Temperament, Executive function and ADHD

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Temperament, Executive function and ADHD in adolescents: the mediating role of effortful control

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Acknowledgements

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Abstract

Introduction: Temperament dimensions may be related to executive functions (EF) and may be involved in the expression and maintenance of symptoms of attention-deficit/hyperactivity disorder (ADHD). The current study aimed to assess whether effortful control (EC) mediates the relationship between EF and inattentive symptoms, and whether Surgency (S) and Negative affectivity (NA) mediate the relationships between EF and hyperactive-impulsive ADHD symptoms in adolescents. **Methods:** Working individually, participants aged between 12 and 16 years ($N = 118$; 75 with ADHD) performed tests of cognitive EF (working memory, planning, flexibility, and inhibition), and parents and teachers completed a multi-informant assessment focusing on measures of ADHD symptoms and temperament dimensions (EC, S and NA). **Results:** There were significant differences between ADHD and control participants in EF and temperament dimensions. ADHD participants had lower scores than controls in working memory, planning and inhibition EF; they also had lower scores in EC and higher scores in S and NA. Structural equation modeling indicated differential associations between EC, S and NA and working memory, planning and inhibition EF with ADHD symptoms. Mediation analysis suggested that EF exerted indirect effects on the inattentive and hyperactive-impulsive symptoms dimension, via EC; higher EF abilities were related with higher levels of EC, which in turn were related with lower scores of inattentive and hyperactive-impulsive ADHD symptoms. S and NA did not mediate relations among EF and hyperactive-impulsive symptoms. **Conclusion:** The findings expand on those of previous studies of the complex relationship between temperament dimensions and EF and confirm the differential association between impairments in some EF, low EC, and the expression of inattentive and hyperactive-impulsive symptoms in adolescents, which may account for the ADHD-control group differences.

Introduction

        Attention-deficit/hyperactivity disorder (ADHD) is a neurodevelopmental disorder of childhood onset characterized by a set of persistent behaviors involving inattention, excessive motor restlessness, and impulse control deficits. These three

symptom dimensions are severe and inappropriate for developmental level, interfere with daily life activities, cause adverse outcomes for affected individuals (Agnew-Blais et al., 2016), and can give rise to three types of presentation: predominantly inattentive (ADHD-I), predominantly hyperactive/impulsive (ADHD-HI), and combined (ADHD-C) (APA, 2013).

The expression of ADHD symptoms is quite heterogeneous among affected individuals, and the mechanisms that underlie them remain elusive. Key possible causal pathways are deficits in executive functions (EF) and/or temperament features (e.g., Nigg, 2006; Nigg, Goldsmith, & Sachek, 2004; Weyandt & Gudmundsdottir, 2015).

EF has been defined as "a multidimensional construct encapsulating higher-order cognitive processes that control and regulate a variety of cognitive, emotional and behavioral functions" (Vriezen & Pigott, 2002, p. 296). It includes working memory, planning, cognitive flexibility and inhibition (Miyake & Friedman, 2012; Zelazo, Carter, Reznick, & Frye, 1997). Zelazo and Müller (2002) and Zelazo and Carlson (2012) propose that EF varies as a function of the motivational component of the tasks, and make a distinction between its cool (cognitive) and hot (affective) aspects, which may represent higher forms of deliberate and regulatory processes (Perone, Almy, & Zelazo, 2018). In particular, cool features of EF are associated with performance in more abstract, decontextualized and non-affective conditions tasks and are usually subserved by the lateral prefrontal cortex (Zelazo & Carlson, 2012). In contrast, the hot features of EF are supported by the orbitofrontal cortex and associated more with tasks with a high affective or motivational involvement (e.g., reward or punishment) (Welsh & Peterson, 2014; Zelazo & Carlson, 2012).

Evidence of links between cool and hot EF and ADHD, though not conclusive, show that executive functioning deficits are a major feature in ADHD (e.g., Antonini, Becker, Tamm, & Epstein, 2015; Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005; Willcutt,

Doyle, Nigg, Faraone, & Pennington, 2005). Several studies have reported deficits in measures of cool (e.g., Corsi Block, Card Sorting and Stop-signal Reaction Time Tests) and hot EF (e.g., Gambling and Delay Discounting Tests) in ADHD adolescents (e.g., Antonini et al., 2015; Perone et al., 2018; Willcutt et al., 2005). In addition, some data suggest differential links between weakness in measures of cool and hot EF and ADHD symptoms (e.g., Castellanos, Sonuga-Barke, Milham, & Tannock, 2006; Egeland, 2012; Sonuga-Barke, 2002; Zelazo and Müller (2002). In particular, although some authors indicate that deficits in cool EF are related to inattention symptoms and deficits in hot EF are related to hyperactivity-impulsivity symptoms (Castellanos et al., 2006), Zelazo and Müller (2002) suggested that ADHD is associated mainly with difficulties in cool EF. Thus, compared with their non-ADHD peers, some children and adolescents with ADHD show deficits in tasks of working memory (Antonini et al., 2015; Kasper, Alderson, & Hudec, 2012), planning (Boyer, Geurts, & Van der Oord, 2014; Weyandt & Gudmundsdottir, 2015), flexibility (Geurts, Verté, Oosterlaan, Roeyers, & Sergeant, 2005; Mullane & Corkum, 2007) and inhibition (Antonini et al., 2015; Willcutt et al., 2005). It is also noteworthy that EF deficits are not present in all ADHD cases, are specific in some but not all EF tasks, and show considerable heterogeneity (Nigg et al., 2005; Fair, Deepti, Bathula, Nikolas & Nigg, 2012). For instance, some studies have shown that there are very few consistent differences in EF measures of planning, flexibility and inhibition between ADHD presentations (Geurts et al., 2005; Krieger & Amador-Campos, 2017; Martel, Nikolas, & Nigg, 2007; Willcutt et al., 2005) and that they may vary depending on the type of measures used to evaluate EF (Weyandt & Gudmundsdottir, 2015). Indeed, the EF deficits are more common on rating scales of EF than on neuropsychological EF tests (Weyandt & Gudmundsdottir, 2015).

Temperament is defined as individual differences in reactivity and self-regulation in the domains of affect, activity, and attention, which are biologically based and can be

influenced over time by various factors such as maturation (Rothbart, 2007; Rothbart & Bates, 2006). Reactivity refers to dispositions towards reactions and tendencies (i.e., emotional, motor, and orienting) and is related to Surgency and Negative affectivity dimensions (Rothbart & Bates, 2006; Rothbart, 2012). Self-regulation refers to processes that modulate reactivity such as Effortful control (De Pauw & Mervielde, 2010; Rothbart & Bates, 2006; Rothbart, 2012).

Effortful control (EC) has been defined as "the efficiency of executive attention, including the ability to inhibit a dominant response and/or to activate a subdominant response, to plan, and to detect errors" (Rothbart & Bates, 2006, p. 126). EC encompasses attentional control (i.e., shifting or focusing attention), inhibitory control and activation control (Eisenberg, Duckworth, Spinrad, & Valiente, 2014; De Pauw & Mervielde, 2010). A number of studies have pointed out that self-regulation is a key part of the organization of temperament (e.g., De Pauw & Mervielde, 2010; De Pauw & Mervielde, 2011; Nigg, 2006; Rothbart, Ellis, & Posner, 2004; Tackett, Martel, & Kushner, 2012).

Research, though limited, suggests that EC may be related to the subsequent development of psychopathology, including ADHD (e.g., Goldsmith, Lemery, & Essex, 2004; Martel, 2009; Muris & Ollendick, 2005; Nigg et al., 2004). Indeed, research (e.g., Martel, 2009; Nigg et al., 2004, for a review) has consistently shown that as a group, children with ADHD (i.e., inattentive-disorganized symptom domain) appear to be characterized by very low levels of EC, and are therefore more likely to develop impairments related to poor regulation (e.g., Eisenberg, Spinrad, & Eggum, 2010; Nigg, 2006). Also, further empirical evidence for a significant inverse relationship between EC and ADHD symptoms in children and adolescents comes from studies such as those of De Pauw and Mervielde (2010), Martel (2009), Martel and Nigg (2006) and Martel, Nigg, and von Eye (2009). The results of these studies show that, for instance, EC

reported by parents using the Early Adolescent Temperament Questionnaire-Revised (EATQ; Capaldi & Rothbart, 1992) and the California Child Q-Sort (CCQ; Caspi et al., 1992) was associated with symptoms of inattention in children and adolescents, whereas it was related to symptoms of hyperactivity-impulsivity in adolescents only. These authors also found that more reactive aspects of temperament in children and adolescents (e.g., Negative affect) were mainly related to hyperactivity-impulsivity symptoms, probably due to poor self-regulation/EC. These results are to a large extent consistent with studies evaluating Conscientiousness/EC, Surgency/Extraversion and Negative affectivity/ Neuroticism in adults with ADHD (e.g., Parker, Majeski, & Collin, 2004). It should also be noted that EC and ADHD may be associated with some common cognitive processes (i.e., inhibitory control) underlying both EC and core symptoms of inattention and hyperactivity-impulsivity (Rettew & McKee, 2005). Thus, although these findings are inconclusive, EC seems to be closely related to ADHD in multiple ways during development, especially to inattention symptoms (Martel & Nigg, 2006; Martel, Nigg, & Lucas, 2008; Martel et al., 2009). Therefore, low levels of EC might be regarded as a liability factor for ADHD (e.g., Nigg, 2006).

Surgency refers to orientation, sociability and a tendency to experience positive affect while Negative affectivity denotes a tendency to experience negative emotions such as discomfort, fear and anger (De Pauw & Mervielde, 2010). Regarding the relationships between Surgency and Negative affectivity dimensions and ADHD, the results are mixed and inconsistent (Eisenberg et al., 2005; Rettew & McKee, 2005). For example, Martel (2016), using the Child Behavior Questionnaire (CBQ parent-report; Rothbart, Ahadi, Hershey, & Fisher, 2001) and Karalunas et al. (2014), using the Temperament in Middle Childhood Questionnaire (TMCQ parent-report; Simonds & Rothbart, 2004) all found relationships between higher scores of Surgency and ADHD symptoms in children. De Pauw and Mervielde (2011) used the Early Adolescent Temperament

Questionnaire-Revised (EATQ-R; Ellis & Rothbart, 2001) and reported that ADHD children and adolescents do not differ from the controls in the Surgency dimension. Similarly, Cukrowicz, Taylor, Schatschneider, and Iacono (2006) found no differences in Surgency/Positive emotionality between ADHD, conduct disorder (CD) and control groups in a sample of children and adolescents. As for Negative affectivity, several studies (e.g., Martel, 2009; Nigg et al., 2004, for a review) have shown that children with ADHD may present relatively high levels; however, using the Positive and Negative Affect Scale for Children (PANAS-C; Laurent et al., 1999), Okado, Mueller, and Nakamura (2016) found that ADHD adolescents without comorbid disorders showed lower levels of Negative affect than those reported in other studies in nonclinical youth samples (e.g., Anderson & Hope, 2008). These authors also found that ADHD adolescents with one or more comorbid internalizing disorders showed increased levels of Negative affect. According to Rettew (2013), the relationships between ADHD and Negative affectivity also tend to be lower when co-occurring symptoms of other conditions (e.g., externalizing problems behaviors) are controlled statistically.

Taken together, EF and temperament dimensions (i.e., EC, Surgency and Negative affectivity) subserve mechanisms related to self-regulation processes (e.g., Eisenberg & Zhou, 2016; Hofmann, Schmeichel, & Baddeley, 2012) that work for the adaptive adjustment of emotion, behavior and cognition to context (Nigg, 2016). Thus, EF and some temperament dimensions such as EC may explain, for example, certain cognitive and behavioral impairments associated with ADHD (e.g., Douglas, 2008; Martel, 2009; Shiels & Hawk, 2010), that cannot be easily attributed to secondary deficits of the main ADHD symptoms (e.g., Barkley, 2015a). In this context, it is worth noting that EF and EC show a conceptual overlap (Allan & Lonigan, 2011; Eisenberg & Zhou, 2016; Nigg, 2016; Zhou, Chen, & Main, 2012). Eisenberg and Zhou (2016) indicate that the overlap

is more evident when the EC definition focuses only on the more deliberative, effortful,

internally based resources guided by the control/regulation of cognition, emotions, and

actions. Further, in Nigg's conceptualization, EC and EF together with cognitive control

constitute a general domain in the self-regulation of behavior, emotion, or thought,

although EF is available for purposes other than self-regulation (Nigg, 2016). Thus,

even though EC and EF are different constructs, due to the research traditions from

which each one comes (temperament and neuropsychology respectively), both are

closely related to self-regulation (Allan & Lonigan, 2011; Welsh & Peterson, 2014;

Zhou et al., 2012). Accordingly, it is possible to identify some similarities between

these constructs: EC and EF share neural substrates (i.e., anterior cingulate gyrus and

lateral prefrontal cortices) and executive attention (Eisenberg & Zhou, 2016). In

addition, cool EF such as inhibition and planning processes are part of both constructs

(Eisenberg & Zhou, 2016). Notably, in both EC and EF, inhibition is evaluated by

similar experimental measures (e.g., Stroop tasks, Go∕No Go, delay of gratification),

although in EF these measures aim to assess the inhibition of cognitive responses and in

EC they aim to assess the inhibition of motivation or emotional behavioral responses

(Eisenberg & Zhou, 2016; Zhou et al., 2012). Nigg (2016) suggests that EC does not

include high-level EF such as planning, and that the relationship between the two may

be due to their mutual dependence on executive attention processes (Eisenberg, 2017).

However, EC and EF also present differences: for instance, EC is more related to

emotion regulation than EF, and working memory capacity is closely related to

regulation processes as a central component of EF but not of EC (e.g., Eisenberg, 2017;

Eisenberg & Zhou, 2016), although Nigg (2016) suggested that it is related to EC.

Additionally, some authors suggest that both cool and hot EF seem moderately related

to EC and that this association depends on whether or not the task performance

conditions imply a high involvement of affective regulation processes (Allan & Lonigan, 2011; Blair & Razza, 2007; Welsh & Peterson, 2014).

During adolescence, the changes in cool and hot EF and EC dimension co-occur with the protracted structural and functional development of neural networks that involve several prefrontal cortex regions (e.g., Carlson, Zelazo, & Faja, 2013; Vijayakumar et al., 2014; Zelazo & Carlson, 2012). Furthermore, EC seems to be a relevant factor in the development of externalizing behavior problems in children and adolescents (Eisenberg et al., 2010) such as ADHD symptoms (e.g., Martel et al., 2009). Prospective studies show that the inattentive symptoms of ADHD tend to persist more with age than hyperactive-impulsive symptoms (Biederman, Petty, Evans, Small, & Faraone, 2010; Hinshaw, Owens, Sami, & Fargeon, 2006). Thus, during adolescence, the nature of the association between EF and ADHD may be sensitive to individual differences in the development of EC and related constructs (e.g., attentional regulation processes). In particular, EC may be considered as a process mediator that could potentially explain behavioral outcomes regarding the relationships between EF functioning and core symptoms of ADHD (e.g., Carlson et al., 2013; Eisenberg et al., 2010; Pérez-Edgar, 2015). Consequently, during adolescence, EC may be an indirect pathway through which cool EF performance is related to ADHD symptom presentation.

Therefore, the aim of the present study was to elucidate the possible role of EC Negative affectivity and Surgency in the pathway from cool EF to ADHD symptom presentations. Given the findings reviewed above, we expect to find differential associations between EC, Negative affectivity and Surgency, cool EF, and ADHD symptoms. More specifically, we hypothesize that: (1) There will be significant differences between the ADHD and control groups on the measures of cool EF and temperament dimensions; 2) Cool EF may exert indirect effects on inattentive

symptoms through its associations with EC, and also on hyperactive-impulsive

symptoms through its associations with Negative affectivity and Surgency dimensions.

Method

Participants

The sample included 118 adolescents aged between 12 and 16 years. The ADHD group

comprised 75 participants (48 ADHD-I and 27 ADHD-C; age: $M = 13.60$, $SD = 1.31$,

68% males), while the control group consisted of 43 participants (age: $M = 13.42$, $SD =$

1.38, 55.8% males). Of 75 adolescents diagnosed with ADHD, 11 (14.7%) had one

other comorbid disorder besides ADHD: five (6.7%) had anxiety disorders (A), five

(6.7%) depressive disorders (D) and one (1.3%) conduct disorder (CD). Furthermore, 40

(53.3%) had two or more comorbid diagnoses: 10 (13.3%) had A and D; 10 (13.3%) had

A and oppositional defiant disorder (ODD); one (1.3%) had D and ODD; 15 (20%) A

and D and ODD; two (2.7%) had A and D and CD, and two (2.7%) had A and ODD and

CD. Twenty-four (32%) participants had ADHD without any other major psychiatric

diagnosis. The control group had no previous or current diagnosis of psychiatric

disorders (i.e., ADHD, A, D, ODD or CD). All participants were recruited from a major

urban area in the northeastern region of Spain, and all were native Spanish speakers.

Participants with ADHD were recruited from two child and adolescent mental health

centers (85.3%) and a university psychology service (14.7%). Most families were

referred to the research team by a pediatrician, psychiatrist or psychologist. The control

group was recruited from a secondary school. All families of the participants recruited

in this study were representative of the area in which the mental health centers and the

school are located. All participants had been born in Spain, with the exception of seven

(5.9%) who were adopted. Almost all the adolescents (90.5%) lived in two-parent

families. There was no attrition in this sample.

All data were collected by a trained Master's level clinical psychologist under supervision by a doctoral level clinical psychologist. With regard to clinical diagnoses, participants in the ADHD group were required to meet DSM-5 cut-off criteria for core symptoms of ADHD, age of onset, chronicity, impairment, and cross-situational manifestations (APA, 2013). The diagnostic assignment to ADHD-I and ADHD-C was determined using data from the Clinical Interview-Parent Report Form (Barkley & Murphy, 2006) and the Conners-3 parent and teacher rating scales (Conners, 2008). Participants were classified as ADHD-I if they met all the criteria for inattention but not those for hyperactivity-impulsivity in the Clinical Interview (inattention symptoms $M =$ 6.8, $SD = 2.7$; hyperactivity-impulsivity symptoms $M = 1.7$, $SD = 2.1$) and had a T-score ≥ 65 on both the DSM inattentive scale and the ADHD Index, and a T-score < 65 on the DSM hyperactive-impulsive scale of the Conners-3, as assessed by parents and teachers. Participants were classified as ADHD-C if they met the criteria for inattention and hyperactivity-impulsivity in the Clinical Interview (inattention symptoms $M = 7.7$, $SD = 1.8$; hyperactivity-impulsivity symptoms $M = 7.8$, $SD = 1.0$) and had T-scores $\geq$ 65 on both the DSM inattentive and hyperactive-impulsive scales and the ADHD Index of the Conners-3, as reported by parents and teachers. Participants in the control group had fewer than six symptoms of inattention and hyperactivity-impulsivity on the Clinical Interview (inattention symptoms $M = 0.30$, $SD = 0.8$; hyperactivity-impulsivity symptoms $M = 0.50$, $SD = 1.3$) and T-scores ≤ 60 on both the DSM inattentive and hyperactive-impulsive scales and the ADHD Index of the Conners-3, as rated by parents and teachers.

Exclusion criteria were: Full-scale intelligence quotient (FSIQ) < 85 on the Wechsler Intelligence Scale for Children Fourth Edition (WISC-IV; Wechsler, 2005); history of tics, neurological disorders, or sensory impairment (seizures or brain injury); or the

presence of psychiatric disorders (autism spectrum disorder, motor or communication disorders, Tourette's syndrome, psychosis or bipolar disorder).

All potentially eligible cases for the clinical diagnosis of ADHD were reviewed following the Frazier and Youngstrom (2005) and Pliszka (2007) guidelines for assessment of ADHD by a principal investigator and a clinical psychologist or psychiatrist. Unanimous agreement among all members of an independent expert panel of ADHD (two psychologists and one psychiatrist certified in clinical child and adolescent psychology) was required to confirm the ADHD diagnosis, the final assignment of participants to the ADHD or control groups, and differential diagnosis of comorbid conditions. An absolute 100% agreement between all experts was reached in a consensus meeting based on symptom counts for diagnosing ADHD via the Clinical Interview for parents and on the cut-off scores for DSM adolescent ADHD (inattentive, hyperactive-impulsive symptoms) and the ADHD index of the Conners 3 rating scales completed by parents and teachers of all participants ($n = 118$).

Parents of participants with stimulant prescriptions (eight ADHD-C and two ADHD-I) were asked to discontinue their children's medication for 24 hours prior to each testing session, under direct medical supervision. Additionally, in the ADHD group, no participants were taking non-stimulant psychotropic medication for the management of comorbid psychiatric conditions.

The participation of all families was entirely voluntary and no financial compensation was offered. The study complied with the principles of the 1975 Declaration of Helsinki (revised in Tokyo in 2014).

Instruments

Clinical Interview-Parent Report Form (Barkley & Murphy, 2006). This form records information about family environment and developmental history, child's health and

his/her school and friendships and peer relations, and family history of DSM disorders provided by children's parents or primary caretaker. The interview also provides DSM diagnostic criteria for childhood mental disorders (oppositional defiant disorder, attention-deficit/hyperactivity disorder, conduct disorder, disruptive behavior disorder, anxiety and mood disorders). The raw scores for symptom counts for ADHD inattention and hyperactivity-impulsivity scales were used. In the current study ADHD inattention and hyperactivity-impulsivity symptom counts had high reliability (inattention, α = .94; hyperactivity-impulsivity, α = .93).

Assessment of ADHD symptoms

Conners scales, 3rd edition (Conners 3; Conners, 2008). This is a commonly used rating scale to assess ADHD behaviors, related problems and comorbid conditions in children and adolescents. This scale includes parent, teacher and self-report forms, and has the content scales of inattention, hyperactivity-impulsivity, learning problems, executive functioning, defiance-aggression and parent-family relations. It also contains the DSM scales of ADHD inattention and hyperactivity-impulsivity symptoms, CD, and ODD (Hebben & Milberg, 2009). The long forms for parent (Conners 3-P: 6-18), and teacher versions (Conners 3-T; 6-18) were administered. The DSM scales for inattention, hyperactivity-impulsivity and ADHD index were used. Gallant et al. (2007) reported high internal consistency for two forms: Conners 3-P (content scales, .85 - .94; DSM symptom scales, .83 - .93), and Conners 3-T (content scales, .92 - .97; DSM symptom scales, .77 - .95). In our sample, reliability (Cronbach's alpha) was good: Conners 3-P (mean content scales, α = .84; mean DSM symptom scales, α = .82) and Conners 3-T (mean content scales, α = .88; mean DSM symptom scales, α = .82). The T-scores for the long form of the parent and teacher reports were used for the diagnosis, and only the parent report was taken into account for correlational and mediational analysis.

Cognitive measures

The spatial memory subtest (SSp) of the Wechsler nonverbal scale of ability (WNV; Wechsler & Naglieri, 2011). This test measures working memory with visual-spatial information in ages between 8:0 to 21:11 years. In this task, the examinee repeats a sequence of tapping of a series of blocks in the same (forward) and reverse (backward) order as demonstrated by the examiner. The task comprises a series of eight sequences in same order (Spatial Span Forward; SSpF index) and eight in reverse order (Spatial Span Backward; SSpB index). The internal consistency is high: .84 (SSpF) and .79 (SSpB); test-retest reliability is also high (.68; Wechsler & Naglieri, 2011). In the current sample, the reliability (Cronbach's alpha) was good: .86 (SSpF) and .84 (SSpB). The SSpF and SSpB raw index scores were used.

Rey-Osterrieth Complex Figure Test (ROCF; Osterrieth, 1944; Rey, 1941). This commonly used test evaluates visuospatial constructional abilities, attention and concentration, planning, organization and visual memory in ages between 6 years to 89 years. This task is composed of a complex geometric figure of 18 elements and involves a copy trial and a delayed-recall trial (Hebben & Milberg, 2009). The subject must first copy directly the geometric figure and then reproduce it from memory after approximately 3-min (delayed immediate recall) after the copy phase has concluded without any kind of indication. Reliability measured with Kendall coefficients (W) ranged between .95 and 1 (Rey, 2003). In the current sample, the Kendall coefficients (W) ranged between .98 and 1. The copy accuracy, time copy and immediate recall accuracy percentile scores were registered. Osterrieth (1944), Poulton and Moffitt (1995) and Taylor (1959) norms and were used.

Porteus Maze Test (PMT; Porteus, 1973). This test provides a measure of mental anticipation, planning and cognitive impulsivity for ages 3 years and over

(Carlozzi, 2011). The task requires participants to solve a series of mazes that increase in difficulty by drawing a continuous line from a start point to a goal point, without entering any blind alleys. The PMT has good internal consistency (α = .81; Krikorian & Bartok, 1998). The planning time (seconds) before starting to draw each maze, the qualitative Q score, and the test age were recorded. The PMT had acceptable internal consistency (α = .64) in the current sample.

Wisconsin Card Sorting Test (WCST; Heaton, Chelune, Talley, Kay, & Curtiss, 1993). This test assesses abstract reasoning, concept formation, cognitive set maintenance, cognitive flexibility and the ability to change cognitive problem-solving strategies in ages ranging between 6.5 and 89 years. The task consists of 128 cards (two decks of 64 cards) that contain design forms that vary according to color (red, yellow, green or blue), shape (triangle, cross, circle or star) and number of figures (1, 2, 3 or 4). The subject is asked to sort the stimulus cards so that they match with the reference cards without the examiner explaining how to match them. After 10 correct sorts on a determined category, the classification rule changes and the subject must discover the new sorting rule following simple feedback ("correct" or "incorrect") given by the examiner, based on a predetermined sorting rule (Kolakowsky-Hayner, 2011). Test-retest reliability (generalization coefficients) ranges from .37 (percentage of perseverative errors) to .72 (non-perseverative errors) (Strauss, Sherman, & Spreen, 2006). The percentage scores for perseverative error and conceptual level responses and the raw scores for the categories completed were recorded. In our sample, reliability (Cronbach's alpha) was acceptable and good, ranging between (α = .69) conceptual level responses, and (α = .86) percentage of perseverative errors.

The Trail Making Test (tasks A and B: TMT A-B; Reitan, 1992). This test measures attention, speed of processing, visual scanning and mental flexibility. The TMT consists of two parts, A and B. In part A, the participant must draw lines that

connect numbered circles in sequence of ascending order. In part B, the participant must draw the connecting lines alternating between numbered circles and lettered circles in ascending order (e.g., start with 1, then draw a line to A, then 2, then B, and so forth until the end). Each part is timed (Allen, Thaler, Ringdah, Barney, & Mayfield, 2012). Kortte, Horner, and Windham (2002) suggests that TMT part-B is more sensitive to cognitive flexibility than the TMT part-A. Register-Mihalik et al. (2012) reported moderate to good reliability for the TMT part-B (between .65 to .85). The time (seconds) to complete trail B was recorded. The reliability (Cronbach's alpha) for the TMT part-B was acceptable ($\alpha = .65$) in the current study.

The d2 Test of Attention (Brickenkamp & Zillmer, 1998). This is a paper-and-pencil visual cancellation test that evaluates visual scanning speed and selective and sustained attention in ages between 9 and 59 years old. This task includes 14 rows with 47 characters each (d's with two dashes of any kind). The subject must cross out all target characters (d's with a total of two dashes above and/or below) from left to right with a time limit of 20 seconds per row and without a break, and then must move to the next line when the examiner gives the instruction. Internal consistency ranges from $\alpha = .61$ (errors of commission) to $\alpha = .97$ (total test effectiveness; TOT) (Bates & Lemay, 2004). The commission errors and total test effectiveness percentile scores were used. In this study, the reliability (Cronbach's alpha) was acceptable for commission errors ($\alpha = .63$) and high for the total test effectiveness ($\alpha = .97$).

Cognitive EF measures were grouped into four executive domains taking into account the hypothetical underlying cognitive processes involved (Krieger & Amador-Campos, 2017; Mitrushina, Boone, Razani, & D'Elia, 2005; Strauss et al., 2006); 1) Working memory tasks (WM): WNV (SSp forward and backward) and ROCF (immediate recall accuracy), 2) Planning tasks (P): ROCF (Copy accuracy and copy time) and PMT (planning time "seconds" before beginning to draw the mazes V to XIV

and Test Age), 3) Flexibility tasks (F): WCST (perseverative errors, conceptual level responses and categories completed) and TMT (total time to complete Part B), and 4) Inhibition tasks (I): PMT (Qualitative Q-Score) and d2 (commission errors and total test effectiveness).

Effortful control

The Early Adolescent Temperament Questionnaire- Revised (EATQ-R; Ellis & Rothbart, 2001). This parent report questionnaire assesses reactive and regulative aspects of temperament in children and adolescents (9-15 years old). The EATQ-R has 62 items rated on a 5-point scale ranging from 1 = almost always untrue to 5 = almost always true. The temperament scales of the EATQ-R cluster in three broad higher-order factors: Effortful control (activation control, attentional control, and inhibitory control), Surgency (high-intensity pleasure, fear and shyness; these last two are reverse scored) and Negative affectivity (frustration and irritability). Also, the EATQ-R includes the behavioral scales of depressive mood and aggression. A fourth high-order factor labeled Affiliativeness is also included in Rothbart's taxonomies for middle childhood and adolescence. In this study, the longer version was used and the raw scores of the three main higher-order factors of Effortful control, Surgency and Negative affectivity (Rothbart & Bates, 2006) were taken into account. In our sample, the reliability (Cronbach's alpha) was acceptable: EC ($\alpha = .65$), Surgency ($\alpha = .67$) and Negative affectivity ($\alpha = .77$).

Procedure

The study was reviewed and approved by the director and coordinators of the ethics committee of the child and adolescent mental health centers and the secondary school. Parents or legal guardians of participants were provided with information about the aims of the study and gave written consent for their children to take part; participants and

teachers gave oral consent. After recruitment, in the first stage for establishing the clinical diagnosis, a clinical psychologist conducted the interview (i.e., Clinical Interview-Parent Report Form) with participants' parents or legal guardians. The interview covered the child's developmental and medical information, the chronicity and pervasiveness of ADHD symptoms, and the associated functional impairment. In addition, in the clinical interview, special emphasis was placed on the evaluation of comorbidities with DSM diagnostic criteria for childhood mental disorders, given that comorbidity is the rule in ADHD and not the exception (e.g., Kimonis & Frick, 2016). In another session, for both the ADHD and control groups, parents or legal guardians and teachers completed individually the Conners 3-P and the Conners 3-T respectively. In the second stage, once the independent group of experts had confirmed the diagnosis, the assessment procedure started with a session in which the parents completed the EATQ-R. In the case of parents who were not able to attend the EATQ-R evaluation session (7; 5.9%), the questionnaire was sent to their homes and they were contacted by telephone to check that all the questions had been understood and answered. In all cases, the parents delivered the questionnaires. The participants performed the different tests in three sessions lasting between 60 and 90 minutes each, separated by a one-week interval and in a fixed order, as follows: First session (WISC-IV and ROCF), second session (WNV, PMT and TMT) and third session (WCST and d2). All tasks were performed and completed under supervision of a clinical psychologist trained in neuropsychological testing. All participants finished the assessment process. Although the tests were administered following the standard procedures proposed by Hebben and Milberg (2009), in some cases the items of the rating scales and the questionnaires were read aloud, at the request of the participants and parents.

Data Analysis

The chi-square test was used to examine gender differences between groups, while differences in age were explored by means of the t-test. Given that EF tasks have several performance indicators with different score types (percentiles, or standard or raw scores), the scores were transformed into Z-scores. EF tasks were grouped into four cognitive domains (WM, P, F and I) according to the probable underlying cognitive process that they engage (Krieger & Amador-Campos, 2017; Mitrushina et al., 2005; Strauss et al., 2006). To obtain a single score for each EF domain a principal component analysis (PCA) was performed for each of these domains, forcing the solution to extract one component. The factor scores for each cognitive EF domain were obtained using Bartlett's method of regression and were appropriate in each domain. Thus, the total explained variance was: WM, 48.09%; P, 33.67%; F, 59.03%, and I, 55%. Factor scores were considered as weighted Z-scores. Raw scores of the EATQ-R dimensions of temperament (EC, Surgency and Negative affectivity) and T-scores of the Conners 3 (inattentive and hyperactive-impulsive symptoms) parent reports were transformed into Z-scores. For all the analyses, Z-scores of EF domains, temperament and ADHD symptoms of total sample were used. Standardized mean difference (Cohen's d) effect sizes were calculated based on mean and standard deviations of each group to assess differences between groups on EF and temperament dimensions. Two separate multivariate analyses of covariance (MANCOVA) were performed with comorbidity conditions (i.e., A, D, ODD and CD) as covariates to compare EF and temperament dimensions measures between groups. The Cohen's d (1992) guidelines for interpreting effect size criteria were also used: 0.20, small; 0.50, medium, 0.80, large. Cohen's d values of 1.30 were considered very large (Sullivan & Feinn, 2012). Pearson correlation coefficients were calculated to explore the relationships between variables, applying Cohen's criteria for the interpretation of coefficients: r = .10 to .29, low; r = .30 to .49, moderate; r = 0.50 to 1.0, high (Cohen, 1988).

Inattention and impulsive behaviors, temperament and cognitive characteristics

associated with ADHD probably lie along the same continuum where the normal and

the abnormal fall at different points with different possible outcomes (e.g., Nigg, 2006;

Nigg, 2013). Also, self-regulation is empirically related to inattention, impulsivity and

other problems like ADHD in the general population (Nigg, 2013). Thus, in order to

investigate the variability across the two dimensions of inattention and hyperactivity-

impulsivity symptoms related to ADHD and EF, the whole sample underwent

correlational and structural equation modeling (SEM) analysis. The SEM analysis

assumes probabilistic causality, not deterministic causality, and expresses functional

relations between variables (Kline, 2016; Mulaik, 2009). Thus, using SEM analysis we

expected to increase our understanding of the relationship between cool EF,

temperament dimensions, and inattention and hyperactive-impulsive symptoms.

To test the path models, the data analysis strategy was guided by the recommendations

of Hayes (2013), using Mplus 7.3 for Mac OS to test the hypotheses. We used the

working memory, planning, flexibility and inhibition EF to compose a latent EF

variable. A set of path analyses was fitted using SEM to estimate direct, indirect and

total effects of hypothetical relationships between EC, Surgency and Negative

affectivity and cool EF on inattentive and hyperactive-impulsive symptoms. These

analyses tested three independent models with the mediator (i.e., EC, Surgency and

Negative affectivity) included in the pathway between EF and ADHD inattentive and

hyperactive-impulsive symptoms (see Figure 1). Here, a change in EC was

hypothesized to mediate the indirect effects of EF on inattentive symptoms.

Additionally, a change in Surgency and Negative affectivity was hypothesized to

mediate the indirect effects of EF on hyperactive-impulsive symptoms.

The parameters were estimated using the robust maximum likelihood method, which is

robust to the non-normality and non-independence of observations (Muthén & Muthén,

1998-2012) and therefore allows the fitting of non-normally distributed data. Model fit was assessed with the following fit indices: χ^2/df, the standardized root mean square residual (SRMR) and the root mean square error of approximation (RMSEA), the Tucker-Lewis Index (TLI), and the comparative fit index (CFI). A $\chi^2/df = p > .05$, RMSEA (or SRMR) $\leq .08$, CFI $\geq .90$ and TLI $> .90$ were deemed to indicate an acceptable fit, while a $\chi^2/df = p > .05$, RMSEA (or SRMR) $\leq .06$, CFI $\geq .95$ and TLI $> .95$ were interpreted as indicating a good fit with a confidence interval of 95%. Additionally, a bootstrapping method (bootstrap replicates = 10,000) was used to estimate indirect effects and standard errors in order to obtain more accurate confidence intervals, reduce Type I errors, and maximize the statistical significance. This approach is especially useful when dealing with any non-normal sampling distributions and a small sample size (e.g., Hayes & Preacher, 2010; MacKinnon, Fairchild, & Fritz, 2007; Shrout & Bolger, 2002). There are no strict rules with respect to the sample size required for SEM or factor structure analyses. Adequate sample size relies on the structure and nature of the data: the stronger the data, the smaller the sample needed to reproduce them in a model (MacCallum, Widaman, Preacher, & Hong, 2001; Wolf, Harrington, Clark, & Miller, 2013). Indeed, as Wolf et al. (2013) point out, one size does not fit all: in some cases, complex models with robust data require smaller sample sizes in order to uncover mediation or indirect effects. Although some "rule-of-thumb" textbooks assert that an observations-to-parameters ratio lower than 5:1 can lead to unstable parameters (ours was 4:1), a closer examination of the bootstrapped standard errors of the estimates reveal that they are actually small: in standardized terms, they range from 0.06 to 0.14, the latter corresponding to a large effect size (-0.43). This suggests that our data are sufficiently robust.

Results

Table 1 summarizes the descriptive statistics and Cohen's *d* effect size for the ADHD

and control groups on inattention and hyperactivity-impulsivity symptoms of the

Clinical Interview, Conners 3, EF, and temperament dimensions. The ADHD and

control groups showed no differences in age [control: $M = 13.42$, $SD = 1.38$; ADHD: M

$= 13.60$, $SD = 1.32$; $t(116) = 0.71$, $p = .49$] and gender, $\chi^2 (1, N = 118) = 1.75$, $p = .18$.

There were no significant differences according to age and gender in EF [age (WM:

$F(4, 113) = 0.15$, $p = .96$; P: $F(4, 113) = 2.10$, $p = .08$; F: $F(4, 113) = 0.73$, $p = .58$; and

I: $F(4, 113) = 0.67$, $p = .61$), and gender (WM: $F(1, 116) = 1.38$, $p = .24$; P: $F(1, 116) =$

2.32, $p = .13$; F: $F(1, 116) = 1.16$, $p = .29$; and I: $F(1, 116) = 1.97$, $p = .16$)], and

temperament dimensions [age (EC: $F(4, 113) = 2.53$, $p = .07$; Surgency: $F(4, 113) =$

0.41, $p = .80$; Negative affectivity: $F(4, 113) = 1.69$, $p = .16$), and gender (EC: $F(1, 116)$

$= 1.57$, $p = .21$; Surgency: $F(1, 116) = 1.83$, $p = .18$; Negative affectivity: $F(1, 116) =$

0.34, $p = .56$)]. Therefore, these variables were not taken into consideration in the

subsequent statistical analyses.

Insert Table 1 here

Executive Functions

Adolescents with ADHD performed worse than controls on most EF measures (see

Table 1) with medium to large effect sizes for working memory ($d = 0.78$), planning (d

$= 0.69$) and inhibition ($d = 1.24$).

MANCOVA was used to test for differences between the ADHD and control groups in

EF measures while controlling for comorbid conditions. MANCOVAs of working

memory, planning and inhibition EF measures using Pillai's trace revealed that after

controlling comorbid conditions the group effects remained significant: V $= .25$, $F(4,$

$112) = 9.67$, $p = .001$, $\eta^2 = .25$. Thus, the effect of comorbid conditions was not

significant.

Temperament dimensions

ADHD adolescents and controls showed significant differences on temperament dimension measures (see Table 1) with medium and very large effect sizes for Surgency ($d = 0.43$), Negative affectivity ($d = 0.81$), and EC ($d = 2.23$).

MANCOVA was used to test for differences between the ADHD and control groups in temperament dimensions while controlling for comorbid conditions. MANCOVAs of Effortful control, Surgency and Negative affectivity temperament dimensions measured using Pillai's trace revealed that after controlling comorbid conditions the group effects remained significant: $V = .43$, $F(4, 112) = 21.13$, $p = .001$, $\eta^2 = 1.00$. Thus, the effect of comorbid conditions was not significant.

Relationships between EF, temperament and ADHD Symptoms

Table 2 shows Pearson correlations between EF, temperament dimensions, and inattentive and hyperactive-impulsive symptoms for the total sample. EC showed significantly positive and low to moderate correlations with EF, with coefficients ranging between $r(118) = .19$, $p < .05$ (working memory) and $r(118) = .36$, $p < .01$ (inhibition). Correlations between temperament dimensions and ADHD symptoms were significant, low to high, and ranging between $r(118) = .21$, $p < .01$ (Surgency and inattentive symptoms) and $r(118) = -.63$, $p < .01$ (EC and inattentive symptoms). In addition, correlations between EF and ADHD symptoms were significantly negative and low to moderate, ranging between $r(118) = -.23$, $p < .05$ (working memory and hyperactive/impulsive symptoms) and $r(118) = -.43$, $p < .01$ (inhibition and inattentive symptoms). No significant correlations were found between the Negative affectivity and Surgency temperament dimensions and EF.

Insert Table 2 here

In order to test our mediation hypothesis, we explored the role of EC, Surgency and Negative affectivity as potential mediators of associations between EF and inattentive and hyperactive-impulsive symptoms. We tested three mediation pathways, one with cool EF indirectly related to inattentive symptoms via EC, and the other two with cool EF indirectly related to hyperactive-impulsive symptoms via Surgency and Negative affectivity. Here, we allowed ADHD symptoms to be correlated. A structural equation modeling for EC revealed a good global fit: $\chi^2 = 12.10$, $df = 2$, $p > .35$, RMSEA = 0.02 (90% CI = .00 - 0.10); CFI = 0.99; TLI = 0.99; and SRMR = 0.03. The models that included Surgency [$\chi^2 = 12.69$, $df = 2$, $p > .31$, RMSEA = 0.04 (90% CI = 0.00 - 0.10); CFI = 0.99; TLI = 0.98; and SRMR = 0.03] and Negative affectivity [$\chi^2 = 9.95$, $df = 2$, $p > .53$, RMSEA = 0.00 (90% CI = 0.00 - 0.08); CFI = 1.0; TLI = 1.0; and SRMR = 0.03] as mediators revealed a good fit. The factor load was also examined and each path of EF was statistically significant: working memory ($\lambda = 0.74$, $SE = 0.06$, $p \leq .001$), planning ($\lambda = 0.68$, $SE = 0.06$, $p \leq .001$), flexibility ($\lambda = 0.17$, $SE = 0.08$, $p \leq .05$) and inhibition ($\lambda = 0.77$, $SE = 0.07$, $p \leq .001$). In addition, the EF model explained 55% ($p \leq .001$) of the variance in working memory, 47% ($p \leq .001$) of the variance in planning and 60%, ($p \leq .001$) of the variance in inhibition. The R-Square value for flexibility EF was not acceptable.

The results of mediational analysis showed that the indirect effect of EF on inattentive symptoms through EC was significant (ß = -0.18; $SE = 0.05$, 95% CI [-0.30, 0-.09], $p = .001$). We also found an indirect effect of EF on hyperactive-impulsive symptoms through EC (ß = -0.17; $SE = 0.05$, 95% CI [-0.29, -0.81], $p = .001$). In addition, there were direct effects of EF on inattentive symptoms (ß = -0.31; $SE = 0.09$, 95% CI [-0.49, -0.14], $p = .001$). Finally, we did not find any specific, direct effects of EF on hyperactive-impulsive symptoms (ß = -0.14; $SE = 0.09$, 95% CI [-0.35, -0.04], $p = .13$). This model explained up to 49% of the variance in inattentive symptoms ($R^2 = 0.49$) and

29% of the variance in hyperactive-impulsive symptoms ($R^2 = 0.29$). The results showed that EC mediates the associations between cool EF and inattention and hyperactive-impulsive symptoms. The final model is described in Figure 1.

The mediation analysis showed that the indirect effects of EF on inattention symptoms (ß = -0.02; *SE* = 0.02, 95% CI [-0.08, 0-.00], *p* = .29) and hyperactive-impulsive symptoms (ß = -0.05; *SE* = 0.03, 95% CI [-0.12, -0.00], *p* = .12) through Surgency was not significant. We also found direct effects of EF on inattentive (ß = -0.31; *SE* = 0.09, 95% CI [-0.63, -0.26], *p* = .001) and hyperactive-impulsive symptoms (ß = -0.26; *SE* = 0.10, 95% CI [-0.45, -0.03], *p* = .01). This model explained up to 26% of the variance in inattentive symptoms ($R^2 = 0.26$) and 18% of the variance in hyperactive-impulsive symptoms ($R^2 = 0.18$). The results showed that Surgency does not mediate the associations between cool EF and inattention and hyperactive-impulsive symptoms.

Mediation analysis showed that the indirect effects of EF on inattention symptoms (ß = -0.04; SE = 0.03, 95% CI [-0.12, 0-.00], *p* = .11) and hyperactive-impulsive symptoms (ß = -0.07; SE = 0.04, 95% CI [-0.18, -0.00], *p* = .11) through Negative affectivity were not significant. Direct effects of EF were also found on inattentive (ß = -0.45; SE = 0.09, 95% CI [-0.63, -0.24], *p* = .001) and hyperactive-impulsive symptoms (ß = - 0.24; SE = 0.09, 95% CI [-0.42, -0.04], *p* = .01). This model explained up to 68% of the variance in inattentive symptoms ($R^2 = 0.68$) and 75% of the variance in hyperactive-impulsive symptoms ($R^2 = 0.75$). The results showed that Negative affectivity does not mediate the associations between cool EF and inattention and hyperactive-impulsive symptoms.

Insert Figure 1 here

Discussion

Elucidating the associations between EF, temperament dimensions, and ADHD symptoms is important for understanding the processes underlying self-regulation during adolescence. Our aim here was to examine whether ADHD and control groups differed significantly on measures of EF and temperament dimensions. We also assessed, in particular, whether EC, Surgency and Negative affectivity would explain the relationship between cool EF and inattentive and hyperactive-impulsive symptoms. The first hypothesis of this study is partially confirmed. The results showed statistically significant differences between the task performance of ADHD and control groups in three of four cool EF and all temperament dimension measures. Concerning EF, our findings are in line with those of previous studies in which children and adolescents with ADHD performed worse than controls on tasks of working memory, inhibition and planning (Antonini et al., 2015; Willcutt et al., 2005). Notably, the broad body of available research suggests that working memory and inhibition impairments are central deficits in ADHD children and adolescent samples (e.g., Antonini et al., 2015; Hart, Radua, Nakao, Mataix-Cols, & Rubia, 2013; Lambek et al., 2011; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005). Most investigators agree that these EF support processes involved in the self-regulation of goal pursuit, which seems to be altered in ADHD (e.g., Barkley, 2015b; Eisenberg & Zhou, 2016; Hofmann et al., 2012; Nigg, 2016). As to the planning, several studies suggest that weakness on motor and visual–spatial planning tasks (e.g., Tower of Hanoi, Kotovsky, Hayes, & Simon, 1985 & Porteus Maze Test), may be linked to ADHD although it is not characteristic of all cases (Dahan & Reiner, 2017; Weyandt & Gudmundsdottir, 2015). Furthermore, several studies indicate that implementation of self-regulation requires EF capacities of planning (e.g., Barkley, 2015a; Blair, 2016). Finally, no group differences were found in performance on EF tasks of flexibility. These results are consistent with those obtained by Scheres et al. (2004) who found no difficulties in children with ADHD using the

WCST. Interestingly, some studies suggest that the specificity of performance impairments of ADHD people on the WCST (Heaton et al., 1993) has not been consistently established and probably depends on the group's age and the WCST variables used (Romine et al., 2004; Sergeant, Geurts, & Oosterlaan, 2002).

In all, this pattern of findings supports the notion that cool EF deficits and ADHD symptoms may be closely related during adolescence. In addition, given the links between EF and self-regulation processes (Blair, 2016, Hofmann et al., 2012), deficits in working memory or inhibition could explain, at least partially, the difficulties of self-regulation observed in some children with ADHD (Barkley, 2015a; Shaw, Stringaris, Nigg, & Leibenluft, 2014).

On the other hand, no effects of comorbidity were found on performance in EF measures. These findings are consistent with previous research in children showing that deficits in working memory and planning EF remained significant in ADHD groups, after controlling for ODD/CD comorbid conditions (e.g., Kalff et al., 2002; Oosterlaan, Scheres, & Sergeant, 2005). Also, children with ADHD and ODD or CD performed worse than controls in inhibition (e.g., Stroop Color Test; Stroop, 1935) and working memory EF (e.g., children's memory scale numbers subtest; Cohen, 1997), and behavioral EF rating scales (i.e., BRIEF, Gioia et al., 2000) (Hummer, Kronenberger, Wang, & Dunn, 2010). Regarding ADHD and comorbid anxiety disorders, Ter-Stepanian et al. (2017) found that ADHD children aged 6 to 12 years old showed difficulties in EF measures of inhibition and working memory compared to controls. In the same study, the authors found that ADHD and comorbid CD were associated with difficulties in the set-shifting EF task (i.e., WCST; Heaton et al., 1993), which were not observed in the current study. Regarding ADHD and comorbid depressive disorder, in a sample of 252 ADHD children and adolescents aged 10 to 15 Günther, Konrad, De Brito, Herpertz-Dahlmann, and Vloet (2011) found that performance on attention

measures of EF could not differentiate between ADHD with and without comorbid disorder. Finally, in the study by Sarkis, Sarkis, Marshall, and Archer (2005) in a sample of children and adolescents, ODD, anxiety disorders, and mood disorders co-occurring with ADHD were not related to performance in planning and working memory EF (i.e., TOL; Shallice, 1982). Together, these results indicate complex and unclear relationships between ADHD, comorbid conditions and EF (Sarkis et al., 2005).

As regards temperament dimensions, ADHD adolescents showed lower EC, higher Surgency and higher Negative affectivity than controls. These results are in line with previous studies showing low EC/Conscientiousness in ADHD children and adolescents (e.g., Martel, Gremillion, & Roberts, 2012; Martel et al., 2009). This is significant, given that regulation problems associated with low EC may contribute to the expression and severity of ADHD symptoms, especially inattentive symptoms (Nigg, 2006; Nigg et al., 2004; van Stralen, 2016). Thus, our findings may be related to the fact that ADHD-I and ADHD-C presentations share inattentive symptoms, which are closely related to EC.

Although the links between Negative affectivity, Surgency and ADHD symptoms seem less clear (Rettew & Mckee, 2005), our results show significant links between these temperament dimensions and ADHD symptoms in children and adolescents, similar to those found in other studies (Karalunas et al., 2014; Martel, 2016; Martel & Nigg, 2006; Rettew, 2013; van Stralen, 2016). For instance, in a study with adolescents, De Pauw and Mervielde (2011) found relationships between Negative affectivity and ADHD symptoms but not Surgency, while focusing on youth adults Parker et al. (2004) found positive relationships between ADHD symptoms and both Surgency/Extraversion and Negative affectivity/Neuroticism. Regarding Surgency, Karalunas and colleagues (2014) found that ADHD symptoms were related to severe and extreme levels of positive approach motivation and activity level (type 2 Surgent). Furthermore, Okado et

al. (2016) found that after controlling for comorbid conditions, the associations between ADHD and Negative affectivity tended to be lower in a sample of adolescents. In the current study, it is worth noting that after controlling for the comorbid conditions (A, D, ODD and CD), the associations between ADHD and Negative affectivity and Surgency dimensions remain significant. In addition, although in our sample the ADHD-C group had fewer cases than the ADHD-I group, the relationship between Surgency and ADHD was significant. Finally, in this study, the significant relationships between EC and Negative affectivity dimensions ($r = -.50$) probably represent a risk factor for the presence of externalizing behaviors associated with ADHD (Foley, McClowry, & Castellanos, 2008; Martel & Nigg, 2006; Nigg, 2006). These results may suggest distinct and complex temperament pathways involved in ADHD with weakness in reactive and/or regulatory processes and the presence of comorbid conditions (i.e., A, ODD, and CD) (Nigg, 2006; Nigg et al., 2004). In addition, several other factors may influence the relationships between ADHD and temperament dimensions such as age and the type of temperament measure used, or whether the symptom domains are analysed together or separately.

In summary, with regard to our first hypothesis, our findings indicate that the ADHD group performed worse in cool EF and had more difficulties in temperament dimensions of EC, Surgency and Negative affectivity. Specifically, our results highlight the relationships between weaknesses in cool executive domains and ADHD (Zelazo & Müller, 2002). In addition, the relationships between ADHD, temperament dimensions and EF remained significant after adjustment for comorbid conditions, which indicates that in the current study the comorbidities did not have significant effects.

Taken together, these findings suggest that ADHD in adolescence may be characterized by weaknesses in cool EF (Zelazo & Müller, 2002) and, together with low EC, high Surgency and Negative affectivity, may be linked to difficulties in both behavioral

regulation and the expression of symptoms (e.g., Eisenberg et al., 2010). This would support the suggestion made by Nigg and colleagues (2004) that the executive control difficulties observed in ADHD are a component of temperament involved in the liability to ADHD. Finally, our findings underline the usefulness of certain traits to partially explain the differences between ADHD and control groups (e.g., De Pauw & Mervielde, 2011; Karalunas et al., 2014).

With regard to associations between cool EF, temperament dimensions, and inattentive and hyperactive-impulsive symptoms, the results indicate significant and differential patterns of relations. These findings are in line with previous reports showing associations between EF deficits, low EC/Conscientiousness, high Negative affectivity and high Surgency with ADHD symptoms in children and adolescents (Martel, 2016; Martel et al., 2008; Wiersema & Roeyers, 2009). Also, in line with previous research (Martel et al., 2008; Martel et al., 2009; Wiersema & Roeyers, 2009), we found low to moderate correlations between working memory, planning, inhibition EF and EC (i.e., parent reports). In particular, the pattern of low-to-moderate and positive correlations between EF and EC probably reflects partial links between the cognitive processing abilities required for task performance (e.g., working memory, inhibition) (e.g., Eisenberg & Zhou, 2016). These findings are consistent with data indicating that EC and EF probably share similar processes (Martel et al., 2009). The low or negligible associations between EF measures and Negative affectivity and Surgency dimensions are at odds with previous studies that have reported relationships between these two temperament dimensions and EF measures (i.e., working memory and flexibility) in ADHD children (Bauer, Gustafsson, Nigg, & Karalunas, 2017; Martel, 2016).

There are significant correlations between cool EF and both ADHD symptom clusters, except for flexibility. These results support a broad body of research that has reported key connections between EF deficits and ADHD symptoms (e.g., Castellanos et al.,

2006; Willcutt et al., 2005; Zelazo & Müller, 2002). Corroborating previous reports (De Pauw & Mervielde, 2011; Martel et al., 2009; Nigg et al., 2004) significant correlations were found between EC, Negative affectivity, Surgency and the ADHD inattentive and hyperactive-impulsive symptoms. Overall, these findings suggest that cool EF and temperament measures may partially account for the variability of cognitive deficits and self-regulation behavior problems associated with ADHD in adolescents.

Our second hypothesis which related cool EF with inattentive symptoms via EC, and cool EF with hyperactive-impulsive symptoms via Surgency and Negative affectivity, was only partially fulfilled. As far as EC is concerned, our analysis provides partial support for the predictions. EC mediates the relationship between cool EF and inattentive and hyperactive-impulsive symptoms. In the overall sample, mediation analysis revealed that higher performance in EF is indirectly associated with lower inattentive and hyperactive symptoms, via its associations with higher EC. Therefore, EC seems to explain the relationships between cool executive functioning and the expression of both inattentive and hyperactive-impulsive symptoms. These results are consistent with those of Martel et al. (2009) who found associations between EF (i.e., flexibility and inhibition), EC/Conscientiousness and inattentive and hyperactive-impulsive symptoms in adolescents. Our findings suggest that adolescents with inattentive and hyperactive-impulsive symptoms may also be characterized by low EC and cool EF deficits, which may represent a risk factor for the presence of weakness in regulatory control abilities (Barkley, 2015a; Nigg et al., 2004). In addition, cool EF were directly related to EC, supporting previous reports of a certain overlap between EF and EC (Eisenberg & Zhou, 2016; Zhou et al., 2012). We also found a direct relationship between cool EF and inattentive symptoms, as reported in other studies with ADHD children (Martel, & Nigg, 2006; Martel et al., 2008) but not in children with hyperactivity-impulsivity symptoms. Furthermore, as in previous studies (e.g.,

Goldsmith et al., 2004) EC was directly related to both inattentive and hyperactive-impulsive symptoms, suggesting that symptoms may be differentially associated with children's EC skills during adolescence (Martel, 2016; Martel et al., 2009). In addition, this relationship may be explained by common cognitive processes (i.e., inhibition) (e.g., Eisenberg & Zhou, 2016) or by the conceptual frameworks that underlie EC and ADHD measures, which may entail item content overlap between the measures of ADHD symptoms and temperament dimensions (parental report). Note that in the current study hot EF measures were not used, and it is impossible to establish inferences regarding their relations with the hyperactive-impulsive symptoms, as previous studies have found (e.g., Toplak, Jain, & Tannock, 2005).

In general, EC is related to EF and both inattentive and hyperactive-impulsive symptoms. The effects of cool EF on inattentive and hyperactive-impulsive symptoms, via EC, are probably explained by the maturational course during the adolescent years of EC. In particular, these effects may be associated with the protracted and widespread refinement of neural systems (i.e., the anterior cingulate cortex, medial and lateral prefrontal structures) (Casey, Jones, & Hare, 2008) which underlie EC (MacDonald, 2008) and are closely related to the interface of cognition and emotion (Shaw et al., 2014; Zhou et al., 2012). Thus, the mediation effect of EC in these relationships is relevant given that this temperamental dimension is thought to play a key role in the etiology and maintenance of ADHD symptoms (e.g., Martel, 2009; Nigg et al., 2004).

Regarding Surgency and Negative affectivity, the SEM analysis does not support the prediction that cool EF are indirectly associated with hyperactive-impulsive symptoms via these two temperament dimensions. Therefore, in the current study, these two temperament dimensions do not seem to explain the relationships between performance on cool EF and the expression of hyperactive-impulsive symptoms. Additionally, in line with previous research (Martel et al., 2008; Martel et al., 2009), cool EF seems not to

have direct links with Surgency and Negative affectivity. These results contrast with those reported in previous studies with samples of ADHD children which showed negative relationships between cool EF measures (e.g., working memory index, WMI, Wechsler, 2005) and Negative affectivity (e.g., Rabinovitz, O'Neill, Rajendran, & Halperin, 2016). The absence of relationships would suggest that the performance in cool EF could be related to more regulatory (i.e., EC) than reactive (i.e., Surgency and Negative affectivity) processes of the temperament dimensions because both are related to the activity in prefrontal cortex regions, which is salient in the support of control functions (e.g., Posner & Rothbart, 2007). We also found that Surgency was directly related to hyperactive-impulsive symptoms whereas Negative affectivity was directly linked to both inattentive and hyperactive-impulsive symptoms. This is in line with other studies in samples of children, where both these temperament dimensions were differentially associated with inattentive and hyperactive-impulsive symptoms, but were based on biologically influenced indicators (Karalunas et al., 2014).

Overall, cool EF deficits and EC, Surgency and Negative affectivity difficulties were associated with ADHD symptoms. The patterns of the links between EF, EC, Surgency and Negative affectivity and inattentive and hyperactive-impulsive symptoms highlight the heterogeneity of ADHD in adolescence. They also suggest that cool EF and temperament dimensions may be related but independent constructs when it comes to explaining ADHD symptoms. Additionally, in the current study the measures of EF and temperament dimensions reflect significant differences in cognitive and behavioral functioning between adolescents with and without ADHD. The mediation analysis indicated that EC mediates the associations between cool EF and inattentive symptoms, but that Surgency and Negative affectivity did not mediate relations between cool EF and hyperactive-impulsive symptoms.

This study has some limitations. First, the use of parents' and teachers reports may reflect biased perceptions of adolescents' performance. Second, the administration of cool EF, ADHD symptoms and temperament dimensions measures followed a fixed order without counterbalance, which may have affected the results. In addition, hot EF measures were not considered in the current study, and so it was impossible to explore the relationships between tasks of this kind and ADHD symptoms to provide a more complete view of executive functioning in ADHD. Furthermore, the sample size probably did not allow a full exploration of the nature of relationships between EC, EF and ADHD symptoms.

An important contribution of this study is its rigorous combination of information gathered from different informants (parents, teachers, and participants) through clinical interviews and rating scales for clinical diagnosis. Cool EF and temperament measures can accurately map cognitive and behavioral functioning between adolescents with and without ADHD. Cognitive functioning should be routinely evaluated together with comorbid conditions and temperament factors in adolescents diagnosed with ADHD. These measures provide complementary information on early temperament dimensions and proficiency in executive abilities, which may be valuable for identifying treatment targets and for designing interventions that enhance self-regulation and coping skills in adolescents. This approach is useful in the developmental screening and assessment of domain-specific self-regulatory skills in ADHD. It is also worth noting that, to our knowledge, the mediating role of EC on the associations between EF and ADHD symptoms has not been assessed to date.

In summary, our findings emphasize the complex and elusive nature of the relationship between EF, temperament dimensions and ADHD. The study also provides evidence that EC has a significant mediating effect on the relationships between EF and inattentive and hyperactive-impulsive symptoms in adolescents.

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Table 1

Means, Standard Deviation and Cohen's d effect size of ADHD and control groups on ADHD *symptoms of Clinical*

Interview for parent, Conners 3, EF and EATQ-R parents report measures

	ADHD (n = 75)	CG (3) (n = 43)		Univariate		
	Mean (SD)	Mean (SD)	t	df	p	Cohen's d
ADHD Symptoms Clinical Interview (Parent)§						
Inattention	7.25 (2.25)	0.30 (0.8)				
Hyperactivity-impulsivity	4.75 (1.55)	0.50 (1.3)				
Parent Conners 3#						
DSM-IV Inattention scale	74.57 (11.88)	46.04 (7.93)				
DSM-IV Hyperactivity scale	66.22 (16.65)	49.53 (10.06)				
Conners-3 Index ADHD	70.68 (13.69)	48.95 (8.84)				
Teacher Conners 3#						
DSM-IV Inattention scale	76.37 (10.43)	47.72 (8.34)				
DSM-IV Hyperactivity scale	64.94 (16.44)	48.88 (9.27)				
Conners-3 Index ADHD	72.81 (13.55)	50.30 (11.00)				
Cognitive EF*						
Working Memory	-.262 (.995)	.457 (.837)	3.992	116	.001	0.782
Planning	-.234 (1.015)	.409 (.835)	3.528	116	.001	0.691
Flexibility	-.083 (1.031)	.146 (.935)	1.204	116	.231	0.232
Inhibition	-.378 (.947)	.659 (.710)	6.242	116	.001	1.239

Temperament EATQ-R[§]

Effortful control (EC)	2.590 (.473)	3.680 (.503)	11.762	116	.001	2.232
Surgency	3.201 (.500)	2.986 (.495)	2.260	116	.026	0.432
Negative affectivity	2.982 (.665)	2.465 (.601)	4.198	116	.001	0.815

Note. ADHD = attention deficit hyperactivity disorder; *CG* = control group; *df* = degree of freedom; *d* = Cohen's *d* effect size. *p* = statistical significance level. *§* = raw scores; # = T-scores, * Z-scores.

Table 2

Correlations between EF, temperament dimensions EATQ-R parent report and inattentive and hyperactive-impulsive symptoms of Conners 3 parent report (DSM subscales) for ADHD and Control groups (N = 118)

Measures	1	2	3	4	5	6	7	8	9
1.Working memory	-								
2.Planning	.54**	-							
3.Flexibility	.11	.10	-						
4.Inhibition	.57**	.51**	.18	-					
5.Effortful control	**.19***	**.23***	.03	**.36****	-				
6.Surgency	-.15	-.13	-.13	-.10	-.20*	-			
7.Negative affectivity	-.14	-.03	-.04	-.18	-.50**	.03	-		
8.Inattentive	**-.35****	-.33**	-.03	**-.43****	**-.63****	**.21***	**.34****	-	
9.Hiperactive-impulsive	**-.23***	-.10	-.03	**-.33****	**-.53****	**.34****	**.44****	.60**	-

Note. ADHD = attention deficit hyperactivity disorder. In bold type significant correlations between cognitive EF, temperament dimensions and inattentive and hyperactive-impulsive ADHD symptoms.
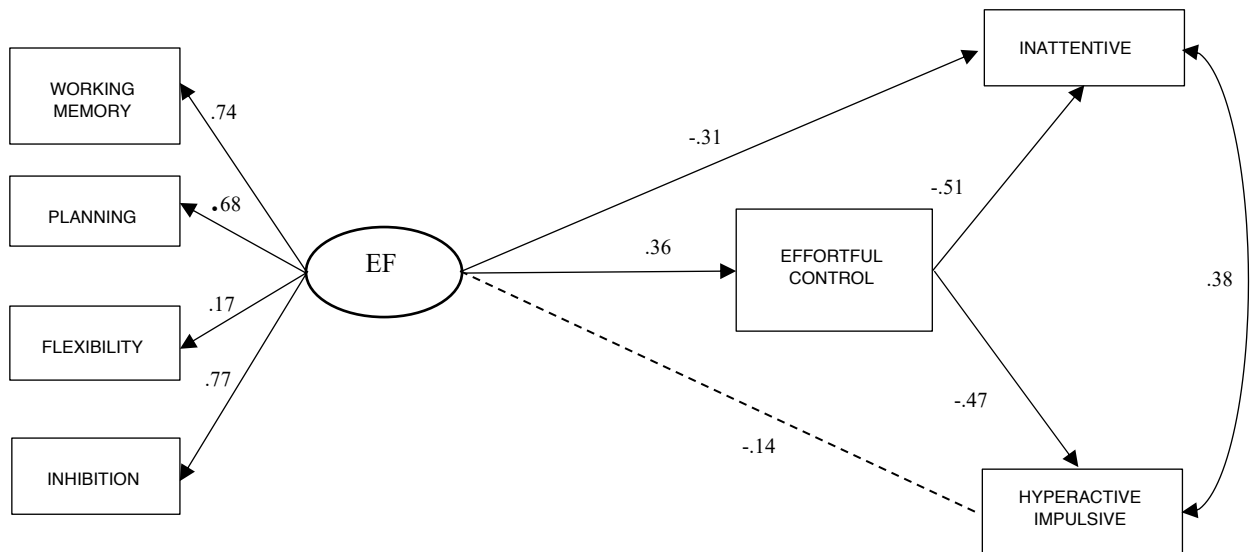
* $p < .05$ ** $p < .01$.

Figure 1. Final model with standardized parameter estimates of relationship between executive function, effortful control and inattentive and hyperactive-impulsive symptoms. Note. $N = 118$. Solid lines indicate significant paths coefficients at the $p < .001$ level and dashed lines indicate are non-significant paths.