Few differences in hot and cold executive functions in children and adolescents with combined and inattentive subtypes of ADHD

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The aim of the study was to compare executive processes with pronounced (hot) and less pronounced (cold) emotional salience in medication naïve children and adolescents with ADHD-combined (ADHD-C) and ADHD-inattentive (ADHD-I) subtypes. Thirty-six subjects with ADHD-C, 44 with ADHD-I, and 50 healthy controls between 8 and 17 years were assessed with laboratory tests and inventory-based scales assessing hot and cold executive functions (EF) (controlled attention, working memory, planning, cognitive flexibility, verbal fluency, hot decision making) and the Behavior Rating Inventory of Executive Function (BRIEF). The ADHD-C group displayed significantly more impairment compared to the ADHD-I group on the cold BRIEF Inhibition and Monitor scales. There were no significant differences between ADHD subtypes on cold and hot laboratory tests. The hot decision-making task did not correlate with the other cold or hot EF measures. Overall, few EF measures were shown to differentiate between ADHD subtypes nor were there any relationships between the hot decision-making task and the other EF measures, which seems to indicate separate developmental trajectories.

Keywords: Attention deficit/hyperactivity disorder; Children; Adolescents; Neuropsychological tests; Decision making; BRIEF.

Attention deficit/hyperactivity disorder (ADHD) is characterized by a cluster of symptoms consisting of inattention, hyperactivity, and impulsivity. Following the Diagnostic and Statistical Manual of Mental Disorders, text revision (DSM-IV-TR; American Psychiatric Association [APA], 2000), ADHD can be divided into three subtypes: the...
predominantly inattentive subtype (ADHD-I), the predominantly hyperactive/impulsive subtype (ADHD-H), and the combined subtype (ADHD-C). In the *DSM-IV-TR*, these three subtypes belong to the same diagnostic entity, despite large differences between groups in terms of symptoms, comorbid disorders, and cognitive impairments (Adams, Derefinko, Milich, & Fillmore, 2008; Castellanos, Sonuga-Barke, Milham, & Tannock, 2006; Diamond, 2005). However, the instability of ADHD subtype characteristics throughout childhood raises the issue of the usefulness of having different ADHD categories in *DSM-IV-TR* (Lahey, Pelham, Loney, Lee, & Willcutt, 2005). As behavioral symptoms have not always proven to be stable over time, cognitive functions may potentially be a more reliable endophenotypic trait, differentiating ADHD subtypes from each other (Barkley, 1997a; Chhabildas, Pennington, & Willcutt, 2001; Nigg, 2001).

One central source of the disability associated with ADHD has been deficits in executive functions (EFs; Biederman et al., 2007). EFs refer to higher order cognitive functions relating to control of thought, action, and emotion (Zelazo & Cunningham, 2007). Traditionally, most neuropsychological tests measuring EF reflect cognitive processes with little emotional salience, referred to as cold EF (Chan, Shum, Toulopoulou, & Chen, 2008). In Barkley’s (1997b) influential model, cold EF impairments are explained by a primary deficit in controlled attention and are related to ADHD-C but not to ADHD-I. With regard to the ADHD-I group, Diamond (2005) argue in a comprehensive review that working memory impairments constitute a core deficit. However, in a meta-analytic review of 83 studies, Willcutt, Doyle, Nigg, Faraone, and Pennington (2005) did not find support for reliable EF differences between ADHD-C and the ADHD-I subtypes. Overall, research results on cold EF deficits are inconsistent, making ADHD subtype differentiation unreliable.

Even though EF has been regarded as a promising endophenotype in ADHD (Barkley, 1997a; Chhabildas et al., 2001; Nigg, 2001), recent studies suggest that many subjects with ADHD perform normal on tests of cold EF (Biederman et al., 2004; Egeland, 2010; Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005). According to the dual-pathway model, EF impairments more often appear in complex everyday situations where affective and motivational processes interact with cold EF processes (Sonuga-Barke, 2003, 2005). Thus, deficits in cold EF and emotional-reward dysregulation may constitute independent routes to ADHD symptoms in general (Sonuga-Barke, 2003, 2005) and potential loci for ADHD subtype characteristics in particular (Castellanos et al., 2006). Executive processes in situations with stronger affective significance are often referred to as hot. These hot EF processes have been shown to activate areas of the brain that control emotions and the brain’s reward systems (e.g., orbito-frontal cortex, ventral striatum, and the limbic system), while traditional cold EF tests activate the dorsolateral parts of the prefrontal cortex (Castellanos et al., 2006). Despite that cold EF impairments are showing robust associations with ADHD, it is unlikely that these impairments are the single necessary and sufficient cause of the disorder (Seidman, 2006; Willcutt et al., 2005). As proposed by multiple pathway models in ADHD, hot EF processes may constitute another promising endophenotype explaining ADHD symptoms (Sonuga-Barke, 2003, 2005).

Decision-making tasks represent one way of investigating EF under emotion-laden circumstances in a laboratory test situation (Chan et al., 2008). In these tasks the interaction between hot and cold EF is important for the ability to make long-term, advantageous choices. According to the somatic marker hypothesis, the experience of emotion is related to the decision-making process (Damasio, 1994). These emotional experiences can be referred to as “gut feelings” or “hunches” and are the so-called somatic markers (as indexed
by heart rate and skin conductance) that guide decision making (Bechara, Damasio, Tranel, & Damasio, 1997). It has been demonstrated that anticipatory somatic markers are associated with an advantageous response strategy on the Iowa Gambling Task (IGT; Bechara, Tranel, Damasio, & Damasio, 1996) and the Hungry Donkey Task (HDT; Crone & van der Molen, 2007). The computer-based HDT (Crone & van der Molen, 2004) is a child version of the Iowa Gambling Task (Bechara at el., 1996). In order to make the IGT more meaningful for children, card gambling is changed into a prosocial game where the players are urged to win as many apples as possible for a hungry donkey (Crone & van der Molen, 2007). Comparable autonomic responses to IGT and HDT have been documented in both adult populations (Crone, Somsen, Beek, & van der Molen, 2004) and adolescents (> 16 years) (Crone & van der Molen, 2007). Children (< 14 years) have been shown to have less consistent anticipatory autonomic responses on the HDT compared to adolescents and adults, but they show autonomic responses following reward and loss comparable to adolescents (Crone & van der Molen, 2007). Thus, empirical support for the implicit and affective processes involved in HDT parallels IGT findings (Bechara et al., 1996).

To date, few studies have investigated hot decision making in children and adolescents with ADHD. Some have found impaired performance on hot decision-making tests in children with ADHD (Garon, Moore, & Waschbusch, 2006; Luman, Oosterlaan, Knol, & Sergeant, 2008), while other studies have not (Geurts, van der Oord, & Crone, 2006; Lambek et al., 2010; Masunami, Okazaki, & Maekawa, 2009). None of these studies investigated differences across ADHD subtypes. However, Toplak, Jain, and Tannock (2005) found that symptoms of hyperactivity/impulsivity correlated with reduced decision-making performance in adolescents from age 14 to 17 with ADHD. One explanation for the divergent results in the decision-making literature may be the age differences in the groups. Research using decision-making tasks indicates that normal developing children aged 6 to 12 years make more disadvantageous choices, while older subjects learn to make more advantageous choices (da Mata et al., 2011). Thus, as the ability to make long-term advantageous choices increases with age in typically developing adolescents, adolescents with ADHD may remain impaired. This may explain why impaired decision making has been found to be more evident in adolescents with ADHD (Toplak et al., 2005) than in children with ADHD (Geurts et al., 2006; Lambek et al., 2010; Masunami et al., 2009). It has been suggested that performance on decision-making tasks may be explained by cold EF abilities such as working memory and inhibition (Dunn, Dalgleish, & Lawrence, 2006). Decision-making performance could thus potentially be mediated by the maturation of cold EF abilities. However, when reviewing 43 studies examining the association between IGT/HDT and other cognitive abilities, Toplak, Sorge, Benoit, West, and Stanovich (2010) found no strong associations between IGT/HDT performance and working memory, controlled attention, cognitive flexibility, or intelligence.

Another method for examining EF under more emotion-laden circumstances is the Behavior Rating Inventory of Executive Function (BRIEF; Gioia, Isquith, Guy, & Kenworthy, 2000). BRIEF was developed to improve the ecological validity of EF assessment (Sbordone, 2000) and has shown consistent but modest correlations with neuropsychological cold EF tests (Anderson, Anderson, Northam, Jacobs, & Mikiewicz, 2002; Toplak, Bucciarelli, Jain, & Tannock, 2009). Whereas traditional, cold EF tests demand relatively simple responses in a quiet and structured test environment, the BRIEF captures EF performance in a “real world” situation (McCue & Pramuka, 1998). A confirmatory factor analysis (CFA) of the BRIEF found evidence of a separate emotional regulation factor, consisting of the Emotional Control and Shift scales (Gioia, Isquith,
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Retzlaff, & Espy, 2002). In replicating this finding with both the parent and the teacher versions, Egeland and Fallmyr (2010) speculated that the Emotional Regulation factor really was a measure of hot EF, in contrast to the less emotional items constituting the remaining scales, that is, cold EF. Recently, Peters, Algina, Smith, and Daunic (2011) replicated the three-factor model found in CFAs by Egeland and Fallmyr and Gioia et al.. Children with ADHD-C have been found to display significantly more impairments in Inhibition (cold EF; Gioia et al., 2000; McCandless & O’Laughlin, 2007; Semrud-Clikeman, Walkowiak, Wilkinson, & Butcher, 2010) and Emotional Control (hot EF; McCandless & O’Laughlin, 2007; Semrud-Clikeman et al., 2010) on the BRIEF when compared to children with ADHD-I.

The purpose of the current study is to include a comprehensive test battery of both laboratory and inventory hot and cold EF measures in medication naïve boys and girls with ADHD to examine possible differences across ADHD subtypes.

It was hypothesized that cold EF profiles would not differentiate ADHD subtypes from each other. Second, we hypothesized that there would be no significant differences between groups on a hot decision-making task. However, in the older age groups (≥ 12 years), the ADHD-C subtype would be associated with most risky decisions relative to healthy controls. Third, we hypothesized that the ADHD-C group would display more severe symptoms on the cold Inhibition and on the hot Emotional Control scales in the BRIEF compared to the ADHD-I group. In addition, we expected to find modest correlations between cold BRIEF scales and cold EF tests, and weaker associations between hot BRIEF scales and cold EF tests. Finally, on an exploratory level, we believed that the laboratory task measuring hot EF would show a stronger association with hot BRIEF scales than cold BRIEF scales.

METHOD

Procedure and Participants

The study was approved by the Regional Committee for Medical Research Ethics in Eastern Norway (REK-Øst) and by the Privacy protection ombudsman for research at Innlandet Hospital Trust. It was conducted in accordance with the Helsinki Declaration of the World Medical Association Assembly. Demographic characteristics are presented in Table 1. The subjects were recruited as consecutive referrals for assessment of ADHD, from all seven child and adolescent outpatient mental health centers in two neighboring Norwegian counties (Hedmark and Oppland). Forty-four subjects with ADHD-I (M = 11.6 years; 20 males), 36 with ADHD-C (M = 11.4 years; 23 males), and 50 Healthy Controls (HCs; M = 11.6 years; 32 males), between 8 and 17 years participated in the study. None of the participants met the criteria for the hyperactive-impulsive subtype when diagnoses were assessed. All participants underwent a comprehensive assessment according to common clinical practice. Semi-structured clinical interviews (Kiddie-Schedule for Affective Disorders and Schizophrenia [Kiddie-SADS]; Kaufman et al., 1997) were conducted separately for children/adolescents and parents to assess psychopathology. The interviewers were experienced clinicians, and they were trained to high levels of interrater reliability for the assessment of diagnosis. The diagnostic evaluation with Kiddie-SADS was supplemented with information from the ADHD Rating Scale IV (ARS-IV; DuPaul, Power, Anastoupoulos, & Reid, 1998) and the Child Behavior Checklist (CBCL;
Table 1  Demographic Characteristics: Means and Standard Deviations Within the Three Groups.

| Variable                              | ADHD-C (C) \((n = 36)\) | ADHD-I (I) \((n = 44)\) | Healthy Controls (HC) \((n = 50)\) | Group Comparison | F     | p     | Scheffe |
|---------------------------------------|---------------------------|--------------------------|-----------------------------------|------------------|-------|-------|---------|
| Sex (male/female)                     | 23/13                     | 20/24                    | 32/18                             |                  | ns    |       |         |
| Age (months)                          | 142.1 (25.8)              | 145.4 (23.5)             | 144.0 (24.4)                      |                  | F (2, 127) = 0.18 | ns    |         |
| Mother’s education (yrs)              | 12.4 (2.3)                | 13.1 (1.9)               | 14.6 (2.4)                        |                  | F (2, 127) = 11.36 | < .001 | C,I < HC |
| FSIQ (WASI)\(^a\)                    | 96.6 (13.3)               | 94.2 (15.0)              | 103.8 (12.9)                      |                  | F (2, 127) = 6.17  | = .003 | I < HC  |
| Inattention\(^b\)                    | 16.8 (6.1)                | 15.0 (5.4)               | 1.7 (2.0)                         |                  | F (2, 126) = 145.32 | < .001 | HC < C,I |
| Hyperactivity / Impulsivity\(^c\)     | 13.8 (5.7)                | 7.0 (5.7)                | 1.0 (1.3)                         |                  | F (2, 126) = 85.40 | < .001 | HC < I < C |
| ODD symptoms\(^d\)                   | 62.5 (9.3)                | 57.5 (6.7)               | 51.4 (2.4)                        |                  | F (2, 126) = 31.44 | < .001 | HC < I < C |

\(^a\)Full Scale IQ. \(^b\)ADHD rating scale – IV (ADHD-I: One boy missing). \(^c\)ADHD rating scale – IV (ADHD-I: One boy missing). \(^d\)CBCL, Oppositional Defiant Problems Scale (HC: One boy missing).
Achenbach, 1991), which covers the DSM-IV-TR symptoms for ADHD. Additional information about school functioning, both academic and social, which is mandatory on referral, was incorporated into the diagnostic evaluation. If both parents could not report on Kiddie-SADS and rating scales together, information from mothers was used. In cases of disagreement between parents, information from mothers was emphasized. When information on the Kiddie-SADS was not consistent with rating scales, Kiddie-SADS was emphasized in the assessment. Diagnoses were considered positive if, based on a comprehensive evaluation of Kiddie-SADS, teacher information and rating scales, DSM-IV-TR (APA, 2000) criteria were met. The project manager (neuropsychologist) reviewed independently all diagnostic judgements set by the interviewers. Disagreements were discussed to arrive at a consensus diagnosis in 15 subsequent meetings with all the interviewers.

Based on diagnostic evaluation with Kiddie-SADS, comorbid oppositional defiant disorder (ODD) was evident in 22.3% of the subjects with ADHD-C and 2.3% of the ADHD-I subjects. Exclusion criteria for all participants included prematurity (< 36 weeks), IQ below 70, a history of stimulant treatment, or any disease affecting the central nervous system.

All HCs were screened for mental disorders with the Kiddie-SADS in separate interviews for children/adolescents and parents. The HCs were recruited from local schools and were given a small compensation for participating. The HCs could not have been treated for a mental disorder, have a psychiatric diagnosis, have had a head injury (with loss of consciousness) or have known dyslexia.

The three groups did not differ significantly with regard to age and gender distribution. The Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999) was administered to estimate IQ in all subjects. The groups differed significantly with regard to IQ, $F(2, 127) = 6.17, p = .003$, $\eta^2 = .09$, and Scheffe’s post hoc analysis showed that the ADHD-I group scored significantly below the HC group. Both clinical groups displayed more inattention symptoms (ARS-IV; DuPaul et al., 1998) than the HC group, $F(2,126) = 145.32, p < .001$, $\eta^2 = .80$. The level of inattention symptoms was almost equal between the ADHD-C and the ADHD-I group. With regard to hyperactivity/impulsivity symptoms (ARS-IV; DuPaul et al., 1998), groups differed significantly, $F(2,126) = 85.40, p < .001$, $\eta^2 = .58$, and Scheffe’s post hoc analysis showed that both clinical groups showed significantly more hyperactivity/impulsivity symptoms than the HC group ($p < .001$). The ADHD-C group showed in addition significantly more hyperactivity/impulsivity symptoms than the ADHD-I group ($p < .001$). The mothers in the HC group had significantly higher education than the mothers in both clinical groups, $F(2,127) = 11.36, p < .001$, $\eta^2 = .15$.

Measures

Cold Neuropsychological EF tests

**Working Memory.** The Letter-Number Sequencing Test (LN) (a subtest from the Wechsler Intelligence Scale for Children - Fourth Edition; Wechsler, 2004) consists of 10 items. Each item contains three trials with the same number of digits and letters. The test administrator read aloud each trial and asked the child to recall the numbers in ascending order and the letters in alphabetical order. In the present study, total correct recalled trials were examined. Lower raw scores indicated difficulties with the task.
We also included selected measures from the Delis-Kaplan Executive Function System (D-KEFS; Delis, Kaplan, & Kramer, 2001).

**Controlled Attention: The Colour-Word Interference Test, Condition 3 (CW 3; D-KEFS; Delis et al., 2001; Stroop, 1935).** The examinee needed to inhibit an overlearned verbal response when naming the dissonant ink colors in which the words are printed. For the present study, completion time in seconds was examined. Higher raw scores indicated difficulties with the task.

**Cognitive Flexibility: The Trail-Making Test, Condition 4 (TMT 4; D-KEFS; Delis et al., 2001).** The examinee is asked to draw a line interchangeably between numbers and letters in the right order. For the present study, time to complete task was examined. Higher raw scores indicated difficulties with the task.

**Planning: The Tower Test (D-KEFS; Delis et al., 2001).** In this task, the examinee is asked to construct several target towers by moving five disks, varying in size, across three pegs in the fewest number of moves possible. While doing this, the examinee is allowed to move only one disk at a time and not to place a larger disk over a smaller disk. In the present study, total achievement score within the time limit as specified in the D-KEFS manual was examined. Lower raw scores indicated difficulties with the task.

**Verbal Fluency: The Letter Fluency Test (LF; D-KEFS; Delis et al., 2001).** This task includes three 60-second trials where participants were asked to generate words fluently in an effortful, phonemic format with the letters F, A, and S. For the present study, total correct responses were examined. Lower raw scores indicated difficulties with the task.

**D-KEFS Contrast Measures.** To adjust for potential difficulties with more basic skills like processing speed, contrast measures were calculated (Delis et al., 2001). From the time used in CW3, we subtracted the mean sum score of the preceding processing tasks of test Condition 1 (color naming) (CW1), and Condition 2 (reading) (CW2); (CW3 – [CW1 + CW2]/2). This variable was termed controlled attention contrast (CW3 contrast). Similarly, the mean sum scores on the simple visual search task, The Trail-Making Test, Condition 2 (TMT 2) and Condition 3 (TMT3) were subtracted from TMT4; (TMT4 – [TMT2 + TMT3]/2). In TMT2 and 3, subjects are asked to draw lines from numbers and letters, respectively, without having to change flexibly between ordering systems. This measure was termed cognitive flexibility contrast (TMT4 contrast). Lower contrast scores indicated difficulties with more basic skills on the tasks (Delis et al., 2001).

**Hot Decision-Making EF Test.** The computer-based Hungry Donkey Task (HDT; Crone & van der Molen, 2004) is a child version of the Iowa Gambling Task (IGT; Bechara, Damasio, Damasio, & Anderson, 1994). The children were asked to help a hungry donkey collect as many apples as possible by choosing one of four doors (A, B, C, or D). The amount of wins and losses varied between choices, and overall gains/losses were displayed with a red/green bar at the bottom of the screen. Doors A and B represented disadvantageous choices (resulting in overall loss), and Doors C and D represented advantageous choices (resulting in overall gain). The task ended after completion of
150 trials. Net difference scores were calculated by subtracting the amount of disadvantageous choices (A+B) from the number of advantageous choices (C+D) (e.g., Bechara et al., 1994). Higher net scores indicated better performance on the task. In order to investigate any strategy change during task performance, the net scores were calculated for 10 blocks of 15 trials (Brand, Recknor, Grabenhorst, & Bechara, 2007). As the risk parameters are uncertain in early phases of decision-making tasks, the decision-making process can thus be considered first as decision making under ambiguity and later as decision making under risk (Brand et al., 2007). Therefore, net difference scores were also investigated separate in the first and last five blocks. In order to investigate a developmental effect on the task, the oldest and youngest participants were divided into two age groups: 8–11 years (n = 72, ADHD-C = 21, ADHD-I = 25, HC = 26) and 14–17 years (n = 29, ADHD-C = 9, ADHD-I = 11, HC = 9). The middle age group (12–13 years) was not included in these analyses. Pearson correlation between odd and even blocks revealed adequate internal consistency (.694) on the task in our sample.

**Inventory-Based Information of Cold and Hot EF.** The BRIEF for children and adolescents aged 5 to 18 includes a parent form and a teacher form (Gioia et al., 2000). In the current study, parents were asked to complete the written form of the Norwegian parent rating version. The BRIEF is composed of eight clinical scales (Inhibition, Shift, Emotional Control, Initiate, Working Memory, Plan/Organize, Organization of Materials, and Monitor). Fallmyr and Egeland (2011) reported high internal consistency (Chronbach’s $\alpha = .76−.92$) on the Norwegian parent rating version of the BRIEF. These values are at the same level as Chronbach’s $\alpha$ reported in the BRIEF manual (.80−.98) (Gioia et al., 2000). The Shift and Emotional Control scales were used to measure hot EF, whereas the other six scales were used to assess functions that are less affective, that is, cold EF (Egeland & Fallmyr, 2010; Gioia et al., 2002). In the current study, $T$-scores are based on the original norms. Elevated BRIEF $T$-scores indicate a higher degree of impairment.

**Data Analyses**

Data analyses were conducted using the statistical package SPSS for Windows, Version 15.0 (SPSS, Inc., Chicago, IL). Demographic characteristics were investigated using the Chi-square test for independence (nominal variables) and analysis of variance (ANOVA) (continuous variables) followed up by Scheffe’s post hoc tests for group comparisons when adequate. Group differences in EF performance were examined with multivariate analysis of variance (MANOVA). In case of significant group effects ($p < .05$), analyses of variance (ANOVA) with Scheffe’s post hoc tests for group comparisons were conducted. All significant group differences were further analyzed in pairwise analysis of covariance (ANCOVA) controlling for the effect of IQ, mother’s education, and ODD symptoms assessed with the CBCL Oppositional Defiant Problems Scale. D-KEFS contrast measures were examined in separate analyses. To check for possible confounding gender effects, we ran intragroup analyses comparing boys and girls on all main variables. Correlation analyses (Pearson) were used to investigate associations between the hot decision-making task, cold EF tests, and EF in everyday life assessed with the BRIEF. Missing data are listed as footnotes in Table 1, Table 2, Figure 1, and Figure 2.
Table 2 Results of Cold EF Tests: Means and Standard Deviations Within the Three Groups, Results from ANOVAs with Post Hoc Group Comparisons (Scheffe), and Pairwise ANCOVA Controlled for IQ.

| Variable                | ADHD-C (C) (n = 35) | ADHD-I (I) (n = 42) | Healthy Controls (HC) (n = 50) | Group comparison (df = 2, 124) | Scheffe | Controlling for IQ* |
|-------------------------|----------------------|----------------------|-------------------------------|--------------------------------|---------|--------------------|
| Working memory\(^a\)   | 15.4 (3.5)           | 15.5 (3.2)           | 18.2 (1.9)                    | 13.8                           | <.001   | C,I < HC           |
| Controlled attention\(^b\) | 86.6 (27.8)         | 88.5 (32.9)         | 72.5 (22.3)                   | 4.6                            | =.012   | I < HC             |
| Cognitive flexibility\(^c\) | 122.0 (54.7)       | 127.5 (43.0)        | 99.9 (35.2)                   | 5.0                            | =.008   | I < HC             |
| Planning\(^d\)         | 15.7 (3.4)           | 16.6 (3.2)           | 16.7 (2.9)                    | 1.3                            | ns      | ns                 |
| Verbal fluency\(^e\)   | 22.7 (9.6)           | 21.7 (8.7)           | 29.9 (11.1)                   | 9.3                            | <.001   | C,I < HC           |

Note. ADHD-C: One boy missing’ ADHD-I: One boy and one girl missing.

\(^a\)Letter-Number Sequencing.
\(^b\)Color-Word Interference Test Condition 3.
\(^c\)Trail-Making Test Condition 4.
\(^d\)Tower Test.
\(^e\)Letter Fluency Test.

\(*p < .05\) in pairwise ANCOVA controlling for the effect of IQ.
Figure 1 The Hungry Donkey task: Net difference scores (advantageous choices – disadvantageous choices) across 10 blocks of 150 trials for the ADHD-C, ADHD-I, and HC groups.  
*Note.* ADHD-C: One boy and two girls missing; ADHD-I: Two girls missing.

Figure 2 The Hungry Donkey task: Net difference scores (advantageous choices – disadvantageous choices) across last five blocks (6–10) for the age groups 8–11 and 14–17 years.  
*Note.* ADHD-C: One boy and two girls missing; ADHD-I: One girl missing.
RESULTS

Cold Neuropsychological EF Tests. The results are shown in Table 2. The MANOVA indicated a main effect for Group, $F(2, 124) = 3.51, p = .001, \eta^2 = .13$. ANOVAs with Scheffe’s post hoc analysis revealed that both ADHD subtypes scored significantly impaired compared to the HC group on measures of working memory ($p < .001$) and verbal fluency ($p < .05$). Only the ADHD-I group scored significantly below the HC group on controlled attention ($p = .024$) and cognitive flexibility ($p = .015$). ANOVA analyses revealed no significant differences between the three groups in planning ability, $F(2, 124) = 1.30, p = .275, \eta^2 = .02$.

Pairwise ANCOVAs showed that IQ was significantly related to all cold EF tests. When controlling for IQ in pairwise ANCOVAs, the differences between the ADHD-C group and the HC group remained significant on working memory, $F(1, 83) = 16.05, p < .001, \eta^2 = .16$, and on verbal fluency, $F(1, 83) = 4.60, p = .035, \eta^2 = .05$. When comparing the ADHD-I group and the HC group, the group differences remained significant for the EF measures working memory, $F(1, 90) = 12.95, p = .001, \eta^2 = .13$, cognitive flexibility, $F(1, 90) = 5.80, p = .018, \eta^2 = .06$, and verbal fluency, $F(1, 90) = 6.04, p = .016, \eta^2 = .06$. Controlled attention, $F(1, 90) = 2.58, p = .112, \eta^2 = .03$, did not remain significantly different between the ADHD-I and HC group in pairwise ANCOVAs. When controlling for mother’s education in pairwise ANCOVAs, all between-group differences remained significant, except for verbal fluency between the ADHD-C and HC groups. When controlling for ODD symptoms in pairwise ANCOVAs, all between-group differences remained significant. ANOVAs with Scheffe’s post hoc analysis revealed that the ADHD-I group showed significantly higher scores compared to the HC group on the cognitive flexibility contrast measure ($p = .003$), corroborating results found with TMT 4. Scheffe’s post hoc analysis revealed, however, no significant differences between groups on the contrast measure of controlled attention. When analyzing the entire sample, there was no significant gender effect in any of the cold neuropsychological EF tests.

Hot Decision-Making EF Test. Overall, the three groups made only marginally more advantageous than disadvantageous choices on the hot decision-making task (ADHD-C: $M = 4.91$; ADHD-I: $M = 4.86$; HC: $M = 5.08$), indicating a response strategy on a chance level for all three groups (Figure 1). There were no significant interactions between Group and Trial Block, $F(18, 122) = 0.65, p = .86, \eta^2 = .05$, no effect of Trial Block, $F(9, 122) = 1.25, p = 0.27, \eta^2 = .09$, and no main effect for Group, $F(2, 122) = 0.00, p = 1.00, \eta^2 = .00$. Adjusting for IQ, mother’s education or ODD symptoms did not affect results, and between-group differences remained nonsignificant. Separate analyses of net difference scores in the first and last five blocks showed no significant interactions between Group and Trial Block, no effect of Trial Block, and no main effect for Group. However, when investigating the effect of age in the last five blocks using a 2 (Age) x 3 (Group) x 5 (Block) repeated measures MANOVA, there was a main effect of age, $F(1, 91) = 4.72, p = .03, \eta^2 = .05$, (Figure 2). Post hoc tests revealed that performance differences between age groups were evident only in the last block, $F(1, 95) = 3.97, p = 0.05, \eta^2 = .04$, with the older age group performing better than the younger group. Analysis of the subjects from 12 years and older (ADHD-C: $n = 15$; ADHD-I: $n = 17$; HC: $n = 24$) indicated lower total net scores in the ADHD-C group ($M = -0.13$) compared to the ADHD-I group ($M = 3.41$) and the HC group ($M = 9.75$). When excluding the children under 12 years, groups became small and between-group differences did not reach
statistical significance, \( F(2, 53) = 0.32, p = .728, \eta^2 = .01 \). Analysis of the entire sample revealed no significant gender effect on the hot decision-making task.

**Inventory-Based Information of Cold and Hot EF.** The results are shown in Table 3. As expected, the MANOVA showed a main effect for Group on the BRIEF, \( F(2, 127) = 20.45, p < .001, \eta^2 = .58 \). ANOVAs with Scheffe’s post hoc analysis revealed that both ADHD subtypes scored significantly \( (p < .001) \) impaired compared to the HC group on all BRIEF scales. Further, Scheffe’s post hoc analysis revealed that the ADHD-C group was significantly impaired compared to the ADHD-I group on the subscales Inhibition \( (p < .001) \) and Monitor \( (p = .043) \). IQ and mother’s education did not have a significant effect when entered as covariate in the MANCOVA and did not impact any of the significant group effects. ODD symptoms were entered as a significant covariate in the MANCOVA, \( F(2, 124) = 13.97, p < .001, \eta^2 = .49 \), but all group effects remained significant. When analyzing the entire sample, there was no significant gender effect on any of the BRIEF scales.

**Correlations between the Hot Decision-Making EF Test, Cold Neuropsychological EF Tests and Inventory-Based Information for Cold and Hot EF.** Correlations are shown in Table 4. Separate correlations in the ADHD-C/HC group and ADHD-I/HC group revealed no significant correlations between total net score on the hot decision-making task (all 150 trials), the cold EF tests, and the hot and cold EF measures on the BRIEF. Cold EF tests: LN, CW3, and TMT4 showed in general moderate associations with cold BRIEF scales in the ADHD-I/HC group \( (r = .17 \text{ to } .46) \) and somewhat lower correlations in the ADHD-C/HC group \( (r = .11 \text{ to } .45) \). Correlations between cold EF tests: LN, CW3 and TMT4 and hot BRIEF scales were moderate in the ADHD-I/HC group \( (r = .33 \text{ to } .40) \) and small in the ADHD-C/HC group \( (r = .17 \text{ to } .29) \). Cold EF tests: Tower and Letter Fluency showed in general small associations with hot and cold BRIEF scales in both groups.

**DISCUSSION**

The present study aimed at comparing cold and hot EF performance in medication naïve children and adolescents with ADHD-C, ADHD-I, and HC with the use of laboratory tests and inventory-based scales. As expected, we found that children and adolescents with either ADHD subtype showed significantly more impaired functioning on working memory and verbal fluency compared to HC. These findings are consistent with previous studies on cold EF in ADHD subtypes (Willcutt et al., 2005). Only the ADHD-I group displayed significantly more impaired scores on measures of controlled attention and cognitive flexibility relative to HC. Contrast scores, with a higher demand for controlled attention and cognitive flexibility than the primary scores, did not show differences between subtypes either.

As expected, there were no significant differences between groups on the hot decision-making task, with both the clinical groups and the HC performing only marginally above chance level. These results are in line with Geurts et al. (2006), Masunami et al. (2009), and Lambek et al. (2010) reporting no hot decision-making deficit in children with ADHD. Our study corroborates previous findings reporting that neither children with ADHD nor healthy, normal children have developed the long-term decision-making abilities required in the HDT (Crone & van der Molen, 2007; Lambek et al., 2010; Prencipe
Table 3 Results of the BRIEF (T-scores): Means and Standard Deviations Within the Three Groups, Results from ANOVAs with Post Hoc Group Comparisons (Scheffe) Reported, and Pairwise ANCOVA Controlled for IQ.

| Variable               | ADHD-C (C) (n = 36) | ADHD-I (I) (n = 44) | Healthy Controls (HC) (n = 50) | Group Comparison (df = 2, 127) | Scheffe | Controlling for IQ* |
|------------------------|----------------------|----------------------|-----------------------------|-------------------------------|---------|---------------------|
| Cold Executive Skills  |                      |                      |                             |                               |         |                     |
| Inhibit                | 67.6 (14.6)          | 55.6 (12.2)          | 42.4 (3.4)                  | 59.0                          | <.001   | HC < I < C          |
| Initiate               | 61.4 (12.0)          | 59.6 (11.7)          | 40.7 (6.7)                  | 58.3                          | <.001   | HC < I < C          |
| Working Memory         | 70.4 (11.4)          | 69.5 (8.7)           | 42.0 (4.6)                  | 172.3                         | <.001   | HC < I, C           |
| Plan/Organize          | 66.4 (10.5)          | 65.2 (9.7)           | 41.3 (4.9)                  | 127.7                         | <.001   | HC < I, C           |
| Org. of Materials      | 59.7 (10.3)          | 55.6 (11.4)          | 41.6 (7.6)                  | 42.1                          | <.001   | HC < I, C           |
| Monitor                | 65.1 (11.7)          | 59.4 (12.0)          | 38.6 (5.6)                  | 89.0                          | <.001   | HC < I, C           |
| Hot Executive Skills   |                      |                      |                             |                               |         |                     |
| Shift                  | 60.1 (14.5)          | 55.2 (10.5)          | 40.8 (5.0)                  | 43.0                          | <.001   | HC < I, C           |
| Emotional Control      | 61.3 (15.4)          | 59.1 (12.6)          | 41.0 (4.3)                  | 45.0                          | <.001   | HC < I, C           |

Note. Elevated BRIEF T-scores indicate a higher degree of impairment with T-scores of 65 and above considered to represent clinically significant areas of concern. *p < .05 in pairwise ANCOVA controlling for the effect of IQ.
### Table 4

Separate Correlations Among Cold EF Tests (S-Scores), BRIEF (T-scores) and HDT in the ADHD-I/HC and ADHD-C/HC Group.

|                   | ADHD-C and HC |
|-------------------|---------------|
|                   | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 |
| ADHD-I and HC     |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 1. HDT            | -.08 | -.04 | -.12 | -.01 | .20 | -.10 | -.05 | -.00 | -.04 | -.09 | -.09 | -.05 | -.10 |    |
| 2. LN             | .01 | -.59** | .42** | .32** | .47** | -.29** | -.34** | -.45** | -.38** | -.30** | -.34** | -.29** | -.24* |    |
| 3. CW3            | .00 | .52** | -.38** | .33** | .43** | -.18 | -.33** | -.40 | -.33** | -.39** | -.25* | -.17 | -.18 |    |
| 4. TMT4           | -.10 | .37** | .50** | -.29** | .28* | -.16 | -.13 | -.25* | -.17 | -.10 | -.11 | -.23* | -.24* |    |
| 5. Tower          | .01 | .05 | .16 | .20 | -.36** | -.23* | -.18 | -.24* | -.22* | -.13 | -.16 | -.24* | -.18 |    |
| 6. LF             | .12 | .46** | .37** | .23* | .28** | -.19 | -.19 | -.32** | -.24* | -.24* | -.21 | -.18 | -.15 |    |
| 7. Inhibit        | .01 | -.31** | -.36** | -.36** | .10 | -.15 | -.79** | .84** | .87** | .78** | .89** | .82** | .86** |    |
| 8. Initiate       | .06 | -.36** | -.37** | -.34** | -.02 | -.23* | .74** | .89** | .91** | .85** | .84** | .81** | .78** |    |
| 9. Working Memory | .05 | -.46** | -.39** | -.43** | .00 | -.38** | .68** | .83** | .93** | .84** | .89** | .76** | .75** |    |
| 10. Plan/Organize | .06 | -.44** | -.41** | -.38** | .05 | -.31** | .72** | .86** | .93** | -.87** | .91** | .84** | .82** |    |
| 11. Org. of Materials | .04 | -.39** | -.33** | -.17 | .17 | -.17 | .57** | .69** | .74** | .77** | -.81** | .73** | .74** |    |
| 12. Monitor       | .03 | -.42** | -.38** | -.34** | .09 | -.30** | .76** | .77** | .81** | .86** | .68** | -.80** | .82** |    |
| 13. Shift         | .10 | -.40** | -.34** | -.37** | .06 | -.28** | .67** | .77** | .75** | .79** | .60** | .78** | .87** |    |
| 14. Emotional Control | .07 | -.35** | -.33** | -.34** | .05 | -.19 | .62** | .71** | .73** | .79** | .60** | .79** | .80** |    |

*Total net score in partial correlations controlled for age.

*p < .05. **p < .001.
et al., 2011). As expected, increasing ages predicted better hot decision-making performance, supporting our assumption about a developmental effect. When we excluded all subjects below 12 years, analysis of the remaining small groups indicated more disadvantageous choices in the ADHD-C group compared to the ADHD-I group and the HC group. These data support the possibility that between-group differences may become more apparent with increasing ages, with most risky decisions found in the ADHD-C group. One explanation for the lack of between-group differences on the HDT may be that participants were instructed to make choices for a donkey rather than for themselves, which could have the implication that this measure is not as motivating as the standard IGT. For older subjects in particular, the lack of motivation could cause less sensitivity on the task. However, Bowman and Turnbull (2003) found no effect on decision-making performance whether symbolic or real money was applied in the IGT with adults. In addition, Crone and van der Molen (2004) have reported highly comparable response patterns between the HDT and the IGT in adults as well as in developmental populations. Thus, the HDT seems to be valid as a hot decision-making task for older subjects as well.

Children and adolescents with both ADHD subtypes were impaired on all BRIEF scales. In line with our hypothesis, the ADHD-C group displayed more impairment on the cold Inhibition scale relative to the ADHD-I group, replicating previous findings (Gioia et al., 2000; McCandless & O’Laughlin, 2007; Semrud-Clikeman et al., 2010). In addition the ADHD-C group showed significantly more impaired scores on the cold Monitor scale. Contrary to our hypothesis, results did not support elevated impairment on the hot Emotional Control scale in the ADHD-C group relative to the ADHD-I group. Controlling for IQ, mother’s education, and ODD symptoms did not have an impact on any of the significant group effects. Our data provide evidence for some overlap between questionnaires posed on the BRIEF and rating scales applied in the diagnostic process. In particular, the BRIEF Inhibition scale correlated strongly with hyperactivity/impulsivity items in the ADHD Rating Scale IV ($r = .66$). This overlap between the BRIEF Inhibition scale and hyperactivity/impulsivity items formulated in the diagnostic process may thus result in some circularity when interpreting our findings.

Correlation data did not support our assumption about associations between hot decision making and hot executive aspects in everyday life assessed with the BRIEF. One potential distinction between hot EF aspects assessed with the BRIEF and the decision-making task is the aspect of instrumental rationality salient in decision-making performance (Toplak et al., 2010). According to Toplak and colleagues (2010), the aspect of emotion in HDT/IGT is to guide subjects’ choices with the aim of maximizing net profit on the task. In contrast, emotional aspects assessed in the BRIEF are more likely to reflect difficulties with emotional regulation on a daily basis (Egeland & Fallmyr, 2010; Gioia et al., 2002), where external reward mechanisms may be less salient. The separability of hot decision-making performance from cold EF tests is well documented (Toplak et al., 2010) and consistent with our finding of no correlations between the hot EF task (HDT) and cold EF tests. The finding of no association between hot (HDT) and cold EF tests gives some differential validity to the hypothesis of separate pathways (Sonuga-Barke, 2003) and corroborates previous findings (Toplak et al. 2010). Earlier research has indicated that hot and cold EFs seem to follow different developmental trajectories (Zelazo, Carlson, & Kesek, 2008) with cold EF showing maturation with age in subjects with ADHD (Oie, Sundet, & Rund, 2010), while hot decision-making impairments seem to be more pronounced with age in ADHD (Toplak et al., 2005). As hot decision-making tests appear to activate
prefrontal processes distinct from cold EF, age-related differences in decision-making performance may have emotional and social, rather than cognitive underpinnings. Studies have reported that depression and negative mood was related to poor IGT performance in adult populations (Cella, Dymond, & Cooper, 2010; Suhr & Tsanadis, 2007), while better decision-making performance has been reported in groups with higher levels of anxiety (Mueller, Nguyen, Ray, & Borkovec, 2010). When examining decision making in children with ADHD, Garon and colleagues (2006) found that the group with higher levels of internalizing symptoms (anxiety and depression) performed better than children with ADHD with low levels of internalizing symptoms. Thus, affective states may possibly influence decision-making performance, causing different levels of sensitivity against reinforcement and loss (Garon et al., 2006).

Overall cold BRIEF scales reached moderate correlations with cold EF tests as expected in the ADHD-I/HC group but somewhat lower associations in the ADHD-C/HC group. Correlation data displayed marginally higher correlations between cold EF tests and cold BRIEF scales than with the hot BRIEF scales.

Strengths of the present study are inclusion of medication-naïve subjects of both sexes with ADHD-C, ADHD-I, and HC and a relatively big sample size compared to other studies on hot EF. Additional strengths are the assessment of EF with a comprehensive test battery incorporating both hot and cold EF with laboratory tests and inventory based information in the same study. Further, all significant results were checked for the potential impact of varying IQ, mother’s education, and ODD symptoms. One potential limitation is that the sample was drawn from a clinical population and represents those who are willing to seek help in a mental health clinic. Our results and conclusions may therefore not be generalized to the entire ADHD population. Another limitation is the lack of an ADHD-H subtype group in the study. Further, computerized versions of the Colour-Word Interference Test have shown better sensitivity than paper-and-pencil versions of the task (Perlstein, Carter, Barch, & Baird, 1998) and could thus have been more suitable to demonstrate between-group differences than the version applied in this study (Lansbergen, Kenemans, & van Engeland, 2007).

In sum cold and hot measures of EF in everyday life (BRIEF; Inhibition, Monitor) differentiated significantly between ADHD subtypes, that is, more impairment in subjects with ADHD-C compared to ADHD-I. There were no significant differences between subtypes on laboratory tests measuring cold and hot EF. Further, no associations were found between the hot decision-making task and the other EF measures, indicating separate developmental trajectories. Overall, the results indicate few EF deficits differentiating ADHD subtypes from each other. However, our results are in accordance with other studies showing that impaired EF is a central deficit for children and adolescents with ADHD in general, and that neuropsychological assessment is important in daily clinical practice to guide treatment and intervention plans. The results on the BRIEF may also be important to guide treatment, and in addition the results seems more suitable than neuropsychological testing to differential diagnosis of ADHD-C and ADHD-I. Future research should investigate different developmental trajectories of hot and cold EF in a longitudinal study, as most findings to date are based on cross-sectional comparisons.
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