan, 2008). This close relationship between working memory and sustained and selective attention is illustrated in studies which reveal that preschool children with lower working memory capacity perform worse on a selective attention task (Espy & Bull, 2005) and are more likely to exhibit attention issues in the classroom (Gathercole et al., 2008). In addition, response inhibition is critical for a child to successfully select and sustain attention on various problem solving tasks, such as completing a puzzle (Allan et al., 2015). Consistent with this idea, children who perform better on response inhibition tasks also tend to perform better on sustained attention tasks (Reck & Hund, 2011). While these examples certainly suggest some association between AC and specific EF processes in preschool children, they do not confirm nor negate whether AC fits into the underlying structure of EF. Critically, these studies only assess a single EF process when multiple EF processes are usually needed to test EF structure (e.g., Wiebe et al., 2011). Therefore, these studies cannot address whether AC should be incorporated into a unidimensional construct of EF or if AC is related but represents a separate construct.

Studies which do include AC and multiple EF processes are riddled with a number of confusions and inconsistencies. For instance, Veer et al. (2017) found that children with better selective attention exhibited better working memory and response inhibition concurrently and six months later. Other studies indicate that the relation between AC and different EF processes may not be as straightforward. For example, Lan et al. (2011) tested how US and Chinese preschool children's working memory and response inhibition related to their performance on a visual search task. The children's working memory was related to visual search performance in both countries, but response inhibition was related to visual search performance in China only. Similarly, Lin, Liew, & Perez (2019) found that performance on a sustained attention task, was significantly correlated with one "hot" EF task, but was only marginally correlated to a second "hot" EF task as well as to the "cool" EF tasks. ("Hot" or emotionally laden tasks are associated with the presence of salient rewards or punishments; "cool" tasks are associated with emotionally neutral contexts; Zelazo & Carlson, 2012) Overall, it is not clear if these inconsistent results are primarily an artifact of "task impurity" or task selection (Miller et al., 2012), or if they signify a true distinction between AC and EF in preschool children. As previously mentioned, this ambiguity may result from study designs including only one measure per process, making it difficult to know if children's task performance reflects their AC and EF, or something more specific to the task, such as stimulus salience or domain knowledge (e.g., Griffin et al., 2016).

There have been several calls to design studies that include multiple measures per process to help ensure that studies are truly assessing the intended process (Lin et al., 2019; Veer et al., 2017). Allan et al. (2015) examined how working memory, response inhibition, and sustained attention were related by having three measures per process in a preschool sample. They found that EF tasks (working memory and response inhibition) loaded onto a different factor than sustained attention, suggesting some distinction between EF and AC in preschool children. Critically, however, Allan et al. (2015) did not include any assessment of selective attention. Thus, even this more comprehensive study treated AC as a monolithic construct, limiting our knowledge of how AC may fit within the EF structure. In the current study, we included multiple measures for response inhibition and working memory as well as for selective and sustained attention.

The Current Study

While AC is often considered an implicit process in most theories of EF during early childhood, there are few studies assessing multiple processes of AC and testing how they contribute to the underlying structure of EF. The primary objective of the current study was to test how AC and EF were related in preschool children between 3.5 and 5 years of age. Specifically, we sought to identify the underlying structure of children's EF when including measures to also assess both sustained and selective attention in children. To this end, preschool children completed a battery of tasks associated with EF processes (i.e., response inhibition in "cool" and "hot" settings, working memory) and AC processes (i.e., sustained attention, selective attention). Development of the study design was based on a careful review of the literature and extensive pilot testing to ensure that each process had more than one measure that was applicable to the entire age range while ensuring considerable variability in children's performance.

Confirmatory Factor Analyses were conducted to examine the underlying structure in the current battery of EF and AC measures. The main advantage of CFA over similar analytic techniques such as Exploratory Factor Analysis (EFA) and Principal Component Analysis (PCA) is that this method enables researchers to test pre-specified latent structures based on theory and prior empirical studies. Further, CFAs allow for model comparison that directly tests which of two or more competing models fit the data better. The utilization of CFAs has steadily increased as more empirical studies investigate the underlying EF structure at different stages throughout childhood (e.g., Lehto et al., 2003; Lerner & Lonigan, 2014; Miller et al., 2012; Wiebe et al., 2011), allowing for increasingly more specific investigations and inferences about how EF structure changes throughout childhood. The current study was designed to add new insights into how sustained and selective attention may influence this EF structure in preschool children.

CFAs were conducted to test whether a one-factor model with all EF and AC measures loading onto the same factor fit the data better than a two-factor model with all EF measures associated with one factor and AC measures associated with a related but distinct second factor. We hypothesized that the two-factor model would fit the data better than the one-factor model, aligning with preliminary results by Allan et al. (2015).

Methods

Participants

One hundred and thirty-seven preschool children (69 female, M = 50.79 months, range = 41 - 60 months) participated in the study. The majority of children participating in this study were Caucasian (83.94%), and the remainder were either Asian-American (13.14%) or African-American (2.92%). All children included in the study had no history of developmental delays or other significant medical issues. Parents provided informed consent before the start of the study session.

Procedure

Children participated in one lab session lasting between 50 and 65 minutes. There were four EF tasks and three AC tasks. In order to keep children engaged and motivated, they were shown a piece of paper with a snowman who needed to retrieve his hat ten paces away; each pace was demarcated by a snowflake. Children were told that they could help the snowman get one step closer to the hat with every task completed; the child was reminded to color in a snowflake after the completion of every task. All testing sessions were conducted in a single room and were recorded for offline scoring. Cohen's kappa between two scorers for all tasks ranged from 0.87 to 0.98 for 101-105 participants.

Circle/Triangle. This task was based on the day/night task developed by Gerstadt, Hong, & Diamond (1994) to assess children's response inhibition. The experimenter showed the child a picture of a circle and a triangle and asked the child to label each shape. The experimenter then introduced a "silly game" and instructed the child to say "triangle" whenever he saw a picture of a circle and "circle" when he saw a picture of a triangle. The pictures were presented in an ABBABAAB order to ensure that the pictures did not consistently alternate, and no picture was presented more than twice in a row; there were a total of 16 trials. The outcome measure was the proportion of correct trials.

Wrapped Gift. This task was adapted from Kochanska, Murray, & Harlan (2000) to assess response inhibition in a "hot" context. The child was presented with a gift bag and was told there was an exciting prize inside. The experimenter told the child she needed to get tissue paper to make the gift bag ready and instructed the child not to touch or peek inside the gift bag until she returned. The experimenter left the testing room and returned with the tissue paper after four minutes had elapsed. The outcome measure was a composite of latency to touch the bag and latency to look inside it. If the bag was not touched or looked into, children received a maximum score of 480, corresponding to the total seconds elapsed.

Spin the Pots. This task was adapted from Hughes & Ensor (2005) and assessed children's working memory for visual-spatial information. A rubber ducky was hidden under one of eight distinctly colored cups turned upside down and arranged in a circle on a lazy Susan tray. The experimenter then occluded the hiding locations from the child's view and spun the lazy Susan so that each cup was in a new location relative to the child. The child was then instructed to find the hidden rubber ducky. Each trial ended when the child found the rubber ducky or failed to find the rubber ducky after three attempts. There were eight trials, and the outcome measure was the proportion correct on the first search.

Digit Span. This task was adapted from Davis & Pratt (1995) and assessed children's working memory for verbal information. On each trial, the child heard a one-to-seven-digit sequence and was asked to repeat it. There were three trials per digit sequence length, and the task ended when the child was incorrect on two of the three prior trials or the child successfully completed all of the seven-digit sequences. The outcome measure was the proportion of correct trials.

Low-Frequency Continuous Performance Task (CPT). This task was adapted from Corkum, Bryne, & Ellsworth, (1995) and assessed children's sustained attention. The child saw a sequence of animals (i.e. cat, alligator, dog, pig, or elephant) on an iPad or touchscreen laptop using the Paradigm Experimenter software (Perception Research Systems, Walnut Creek, California). The child was instructed to touch the screen whenever he saw a cat and not touch the screen whenever he saw any other animal. Each animal was presented for 1200 ms and each inter-trial interval (ITI) was 750ms. There were 100 trials, with a cat presented on 20% of the trials. The outcome measure for correct responses was d-prime (Macmillan & Creelman, 2005).

High-Frequency CPT. This task was adapted from Rezazadeh, Wilding, & Cornish (2011) and assessed children's sustained attention. The child saw a sequence of vehicles (i.e. car, school bus, boat, plane, and train) on an iPad or a touchscreen laptop controlled with the Paradigm Experimenter software. Children were instructed to touch the screen whenever they saw one of the vehicles except the car. Each vehicle was presented for 1200ms and each ITI was 750ms. There were 100 trials; and the car was presented on 20% of the trials. The outcome measure was d-prime.

Visual Search. This task was adapted from Breckenridge et al. (2013) and assessed children's selective attention. The child saw an array of twenty green apples and twenty red strawberries on an iPad or a touchscreen laptop controlled with the Paradigm Experimenter software. Each array also included one randomly placed red apple, and the child was instructed to find and touch the red apple on each trial. There were 32 trials, and each trial ended when the child found the red apple or ten seconds had elapsed; the ITI was three seconds. The outcome measures were accuracy and reaction time.

Table 1: Mean, Standard Deviations and Range

Measure	Mean (SD)	Range
Circle/Triangle	0.61 (0.32)	0.00 - 1.00
Wrapped Gift (secs)	374 (129)	17 – 480
Spin the Pots	0.64 (0.25)	0.00 - 1.00
Digit Span	0.57 (0.11)	0.19 - 0.91
Low Freq CPT	3.35 (1.35)	0.36 - 7.44
High Freq CPT	2.01 (1.23)	-1.76 - 5.68
Visual Search (acc)	0.70 (0.22)	0.13 - 1.00
Visual Search (RT; ms)	4853 (752)	2967 - 7283

Results

Descriptive Statistics

Table 1 provides a summary of means, standard deviations, and ranges for all EF and AC measures. There was neither a floor nor ceiling effect for these tasks, which is often a problem when testing children from three to five years of age. Table 2 summarizes the intercorrelations between all EF and AC measures. As can be seen, most of the measures were significantly correlated, although the correlations were generally moderate (range .19 to .6) and were therefore difficult to interpret as demonstrating either convergent or discriminant validity as a function of EF vs AC variables. As such, it is difficult to know whether these results are consistent with a unitary or fractionated model. It should also be noted that children who responded faster on the selective attention task (visual search) were also more accurate ($r(130) = -0.41$, $p < 0.001$), which thus precludes the possibility of a speed-accuracy trade-off involving these two measures.

As can be seen in the last row of the correlation matrix in Table 2, children's performance on all except two of the measures (wrapped gift and high-frequency CPT) improved with age. With regard to the delay of gratification task, this is somewhat surprising because children's response inhibition continues to improve with age (Carlson, 2005), and also performance on this task was correlated with every other measure, almost all of which improved with age.

Confirmatory Factor Analysis

Confirmatory Factor Analyses were conducted to test whether the unitary one-factor model or two-factor model (EF and AC) fit the data better. CFAs were run in R using the lavaan package (Rosseel, 2012). The two models were compared using multiple fit statistics: the chi-square test (nonsignificant values indicate good fit), the root mean square error of approximation-RMSEA (values < 0.08 indicate good fit), standardized root-mean square residual-

Table 2: Correlation Matrix

	CT	WG	StP	DS	LCP	HCP	VSA	VSR
CT	—							
WG	0.18*	—						
StP	0.33***	0.19*	—					
DS	0.28**	0.12*	0.36***	—				
LCP	0.15	0.25**	0.29***	0.33***	—			
HCP	0.06	0.23*	0.23**	0.09	0.39***	—		
VSA	0.11	0.27**	0.38***	0.22*	0.56***	0.30***	—	
VSR	-0.33***	-0.20*	-0.32***	-0.29**	-0.45***	-0.32***	-0.41***	—
Age	0.43***	0.13	0.39***	0.36***	0.28**	0.10	0.21*	-0.36***

Note: CT=Circle/Triangle, WG=Wrapped Gift, StP=Spin the Pots, DS=Digit Span, LCP=Low-Frequency Continuous Performance Task, HCP=High Frequency Continuous Performance Task, VSA=Visual Search Accuracy, VSR=Visual Search Reaction Time; Note: *$p < .05$, ** $p <.01$, *** $p <.001$.

SRSM (values < 0.05 indicating good fit), Tucker-Lewis index-TLI (values > 0.90 indicate good fit), and the comparative fit index-CFI (values > 0.95 indicate good fit) (Kline, 2011; Schumacker & Lomax, 2016). Since the models were nested, a chi-square difference test was conducted to compare the two models. If both models fit the data but do not differ significantly, then the simpler one-factor model is preferred due to being more parsimonious (Bollen, 1989).

Figure 1 provides a summary of fit statistics for both the one-factor and two-factor model, as well as the model comparison. While some fit statistics indicated that the one-factor model fit the data adequately (i.e., nonsignificant chi-squared test, RMSEA was 0.06, TLI was 0.90), other fit statistics did not (i.e., SRSM was 0.06, CFI was 0.93). By contrast, all the fit statistics indicate that the two-factor model is a good fit: the chi square was non-significant, the RMSEA was 0.04, SMSR was 0.05, the TLI was 0.97, and the CFI was 0.98. The chi-square difference test also indicated that the two-factor model fit the data significantly better than the one-factor model ($x^2(1)=8.64$, $p<0.001$).

Critically, the two models were also compared using the Akaike information criterion (AIC) which evaluates the best model not only in terms of its predictability but also in terms of the number of variables such that more complex models will not always constitute a better fit (Akaike, 1987). Lower AIC values indicate better model fit (Kline, 2011; Schumacker & Lomax, 2016). The AIC was lower for the two-factor model (3946.84) compared to the one-factor model (3953.48). In sum, the fit statistics and model comparisons indicate that the two-factor model consisting of EF and AC is preferable to the one-factor model. It is nevertheless worth noting that the EF and AC factors are correlated (Figure 1), suggesting that these two factors are related but distinguishable.

An additional three-factor model in which the two EF processes (working memory and response inhibition) were tested as separate factors revealed that these models did not represent better fits. As such, these results are consistent with previous models suggesting that response inhibition and working memory are not structurally separate processes in preschool children.

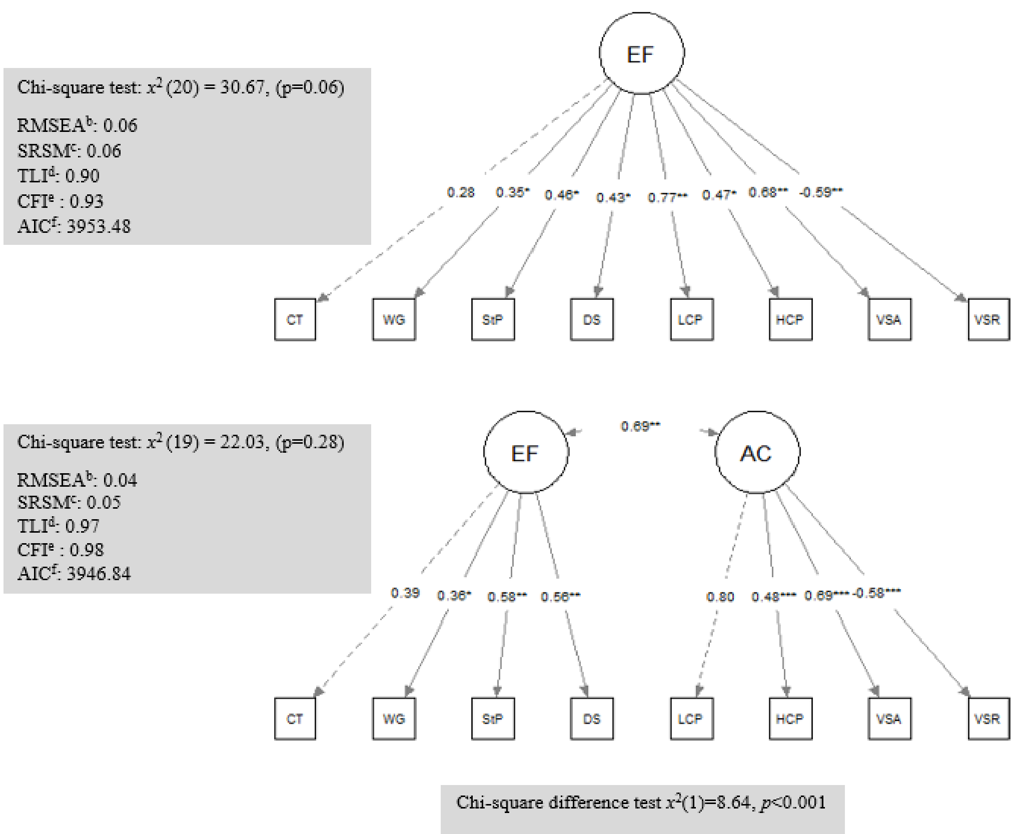

Figure 1: Unitary One Factor Model and EF and AC Two-Factor Model. EF=Executive Function, AC=Attentional Control, CT=Circle/Triangle, WG=Wrapped Gift, StP=Spin the Pots, DS=Digit Span, LCP=Low-Frequency Continuous Performance Task, HCP=High-Frequency Continuous Performance Task, VSA=Visual Search Accuracy, VSR=Visual Search Reaction Time. Standard factor loadings and coefficients are shown; *$p < .05$, ** $p < .01$, *** $p < .001$

Discussion

This study was designed to test whether EF and AC processes were more consistent with a one- or two-factor model during the preschool years. Most previous studies investigating the structure of EF during this age period report that EF is associated with a unitary factor structure. Critically, these studies assumed that AC processes are integral to EF tasks, but never tested this question empirically. The results from the current study reveal that this assumption is at least partially incorrect. By testing the factor structure of EF and AC measures with an a priori predicted model using CFA, we demonstrated that EF and AC are separable but related constructs during the preschool years.

Although our findings challenge the prevailing view that EF is best conceptualized as a unitary construct during the preschool years, they do not support the current opposing view. In fact, our findings converge with previous evidence suggesting that working memory and response inhibition processes represent a unitary process. This is not to suggest, however, that EF constitutes a unitary process during the preschool years. If AC processes are considered integral to the development of EF, then it is important to acknowledge that EF is not a unitary process because AC also develops during this period but is dissociable from EF. It is surprising that this question has remained untested for so long, because attention is broadly viewed as a central process in EF (e.g., Baddeley, 2002; Kane & Engle, 2003).

What are the implications of these findings? First, it is clearly important to appreciate that there is a broad class of AC processes that are often associated with different EF processes, such as the allocation of attention toward representations in memory or serial shifts of attention during visual search (e.g., Woodman & Luck , 1999). As such, there is no one-to-one relation between EF and AC, because there are multiple modes of operation within each of these systems (Awh et al., 2006). Second, there are distinct developmental trajectories for EF and AC during the preschool years, but it remains an empirical question as to whether there is more convergence at later stages of development. This will require more direct comparisons between performance on AC and EF tasks at older ages. Third, distinguishing between unitary and fractionated models of EF and AC may require Occam's razor. It is at least partly dependent on the analytic method. Our findings revealed that the best fit of the data was a two-factor model consisting of EF and AC, but it also revealed a significant correlation between the two factors, suggesting that they are not entirely independent. Indeed, numerous studies reveal significant interactions between sustained or selective attention and working memory processes (e.g., Garon et al., 2008 for a review). The choice of analytic method depends largely on whether the focus is on the interaction between different processes, such as selective attention and working memory, or rather is focused on the latent structure or more common processes involved in EF and AC.

Although most theorists have focused on the development of EF during the preschool years to the exclusion of the development of AC, the work by Posner, Rothbart, and colleagues is a notable exception. They propose that different components of AC are associated with an attention network that develops gradually and leads to EF changes in early childhood (Posner & Rothbart, 2007; Rueda et al., 2005). Posner's Attention Network Theory (Posner, 2012) proposes that AC consists of three related but distinct processes: sustained attention (maintenance of a narrow focus on a single object or event for an extended period of time), selective attention (disengagement from one target in order to orient toward another), and executive attention (monitoring and resolving conflicting information). Although a strict interpretation of our findings might suggest that Posner and colleagues are wrong, we believe that the evidence revealing a correlation between the EF and AC factors at least partially supports rather than refutes their theory.

It is important to note that the executive attention process proposed by Posner and colleagues greatly overlaps with the set shifting processes from the EF literature and similar tasks have been used to assess both (Carlson, 2005; Steele et al., 2012). Critically, we did not include any specific measures of executive attention or set shifting, although the circle/triangle task might be considered an exemplar of both processes. The reason that these tasks were not included is that they are functionally very similar and thus we did not expect to observe a dissociation of the processes involved in these two tasks. As children continue to develop, they will be tested with an increasing number of executive attention or set shifting tasks, which would thus decrease the likelihood of observing a dissociation between AC and EF.

Although we have focused thus far on the findings from the confirmatory factor analyses, a few of the correlational findings merit some brief comments. First, children demonstrated developmental improvements on all but two tasks, thus confirming that both EF and AC are continuing to develop during this period. Second, there is some debate as to whether 'hot' and 'cool' EF tasks will result in similar findings (e.g., Willoughby et al., 2011). In our study, the 'hot' wrapped gift and 'cool' circle/triangle tasks were both designed to measure response inhibition, and contrary to some reports there was a significant correlation between these two measures. We suspect that differences between these two tasks are more likely to occur when there are measurable differences in emotional responsiveness, but there was no evidence of such differences in our study.

In sum, attention is considered a basic building block for the EF system (Garon et al., 2008), but the results from the CFA analyses suggest that it is not fully integrated with EF during the preschool years. Although it is structurally dissociable, our findings as well as those of others suggest that AC and EF are related and interact. The main developmental question for the future is whether AC and EF become more dissociable or more integrated at older ages.

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