CHAPTER 1

GENERAL INTRODUCTION
INTRODUCTION

Behavior problems are common in childhood and adolescence (Verhulst, 1995; Verhulst, Van der Ende, Ferdinand, & Kasius, 1997). If severe and recurrent, these problems adversely affect the child’s daily functioning as well as his environment. Moreover, these problems may lead to many negative outcomes in adulthood (e.g., Bardone et al., 1998; Barkley, Fischer, Smallish, & Fletcher, 2006; Caspi, Wright, Moffitt, & Silva, 1998). It is thus extremely important to learn more about the etiology, diagnostic trademarks, and treatment of the various types of problem behavior. A growing body of scientific evidence suggests that deficits in information processing capacities may be one of the factors that cause, contribute to, or modulate the genesis and form of, behavior problems. Yet, knowledge is still lacking regarding the differential sensitivity and specificity of these deficits (Rutter & Sroufe, 2000).

The aim of the present dissertation was to investigate how multiple aspects of information processing relate to multiple types of problem behavior within a large and unselected population sample of ten- to twelve-year-olds. By comparing the information processing profiles of various groups of children showing different types of problem behavior, this dissertation attempts to provide more insights into the extent to which particular processing deficiencies are specific to certain types of problem behavior.

In this introductory chapter, the terms ‘information processing’ and ‘problem behavior’ are clarified. Furthermore, the theoretical framework and an outline of the remaining chapters are presented.

INFORMATION PROCESSING
DEFINITION

The term ‘information processing’ can refer to any and all of the brain’s activity needed to perceive, evaluate, and react to information in the environment, ranging from the most elementary sensory processes to the most complex levels of thought. Many different conceptualizations of its hierarchical and multifaceted nature exist (see e.g., Baddeley & Hitch, 1974; Posner & Raichle, 1994; Sternberg, 1969). Nevertheless, apart from the diverse terminology and many definitions, there are roughly five basic features of information
processing that most cognitive (neuro)psychologists agree upon (see also Huitt, 2003): (1) the brain has been genetically prepared to process and organize information in specific ways; (2) information processing encompasses several distinct components that function in a more or less serial manner; (3) there is a two-way flow of information: i.e., sensory input is combined with information stored in memory in order to construct meaning; (4) there is a control mechanism that oversees the other components; and (5) the component processes have limited capacities.

**CATEGORIES or ASPECTS of INFORMATION PROCESSING**

In one of the most influential theories of information processing, Sternberg (1969) postulated that on a fundamental level, processing capacities can be subdivided into more input-related (i.e., encoding), central- (i.e., serial comparison and decision making), and output-related (i.e., response organization) processes. Accordingly, this dissertation focuses on ten processing capacities which we assumed tap primarily one of these three aspects, viz., baseline speed of processing, perceptual sensitivity, visuo-spatial pattern detection, visuo-spatial as well as verbal working memory, responsiveness to auditory feedback, response speed variability, attentional flexibility, inhibition of prepotent responses, and response bias (see Appendix A for an elaborated description).

**INDIVIDUAL DIFFERENCES**

Many neuropsychological tests have been developed to study individual differences in the efficiency, i.e., the speed and accuracy, of information processing (see also Sergeant & Taylor, 2002). Well-known examples are classical neuropsychological tests such as the Stroop Color-Word, Trail Making, and Wisconsin Card Sorting Test. These tests, however, have been criticized for their poor construct validity and have been considered as too global as they do not measure the efficiency of single processing capacities but rather assess the product of multiple underlying capacities (De Sonneville, 2005; Nigg et al., 2005; Pennington & Ozonoff, 1996). In contrast, neuropsychological tasks using reaction time (RT) paradigms incorporate simple within-task manipulations that do enable the selective measurement of relatively elementary processing capacities by contrasting task conditions that differ only in the involvement of the associated capacity (Sergeant, Oosterlaan, & Van
Because these tasks are computerized, they additionally provide rigorous control over task administration (e.g., stimulus presentation) and a fine-grained collection of data on processing speed and accuracy, thereby reducing measurement error and enabling the assessment of even subtle inter-individual differences in information processing (see also, Doyle et al., 2005; MacDonald III & Carter, 2002; Sergeant, Geurts, & Oosterlaan, 2002). Therefore, the present dissertation reports on information processing capacities that were assessed by five subtasks from the Amsterdam Neuropsychological Tasks program (ANT; De Sonneville, 1999; De Sonneville, 2005) which is a computer-aided assessment battery of RT-tasks (see also Appendix A).

**PROBLEM BEHAVIOR**

**DEFINITION**

Problem behavior refers to the actions, feelings, and reactions of an individual that are poorly adequate or inappropriate in view of age-appropriate societal norms or rules. Individuals can exhibit these behavior problems to varying degrees. If problem behavior occurs consistently and is accompanied by distress or functional impairment, it can be classified as a disorder (*Diagnostic and Statistical Manual of Mental Disorders, DSM*; American Psychiatric Association, 1994).

**CATEGORIES or TYPES of PROBLEM BEHAVIOR**

The most prevalent types of behavior problems in childhood and adolescence can be subdivided into the broad-band categories of internalizing and externalizing problems. Internalizing problems are behaviors that initially mainly cause internal distress, such as anxious and depressed behavior and accompanying (psycho)somatic complaints, corresponding to the *DSM* categories of Anxiety Disorder, Depressive Disorder, and Somatoform Disorder. Conversely, externalizing problems are behaviors that initially primarily result in conflicts with others, such as aggressive and rule-breaking behavior and often also inattentive and hyperactive/impulsive behavior. These problems are described in the *DSM* as respectively, Oppositional Defiant Disorder (ODD), Conduct Disorder (CD), and Attention-Deficit/Hyperactivity Disorder (ADHD).
PREVALENCE
Approximately 12 to 22% of Dutch children and adolescents exhibit maladaptive behavior problems (Verhulst, 1995), and about 7% qualify criteria for a disorder with significant impairment (Verhulst et al., 1997). Internalizing problems are generally more common among girls, whereas externalizing problems are more often exhibited by boys (Offord, Boyle, & Racine, 1989; Velez, Johnson, & Cohen, 1989).

CO-OCCURRENCE
The various types of problem behavior frequently co-occur. In a large general population of 11-year-olds, for example, more than 55% of children who qualified DSM criteria of any disorder, met the criteria for more than one diagnosis (Anderson, Williams, McGee, & Silva, 1987). These co-occurring problems can be similar in nature (e.g., all internalizing type problems) as well as different (i.e., combined internalizing and externalizing type problems) (Angold, Costello, & Erkanli, 1999). In addition to having multiple problems, children with co-occurring problems generally also show more severe problems (Verhulst & Van der Ende, 1993).

INFORMATION PROCESSING AND PROBLEM BEHAVIOR
The factors causing, contributing to, or modulating the genesis and form of, behavior problems largely remain to be elucidated. From existing literature, however, it becomes apparent that no single etiological factor can explain all cases of one type of behavior problems and that it is most likely a complex interaction of individual and environmental factors that result in problem behavior. It has been suggested that impairments in information processing may be a key route through which personal and environmental influences on problem behaviors find expression and early prevention or remediation of these impairments could, in theory, help reduce levels of problem behavior (Raine et al., 2005).

To date, a large amount of research has attempted to elucidate the neuropsychological underpinnings of problem behavior. Most of these studies, however, focused on
attention-deficit/hyperactivity problems, whereas the information processing abilities of children and adolescents with oppositional defiant/conduct problems or internalizing problems have been investigated less frequently. Knowledge in this area has further been hampered by a number of methodological limitations. First, the majority of previous studies have examined clinical samples which are typically biased toward extreme pathology and toward frequent co-occurrence of a wide range of associated problems (Caron & Rutter, 1991; Goodman et al., 1997). These samples were generally relatively small and encompassed wide age ranges, thereby lacking sufficient power to adequately examine confounding effects. Second, these studies typically focused on a limited range of behaviors without due recognition of the extent to which problems may co-exist. Third and finally, most studies have assessed cognitive functioning with classical neuropsychological tests which, as stated above, only assess the product of multiple processing capacities. As a result, little is known about which aspects of information processing specifically characterize the various types (or combinations of types of) problem behavior (Rutter & Sroufe, 2000).

The present dissertation attempts to contribute to current scientific knowledge by reporting on data from a large and unselected sample of 2230 ten- to twelve-year-olds, i.e., from the first assessment wave of the TRacking Adolescents’ Individual Lives Survey (TRAILS; see Box 1 for a description). In contrast to the major child epidemiological studies from the last decades that have generally traded depth of assessment for breadth of coverage (Brandenburg, Friedman, & Silver, 1990; Hinshaw, 1992), TRAILS not only assessed multiple types of problem behavior by means of symptom checklists but additionally collected data on multiple aspects of information processing by means of RT-paradigms.
The TRacking Adolescents’ Individual Lives Survey (TRAILS) is a prospective cohort study of Dutch preadolescents, who will be measured biennially at least until they are 24 years old. The present dissertation reports data from the first assessment wave of TRAILS, which ran from March 2001 to July 2002. The key objective of TRAILS is to chart and explain the development of mental health from preadolescence into adulthood, both at the level of psychopathology and the levels of underlying vulnerability and environmental risk.

Sample selection. The TRAILS target sample involved ten- to twelve-year-olds living in five municipalities in the North of the Netherlands, including both urban and rural areas. Sample selection involved two steps. First, the municipalities selected were requested to give names and addresses of all inhabitants born between 10-01-1989 and 09-30-1990 (first two municipalities) or 10-01-1990 and 09-30-1991 (last three municipalities), yielding 3483 names. Simultaneously, primary schools (including schools for special education) within these municipalities were approached with the request to participate in TRAILS; i.e., pass on students’ lists, provide information about the children’s behavior and performance at school, and allow class administration of questionnaires and individual testing (neurocognitive, intelligence, and physical) at school. School participation was a prerequisite for eligible children and their parents to be approached by the TRAILS staff, with the exception of children already attending secondary schools (< 1%), who were contacted without involving their schools. Of the 135 primary schools within the municipalities, 122 (90.4% of the schools accommodating 90.3% of the children) agreed to participate in the study.

If schools agreed to participate, parents (or guardians) received two brochures, one for themselves and one for their children, with information about the study; and a TRAILS staff member visited the school to inform eligible children about the study. Approximately one week later, a TRAILS interviewer contacted them by telephone to give additional information, answer questions, and ask whether they and their son or daughter were willing to participate in the study. Respondents with an unlisted telephone number were requested by mail to pass on their number. If they reacted neither to that letter, nor to a reminder letter sent a few weeks later, staff members paid personal visits to their house. Parents who refused to participate were asked for permission to call back in about two months to minimize the number of refusals due to temporary reasons. If parents agreed to participate, an interview was scheduled, during which where they were requested to sign an informed consent form. Children were excluded from the study if they were incapable to participate due to mental retardation or a serious physical illness or handicap; or if no Dutch-speaking parent or parent surrogate was available, and it was not feasible to administer part of the measurements in the parent’s language. Of all children approached for enrollment in the study (i.e., selected by the municipalities and attending a school that was willing to participate, N = 3145), 6.7% were excluded because incapability or language problems. Of the remaining 2935 children, 76.0% (N = 2230, mean age = 11.09, SD = 0.55, 50.8% girls) were enrolled in the study (i.e., both child and parent agreed to participate). Responders and non-responders did not differ with respect to the prevalence of teacher-rated problem behavior, nor regarding associations between socio-demographic variables and mental health outcomes (De Winter et al., 2005).

Data collection. Well-trained interviewers visited one of the parents or guardians (preferably the mother, 95.6%) at their homes to administer an interview covering a wide range of topics, including the child’s developmental history and somatic health, parental psychopathology and care utilization. Besides the interview, the parent was asked to fill out a self-report questionnaire. Children were measured at school, where they filled out questionnaires, in groups, under the supervision of one or more TRAILS assistants. In addition to that, information processing capacities, intelligence, and a number of biological parameters were assessed individually (also at school). Teachers were asked to fill out a brief questionnaire for all TRAILS-children in their class. Measures that were used in this dissertation are described more extensively further on.

OUTLINE OF THE DISSERTATION

Chapters 2 through 5 present empirical findings of the TRAILS sample. In Chapter 2, variations in information processing related to gender, age, intelligence, and socio-economic status are reported. Chapters 3 through 5 describe the relationships between information processing and problem behavior, starting off with an examination of the broad-band categories of internalizing and externalizing behavior problems in Chapter 3. Chapter 4 further describes the information processing capacities within the externalizing behavior domain by investigating the narrow-band categories of oppositional defiant/conduct problems and attention-deficit/hyperactivity problems. Subsequently, the information processing profiles of attention-deficit/hyperactivity subtype problems are explored (Chapter 5). Finally, in Chapter 6, conclusions are presented and possible implications for further research and clinical practice are discussed. It is stressed that the findings presented in this dissertation pertain to parent- and teacher-reported behavior problem syndromes that are not equivalent to DSM disorders, although strong associations between these checklist syndromes and DSM diagnoses have been documented (e.g., Edelbrock & Costello, 1988; Karius, Ferdinand, Van den Berg, & Verhulst, 1997; Kazdin & Heidish, 1984). Please note that Chapters 2 through 5 are based on articles and arranged in a way that seemed the most constructive to the author. They can, however, be read independently of each other.
CHAPTER 2

INFORMATION PROCESSING in a POPULATION-BASED SAMPLE of PREADOLESCENTS: GENDER-, AGE-, INTELLIGENCE-, and SOCIO-ECONOMIC STATUS-RELATED VARIATIONS

ABSTRACT

OBJECTIVE: This study investigates gender-, age-, intelligence-, and socio-economic status-related variations in information processing within a general population sample of ten- to twelve-year-olds \(N = 2223, 51.0\% \text{ girls}\). METHODS: Multiple information processing capacities were assessed by subtests from the Amsterdam Neuropsychological Tasks (ANT) program measuring baseline speed, visuo-spatial pattern recognition, perceptual sensitivity, response variability, working memory, inhibition of prepotent responses, response bias, and attentional flexibility. Groups varying in gender, age, intelligence, and socio-economic status were compared on the speed and accuracy of these capacities. RESULTS: Gender- and age-related differences were small and limited to only a few capacities. Compared to girls, boys demonstrated a somewhat greater response variability, a slower working memory, and a slightly more accurate attentional flexibility. Additionally, small age-dependent increases in baseline speed and the speed of attentional flexibility could be detected. For most capacities, higher levels of intelligence were characterized by faster and more accurate processing. Similar relationships were observed for socio-economic status, however, these were no longer significant after statistical control for IQ. CONCLUSIONS: Our findings underline the importance of accounting for gender- and age-related variations in information processing in the search for pathology-specific processing deficits. Furthermore, it is argued that future clinical studies may benefit from presenting their findings both with and without statistical control for IQ considering the theoretical debate on the relationship between IQ and information processing. In contrast, socio-economic status appears to be a more distal determinant of information processing.
CHAPTER 2

INTRODUCTION

Information processing plays an essential role in the way individuals interact and cope with their environment. Consequently, deficits in the processes needed to perceive, evaluate, and react to information may have detrimental effects on daily functioning. To date, numerous studies have attempted to unravel the relationships between information processing deficits and maladaptive behavior problems in children and adolescents. In evaluating the results of these studies, knowledge of the degree to which variations in information processing are also related to other personal characteristics is important. As gender, age, intelligence, and socio-economic status have each been associated with differences in the prevalence, development, and manifestation of maladaptive behavior (e.g., Anderson, Williams, McGee, & Silva, 1989; Cicchetti & Sroufe, 2000; Crick & Zahn-Waxler, 2003; Lahelma, Martikainen, Laaksonen, & Aittomäki, 2004), the present study will examine to what extent these personal characteristics relate to multiple information processing capacities in a large population-based sample of preadolescents.

Gender and age differences have been relatively well-documented for several aspects of information processing. Males have, for example, been found to perform better at complex systemizing tasks (e.g., mental rotation of visuo-spatial patterns), whereas females are generally better at empathizing (e.g., facial expression processing) and verbal tasks (Baron-Cohen, 2002; McClure, 2000; Voyer, Voyer, & Bryden, 1995). It has been suggested that these processing differences reflect structural or functional differences in underlying brain mechanisms (De Bellis et al., 2001; Gur et al., 1999), possibly in part due to differential psychosocial influences (Krahnstöver Davison & Susman, 2001). Additionally, individual variations in information processing may stem from differences in brain maturation (Casey, Giedd, & Thomas, 2000; Luna et al., 2001). The period of childhood is characterized by marked age-dependent increases in the efficiency of information processing capacities (see for a review: Gomez-Perez, Ostrosky-Solis, & Prospero-Garcia, 2003). By late childhood, last developing capacities are those that have been associated with the prefrontal cortex (e.g., working memory, response inhibition, attentional flexibility), which is known to be one of the last brain regions to mature (Fuster, 2002). Moreover, baseline speed of processing has been found to continuously increase until into adulthood and to decrease again later in life (Cerella & Hale, 1994; Kail, 1991).
In contrast, far less is known about variations in information processing related to intelligence and socio-economic status. In this paper, the term intelligence will be employed to refer to the individual’s general level of intellectual development as measured by a standardized IQ score. Although the concept of psychometric intelligence has been criticized (Ardila, 1999), IQ tests remain widely used and IQ is an acknowledged predictor of academic achievement (Sattler, 1992). With respect to the relationship between intelligence and information processing, however, scientific opinions are greatly divided. On the one hand, IQ scores may reflect general ability or ‘g’ which is distinct from the more specific information processing capacities (Anderson, 1992). On the other hand, information processing abilities may contribute directly to performance on IQ tests or vice versa (see discussion in Doyle et al., 2005). Previous studies have found IQ to be significantly associated with baseline speed of processing (e.g., Scheuffgen, Happé, Anderson, & Frith, 2000), yet knowledge is lacking concerning its relationship with other aspects of information processing. Similarly, as recently pointed out by O’Bryant and colleagues (2004), little is known about the extent to which socio-economic status is related to information processing capacities.

The present study adds to existing scientific knowledge by investigating gender-, age-, intelligence-, and socio-economic status-related variations in information processing in a large and unselected sample of preadolescents (N = 2223), while simultaneously exploring the extent to which these variations in information processing are mutually (in)dependent. To this end, multiple information processing capacities were assessed by means of reaction time (RT) paradigms that enable the selective and powerful measurement of relatively isolated information processing capacities as compared to the more commonly used classical neuropsychological tests (De Sonneville & Njokikijien, 1993; Mulder, 1983).
CHAPTER 2

METHODS

SAMPLE

The present study reports data from the first assessment wave of the TRacking Adolescents’ Individual Lives Survey (TRAILS), an ongoing cohort study investigating the development of mental health from preadolescence into adulthood. From March 2001 to July 2002, 3145 ten- to twelve-year-olds living in five municipalities in the North of the Netherlands, including both urban and rural areas, were approached for enrollment in the study. Children were excluded if they were incapable to participate due to mental retardation or a serious physical illness or handicap; or if no Dutch-speaking parent or parent surrogate was available, and it was not feasible to administer part of the measurements in the parent’s language (N = 210, 6.7%). Of the remaining 2935 children, 76.0% (N = 2230, mean age = 11.09, SD = 0.55, 50.8% girls) agreed to participate. Responders and non-responders did not differ with respect to the prevalence of teacher-rated problem behavior, nor regarding associations between socio-demographic variables and mental health outcomes (De Winter et al., 2005). The present study selected those children for whom the information processing data, and information regarding gender, age, IQ, and SES were available (n = 2223, i.e., 99.7% of the TRAILS sample). More information on sample selection procedures and sample characteristics is provided elsewhere (De Winter et al., 2005; Oldehinkel, Hartman, De Winter, Veenstra, & Ormel, 2004).

PROCEDURE and MEASURES

INFORMATION PROCESSING. To study a variety of fundamental information processing capacities, we administered five subtests from the Amsterdam Neuropsychological Tasks program (ANT; De Sonnevile, 1999). An extensive description of the tasks and resulting measures is provided in Appendix A. In short, children were tested individually for approximately 70 minutes (short breaks included) by trained undergraduate psychologists in a separate room at their school (or, if this was not feasible, in a nearby community center). They consecutively performed, (1) the Baseline Speed task measuring simple visuo-motor reaction time, (2) the Pattern Recognition task measuring automatic and controlled visuo-spatial pattern recognition, (3) the Sustained Attention task measuring response variability, perceptual sensitivity, response bias, and responsiveness to feedback on errors,
(4) the Memory Search task measuring working memory capacity, and (5) the Shifting Set task measuring inhibition of prepotent responses as well as attentional flexibility. Verbal task instructions were given before each task emphasizing both speed and accuracy of performance. To ensure that the children understood these instructions, practice trials were performed preceding task assessment. An overview of the measures can be found in Table 1. Inter-correlations were generally weak suggesting limited overlap between the measures (RT: mean $r = .24$ ranging from $r = .07$ to $r = .55$, accuracy: mean $r = .07$ ranging from $r = .00$ to $r = .46$).

**Table 1. Overview of the information processing measures.**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Measurement Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Speed</td>
<td>The ability to detect and respond to a stimulus (simple reaction time).</td>
</tr>
<tr>
<td>Pattern Search</td>
<td>The central cognitive ability to detect a visuo-spatial target pattern among barely distinguishable (similar) visuo-spatial patterns.</td>
</tr>
<tr>
<td>Pattern Detection</td>
<td>The input-related ability to automatically detect a visuo-spatial target pattern sticking out among easily distinguishable (dissimilar) visuo-spatial patterns.</td>
</tr>
<tr>
<td>Fluctuation in Tempo</td>
<td>The central cognitive ability to maintain a stable performance over a prolonged period of time (response variability).</td>
</tr>
<tr>
<td>Feedback Responsiveness</td>
<td>The central cognitive ability to adjust response behavior following feedback on errors.</td>
</tr>
<tr>
<td>T-O-T D’</td>
<td>Time-On-Task perceptual sensitivity, i.e., the input-related ability to discriminate target signals from nontarget signals.</td>
</tr>
<tr>
<td>T-O-T Beta</td>
<td>Time-On-Task response bias, i.e., the output-related ability to inhibit (task-induced) biased response tendencies.</td>
</tr>
<tr>
<td>WM Capacity</td>
<td>The central cognitive ability to maintain and compare increasing information load in working memory (WM).</td>
</tr>
<tr>
<td>Inhibition of Prepotent Responses</td>
<td>The output-related ability to inhibit an inappropriate, habitual response tendency.</td>
</tr>
<tr>
<td>Attentional Flexibility</td>
<td>The central cognitive ability to mentally switch between two competing and unpredictable response sets.</td>
</tr>
</tbody>
</table>
INTELLIGENCE. The Vocabulary and Block Design subtests from the Revised Wechsler Intelligence Scales for Children (WISC-R; Van Haasen et al., 1986; Wechsler, 1974) were used to estimate Full Scale IQ following Sattler (Sattler, 1992). This two-subtest short form was chosen on the basis of its high multiple correlation with Full Scale IQ ($r = .90$) (Sattler, 1992).

SOCIO-ECONOMIC STATUS (SES). Socio-economic status was determined by combining three key indicators of SES: parental educational level, parental occupational status, and family income. The highest completed educational degree of each parent was measured on a 5-point scale ranging from ‘elementary education’ to ‘university’. Current occupational status of each parent was classified on the basis of the International Standard Classification of Occupations (Ganzeboom & Treiman, 1996), which distinguishes 9 categories ranging from ‘Elementary Occupations’ to ‘Legislators, Senior Officials and Managers’. Net family income was assessed on an 8-point scale, ranging from ‘less than 680 euros’ to ‘over 3860 euros’. A single SES measure was obtained by standardizing and subsequently averaging the values of these three indicators.

ANALYSES
First, scores on each RT- and accuracy measure with an absolute z-score greater than or equal to 4 were defined as outliers (Stevens, 2002, p.16). These outliers together with participants performing at a chance level of accuracy, i.e., making 50% or more errors on any of the relevant task conditions, were listwise deleted from subsequent analyses resulting in a loss of $n = 166$ (7.5% of the study sample) for the set of RT-measures and $n = 116$ (5.2% of the study sample) for the set of accuracy measures. These left-out participants did not differ from the remaining sample on any of the personal characteristics. Next, accuracy measures were logarithmically transformed to approximate normal distributions.

To assess gender-, age-, intelligence-, and socio-economic status-related variations in information processing, multiple subgroups were formed. For age, intelligence, and socio-economic status each, three subgroups were created by grouping the children scoring, respectively, below the P33, between the P33 and P66, and above the P66 of each distribution. Table 2 shows that these groups differ only on the variable by which they were formed, except for the youngest age group which had a slightly higher SES than the
other two age groups and the three intelligence- and socio-economic status-groups which differed in the degree of both IQ and SES.

Table 2. Group Characteristics.

<table>
<thead>
<tr>
<th>Groups</th>
<th>N</th>
<th>Gender (% boys)</th>
<th>Age M (SD)</th>
<th>IQ M (SD)</th>
<th>SES M (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Sample</td>
<td>2223</td>
<td>48.99</td>
<td>11.36 (0.57)</td>
<td>97.22 (14.90)</td>
<td>-0.05 (0.79)</td>
</tr>
<tr>
<td>Boys</td>
<td>1089</td>
<td>100.0</td>
<td>11.38 (0.57)</td>
<td>98.26 (14.97)</td>
<td>-0.07 (0.81)</td>
</tr>
<tr>
<td>Girls</td>
<td>1134</td>
<td>0</td>
<td>11.35 (0.56)</td>
<td>96.22 (14.77)</td>
<td>-0.03 (0.77)</td>
</tr>
<tr>
<td>Youngest</td>
<td>728</td>
<td>46.84</td>
<td>10.74 (0.21)</td>
<td>98.76 (13.53)</td>
<td>0.04 (0.76)</td>
</tr>
<tr>
<td>Intermediate</td>
<td>747</td>
<td>48.73</td>
<td>11.31 (0.16)</td>
<td>98.14 (15.41)</td>
<td>-0.08 (0.75)</td>
</tr>
<tr>
<td>Oldest</td>
<td>748</td>
<td>51.34</td>
<td>12.02 (0.28)</td>
<td>94.81 (15.37)</td>
<td>-0.10 (0.84)</td>
</tr>
<tr>
<td>Low IQ</td>
<td>675</td>
<td>44.74</td>
<td>11.45 (0.55)</td>
<td>80.21 (8.03)</td>
<td>-0.44 (0.75)</td>
</tr>
<tr>
<td>Intermediate IQ</td>
<td>850</td>
<td>50.82</td>
<td>11.34 (0.58)</td>
<td>96.90 (4.21)</td>
<td>-0.04 (0.73)</td>
</tr>
<tr>
<td>High IQ</td>
<td>698</td>
<td>50.86</td>
<td>11.30 (0.55)</td>
<td>114.07 (7.68)</td>
<td>0.31 (0.72)</td>
</tr>
<tr>
<td>Low SES</td>
<td>715</td>
<td>51.33</td>
<td>11.42 (0.56)</td>
<td>90.87 (14.30)</td>
<td>-0.97 (0.35)</td>
</tr>
<tr>
<td>Intermediate SES</td>
<td>771</td>
<td>48.77</td>
<td>11.33 (0.54)</td>
<td>97.02 (13.50)</td>
<td>-0.05 (0.21)</td>
</tr>
<tr>
<td>High SES</td>
<td>737</td>
<td>46.95</td>
<td>11.34 (0.59)</td>
<td>103.59 (14.19)</td>
<td>0.84 (0.33)</td>
</tr>
</tbody>
</table>

Note. Gender: Chi-square tests with asymptotic significance set at .05, other: ANOVA main effects for group with F(2, 2024), p < .05, and $\eta^2 > .010$. Group contrasts significant at p < .05 with moderate or large effect sizes (d ≥ .50) are printed boldfaced. Y = as compared to Youngest, I = Intermediate, and O = Oldest group.

Group differences in information processing were examined by multivariate analyses of variance (GLM, MANOVA, SPSS). For each group variable, two separate MANOVAs were conducted: one on the set of RT-measures and the other on the set of accuracy measures. Multivariate group differences with a value of Wilks’ $\lambda$ significant at $p < .05$ and an accompanying effect size denoting at least a small effect (i.e., partial eta squared, $\eta^2 \geq .010$) (Cohen, 1988) were further examined by exploring the univariate group differences and group contrasts. To examine the mutual (in)dependence of the relationships, gender was
entered as another between-subjects factor in the analyses for age, intelligence, and socio-economic status and the continuous variable age was entered as a covariate in the analyses for gender, intelligence, and socio-economic status. In a separate run of the analyses for gender and age, the continuous variables IQ and SES were entered as covariates in addition to age whereas in the analyses for intelligence and socio-economic status, SES and IQ were added respectively.

In order to visualize group differences and make the various task performances comparable, RT- and accuracy measures were standardized (z-transformed) and adjusted for age. Profiles were then established by presenting the standardized means of the subgroups in a line chart.
RESULTS

GENDER
The multivariate analyses for gender revealed a moderate overall gender difference on the set of RT-measures \( F(8, 2040) = 18.10, \ p < .001, \ \eta^2_p = .066 \) and a small overall difference on the set of accuracy measures \( F(7, 2047) = 5.06, \ p < .001, \ \eta^2_p = .017 \). These differences remained significant after additional statistical control for IQ and SES \( RT: F(8, 2038) = 17.85, \ p < .001, \ \eta^2_p = .065; \ accuracy: F(7, 2045) = 4.41, \ p < .001, \ \eta^2_p = .015 \). As can be seen in Figure 1, girls and boys differed on two of the eight RT-measures and one of the seven accuracy measures, with boys demonstrating greater response variability \( p < .001, \ \eta^2_p = .013 \) and a somewhat slower working memory \( p < .001, \ \eta^2_p = .023 \) but a slightly more accurate attentional flexibility \( p < .001, \ \eta^2_p = .011 \) than girls.

AGE
A small multivariate age difference was found only on the set of RT-measures \( F(16, 4074) = 4.36, \ p < .001, \ \eta^2_p = .021 \) but not on the set of accuracy measures \( p = .615, \ \eta^2_p = .003 \). This multivariate age difference withstood additional control for IQ and SES \( F(16, 4070) = 7.23, \ p < .001, \ \eta^2_p = .028 \) and no significant interactions between age and gender were found \( RT: p = .964, \ \eta^2_p = .002; \ accuracy: p = .472, \ \eta^2_p = .003 \). Oldest children demonstrated a higher baseline speed of processing than both the intermediate and youngest children, whereas for Attentional Flexibility a more equidistant age-related increase in processing speed was observed (see Figure 2).
Figure 1. Gender-related variations in information processing.
Note. The profiles for boys and girls are symmetrical due to the fact that their mean z-scores are derived from subsamples constituting each 50% of the whole sample. Differences observed for Baseline Speed do not account for differences on other RT-measures as this was automatically corrected for in the computation of these measures.
Figure 2. Age-related variations in information processing.
Note. Univariate overall group effects and group contrasts significant at the .05 level and $\eta^2 > .010$ are labeled in the charts by letters; 'Y' meaning youngest, 'I' meaning intermediate, 'O' meaning oldest-group difference.
CHAPTER 2

INTELLIGENCE
The multivariate analyses for intelligence resulted in a moderate overall difference for the set of RT-measures \( F(16, 4072) = 17.30, p < .001, \eta^2_p = .064 \) and small effect the set of accuracy measures \( F(14, 4086) = 10.66, p < .001, \eta^2_p = .035 \). These intelligence-related differences remained significant after additional control for SES \( \text{RT: } F(16, 4070) = 13.23, p < .001, \eta^2_p = .049; \text{accuracy: } F(14, 4084) = 8.75, p < .001, \eta^2_p = .029 \). Again, no multivariate significant interactions were found with gender \( \text{RT: } p = .129, \eta^2_p = .005; \text{accuracy: } p = .565, \eta^2_p = .003 \). Figure 3 shows univariate significant group differences for all of the eight RT-measures and four of the seven accuracy measures. For most of these measures an equidistant linear increase in performance efficiency across the three IQ groups could be detected.

SOCIO-ECONOMIC STATUS
A small multivariate SES differences was found on the set of RT-measures \( F(16, 4072) = 5.36, p < .001, \eta^2_p = .021 \). Again, no multivariate significant interactions were found with gender \( p = .066, \eta^2_p = .006 \). The multivariate analysis on the set of accuracy measures also revealed a significant group difference \( F(14, 4086) = 3.08, p < .001, \eta^2_p = .010 \), yet none of the univariate group differences reached a meaningful effect size. Figure 4 shows that four of the eight RT-measures discriminated significantly among the SES groups. These measures showed a better performance for the children in the high SES group as compared to both the low and intermediate groups, which in turn appeared to perform quite similar. These differences, however, lost significance after additional control for IQ \( p = .010, \eta^2_p = .008 \).
Figure 3. Intelligence-related variations in information processing.
Note. Univariate overall group effects and group contrasts significant at the .05 level and $\eta^2 > .010$ are labeled in the charts by letters; 'L' meaning lowest, 'I' meaning intermediate, 'H' meaning high group difference.
Figure 4. Socio-Economic Status-related variations in information processing.
Note. Univariate overall group effects and group contrasts are marked in the same way as in Figure 3.
DISCUSSION

The results of the present study suggest that the personal characteristics gender, age, intelligence, and socio-economic status are differentially related to a range of information processing capacities within a large general population sample of preadolescents. These relationships were mutually independent, except for the SES-related variations in processing which were dependent upon IQ.

Gender and age differences were small and limited to only a few information processing capacities. Compared to girls, boys demonstrated a somewhat greater response variability, a slower working memory, yet a slightly more accurate attentional flexibility. The most pronounced gender difference was observed for working memory. One explanation for the fact that boys displayed a less efficient working memory may be related to the verbal, instead of spatial, modality of our task. This would be in line with studies showing females to outperform males on tasks using verbal information (e.g., Lowe, Mayfield, & Reynolds, 2003). However, it is also possible that the working memory of boys is generally simply somewhat slower than that of girls. Yet, although gender differences in working memory have often been investigated in terms of accuracy of processing, little is known about gender differences in terms of speed of working memory (Robert & Savoie, 2006). With respect to age, our findings corroborate existing literature in that age-related increases in baseline speed of processing (Cerella & Hale, 1994; Kail, 1991) and speed of attentional flexibility (Gomez-Perez et al., 2003) were found. Contrary to previous studies, however, no age differences were found for the other complex processes such as working memory and response inhibition, which is probably due to the narrow age range investigated.

In contrast to gender and age, intelligence-related variations in information processing were larger and observed for more processing capacities, indicating that IQ and information processing share a considerable amount of variance. As stated previously, this may be because information processing abilities contribute directly to performance on IQ tests or because general intelligence contributes to performance on information processing tasks (Doyle et al., 2005). Although the cross-sectional nature of our study does not allow the dissociation of these two alternatives, it does suggest that the degree of shared variance differs across processing capacities. Moreover, SES-related variations in the speed of information processing were found to be dependent upon the IQ-related variations in
processing. Further examination of the data additionally revealed that controlling for SES did not exert an influence over and above controlling for IQ. This interrelatedness may stem from the fact that SES partially reflects the parental level of education. As IQ has been found to be strongly heritably (Posthuma, De Geus, & Boomsma, 2003), it may be that highly educated people are more likely to have higher IQs, which they may pass on to their children.

Studies investigating pathology-specific deficits in information processing generally compare clinically referred with non-referred children. These clinically referred samples usually encompass wide age ranges of mostly boys with lower levels of both IQ and SES (Bergeron et al., 2000). Results of the present study stress the importance for these studies to account for gender- and age-related variations in information processing. The appropriateness of accounting for IQ-related variations in information processing is, however, a complex theoretical issue (Doyle et al., 2005; Kuntsi, Oosterlaan, & Stevenson, 2001). The argument in favor of controlling for IQ when comparing groups is to ensure that differences in the information processing capacities examined are not confounded by group differences in intelligence. However, the counter-argument for controlling for IQ is that adjusting for differences in IQ may remove a portion of variance that is inherent to information processing itself. Therefore, we argue that future studies may benefit from analyzing their data both with and without statistically controlling for intelligence. In contrast, our findings showed that SES-related variations in information processing are mainly due to IQ suggesting that SES may be a more distal determinant of information processing.
ACKNOWLEDGEMENTS

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CHAPTER 3

INFORMATION PROCESSING PROFILES of INTERNALIZING and EXTERNALIZING BEHAVIOR PROBLEMS: EVIDENCE from a POPULATION-BASED SAMPLE of PREADOLESCENTS

ABSTRACT

OBJECTIVE: The present study explores the relationships between several information processing capacities and internalizing and externalizing behavior problems in a general population sample of 10- to 12-year-olds (N = 2037, 51.1% girls). METHODS: Parent-reported behavior problems as assessed by the Child Behavior Checklist were used to form four groups of children with (1) neither internalizing nor externalizing problems (n = 1470), (2) only internalizing problems (n = 237), (3) only externalizing problems (n = 182), and (4) both internalizing and externalizing problems (n = 148). These groups were compared on measures of speed and accuracy from the Amsterdam Neuropsychological Tasks program reflecting the efficiency of several input-, central cognitive-, and output-related information processing capacities. RESULTS: Children with both internalizing and externalizing problems demonstrated the least efficient performance followed by children with only externalizing problems, whereas children with only internalizing problems did not differ from children without problems. More specifically, response variability and the ability to maintain and quickly compare information in working memory were found to be related to the severity of problem behavior. The ability to inhibit prepotent responses was related to the type of problem behavior, discriminating between the children with only internalizing problems and only externalizing problems. However, this latter capacity no longer differentiated when controlling for IQ. No differences were found between boys and girls. CONCLUSIONS: The results suggest that, in general, cognitive processing deficits are more strongly related to the degree than to the type of maladaptive behavior. Furthermore, response variability and working memory may serve as potential markers for identifying high-risk children and response inhibition as an indicator of the type of maladaptive behavior.
INTRODUCTION

To gain insights into the etiology and outcome of child and adolescent psychopathology, researchers have become interested in identifying not only the characteristics that differentiate maladaptive from adaptive behavior but also the characteristics that distinguish between different types of maladaptive behavior (e.g., Weiss, Süsser, & Catron, 1998; Mesman & Koot, 2000). Although cognitive deficits have repeatedly been associated with maladaptive behavior, the diagnostic specificity of these findings remains to be determined (Rutter & Sroufe, 2000).

Problem behavior in children and adolescents can be distinguished into internalizing and externalizing behaviors. Internalizing behaviors (i.e., anxious, withdrawn, and depressed behavior) reflect ways of adapting to the environment that cause internal distress, whereas externalizing behaviors are characterized by acting out (i.e., aggressive and rule-breaking behavior), resulting in conflict with others (Achenbach & Edelbrock, 1978). A dimensional conceptualization of problem behavior posits that, throughout the general population, children and adolescents exhibit these behaviors to varying degrees ranging from adaptive to maladaptive (Pickles & Angold, 2003). Prevalence estimates indicate that about 12 to 22% of children and adolescents have significant maladaptive behavior problems (see Verhulst, 1995, for a review) with a considerable number exhibiting both internalizing and externalizing problems (Angold, Costello, & Erkanli, 1999). These children often show more severe and chronic symptoms than children with either internalizing or externalizing problems (Verhulst & Van der Ende, 1993).

As not all children with significant behavior problems receive mental health care, clinical study samples are not representative of the full population of children with behavior problems and often contain an overrepresentation of children with more severe and comorbid symptomatology (Caron & Rutter, 1991; Goodman et al., 1997). Studies using large general population samples, which are not liable to such referral biases, are therefore important, especially when attempting to disentangle the cognitive determinants of severity (related to the degree) and direction (related to the type) of problem behavior (Oldehinkel, Hartman, De Winter, Veenstra, & Ormel, 2004).

Previous population-based studies have compared children with internalizing, externalizing, as well as co-occurring internalizing and externalizing problems on measures
of intellectual functioning and several traditional neuropsychological tests such as the Stroop Color-Word, Trail Making, and Wisconsin Card Sorting Test (Anderson, Williams, McGee, & Silva, 1989; Frost, Moffitt, & McGee, 1989; Kusché, Cook, & Greenberg, 1993). Although these studies used different measures, their results were very similar in finding that children with co-occurring internalizing and externalizing problems were the most severely disadvantaged in contrast to children with either internalizing or externalizing problems, whose disadvantage was less severe and confined to fewer measures. Furthermore, none of the cognitive measures differentiated the children with internalizing problems from the children with externalizing problems. However, as traditional neuropsychological tests do not isolate specific cognitive processes but rather assess the product of multiple underlying elementary cognitive processes (Pennington & Ozonoff, 1996), greater specificity in relationships may arise when dysfunctions in these underlying processes can be delineated (Sergeant, Geurts, & Oosterlaan, 2002).

The present study adds to previous research by providing data of several computerized neuropsychological tasks that were administered in a large population-based sample of preadolescents. In contrast to traditional neuropsychological tests, these tasks incorporate simple within-task manipulations based on paradigms from cognitive experimental psychology that enable the selective measurement of relatively specific cognitive component processes also referred to as information processing capacities. Moreover, these tasks provide rigorous control over task administration (e.g., stimulus presentation) and a fine-grained collection of data on processing speed and accuracy, thereby reducing measurement error and enabling the assessment of even subtle inter-individual differences in information processing (see also, Doyle, Faraone, et al., 2005; MacDonald III & Carter, 2002; Sergeant et al., 2002). Because daily life continuously requires us to perceive, evaluate, and react to information, we selected tasks assessing input-related processes (detection, discrimination, and selection), as well as more central cognitive (serial search, sustained attention, and feedback-related effort allocation), and output-related processes (response organization and response inhibition) that are assumed to form the basis of complex cognitive functions (Mulder, 1986; Sanders, 1983).

The aim of the present study was to explore to what extent these information processing capacities are related to internalizing, externalizing and co-occurring
internalizing and externalizing problems within the general population, while attempting to identify severity markers of problem behavior (related to the extent of maladjustment) and direction markers of problem behavior (discriminating between internalizing and externalizing problems). To this end, we compared the information processing performance of children with (a) neither internalizing nor externalizing problems, (b) only internalizing problems, (c) only externalizing problems, and (d) both internalizing and externalizing problems. This typological approach of identifying groups of persons based on the presence or absence of problem behavior is closely related to clinical practice and provides a straightforward and easily interpretable alternative to the more common variable-centered approach (Mandara, 2003). Because problem behavior is known to show gender differences (e.g., Verhulst, 1995), we checked whether relationships were similar for boys and girls. Furthermore, as there is an ongoing debate on whether or not to control for general cognitive ability when investigating specific cognitive processes (see discussion in Doyle, Wilens, et al., 2005), we analyzed our data both with and without controlling for IQ. More precise specification of the relationships between information processing and problem behavior in the general population may help to identify high-risk groups and may yield clues for both research and clinical practice about etiology and outcome.
METHODS

SAMPLE

The present study reports data from the first assessment wave of the TRacking Adolescents’ Individual Lives Survey (TRAILS), an ongoing cohort study investigating the development of mental health from preadolescence into adulthood. From March 2001 to July 2002, 3145 ten- to twelve-year-olds living in five municipalities in the North of the Netherlands, including both urban and rural areas, were approached for enrollment in the study. Children were excluded if they were incapable to participate due to mental retardation or a serious physical illness or handicap; or if no Dutch-speaking parent or parent surrogate was available, and it was not feasible to administer part of the measurements in the parent’s language (N = 210, 6.7%). Of the remaining 2935 children, 76.0% (N = 2230, mean age = 11.09, SD = 0.55, 50.8% girls) agreed to participate. Responders and non-responders did not differ with respect to the prevalence of teacher-rated problem behavior, nor regarding associations between socio-demographic variables and mental health outcomes (De Winter et al., 2005). The present study selected those children for whom both parent-reported behavior problems and information processing data were available (n = 2037, i.e., 91.3% of the TRAILS sample). Detailed information on sample selection procedures and sample characteristics is provided elsewhere (De Winter et al., 2005; Oldehinkel et al., 2004).

PROCEDURE and MEASURES

INTERNALIZING AND EXTERNALIZING BEHAVIOR. Parent-reported (96% mothers) behavior problems were assessed by the Child Behavior Checklist (CBCL/6-18; Achenbach & Rescorla, 2001). Items measuring anxious/depressed behavior, withdrawn/depressed behavior, and somatic complaints together form the broad-band dimension of internalizing behavior, whereas items measuring aggressive and rule-breaking behavior form the broad-band dimension of externalizing behavior. For both dimensions, the 84th percentile has been identified as the ‘borderline range’ cut-off discriminating between adaptive and maladaptive behavior (Achenbach & Rescorla, 2001). Accordingly, the children were assigned to one of the following four groups: (1) no problems (NO: internalizing < P84 and externalizing < P84), (2) only internalizing problems (INT: internalizing ≥ P84 and...
externalizing $< P84$), (3) only externalizing problems (EXT: internalizing $< P84$ and externalizing $\geq P84$), (4) co-occurring internalizing and externalizing problems (COM: internalizing $\geq P84$ and externalizing $\geq P84$). Group characteristics are presented in Table 1 with mean problem scores and mental health care utilization rates indicating that the severity of problem behavior steadily increases from the NO group, through the INT and EXT group, to the COM group, while only the INT and EXT group differ in within-group type (direction) of problem behavior.

<table>
<thead>
<tr>
<th>Measures</th>
<th>NO (n = 1470)</th>
<th>INT (n = 237)</th>
<th>EXT (n = 182)</th>
<th>COM (n = 148)</th>
<th>Pairwise group comparisons 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender ( % boys)</td>
<td>46.46</td>
<td>42.19</td>
<td>69.78</td>
<td>58.78</td>
<td>INT, NO &lt; COM, EXT</td>
</tr>
<tr>
<td>Age M (SD)</td>
<td>11.35 (0.56)</td>
<td>11.31 (0.57)</td>
<td>11.40 (0.56)</td>
<td>11.38 (0.56)</td>
<td>n.s.</td>
</tr>
<tr>
<td>IQ M (SD)</td>
<td>98.68 (14.28)</td>
<td>100.10 (16.59)</td>
<td>91.34 (13.59)</td>
<td>94.30 (14.11)</td>
<td>EXT, COM &lt; NO, INT</td>
</tr>
<tr>
<td>Internalizing Problems M (SD)</td>
<td>0.16 (0.11)</td>
<td>0.52 (0.13)</td>
<td>0.25 (0.09)</td>
<td>0.61 (0.18)</td>
<td>NO &lt; EXT &lt; INT &lt; COM</td>
</tr>
<tr>
<td>Externalizing Problems M (SD)</td>
<td>0.16 (0.11)</td>
<td>0.25 (0.10)</td>
<td>0.56 (0.13)</td>
<td>0.63 (0.18)</td>
<td>NO &lt; INT &lt; EXT &lt; COM</td>
</tr>
<tr>
<td>Mental health care use (%)</td>
<td>2.24</td>
<td>6.33</td>
<td>12.09</td>
<td>21.62</td>
<td>NO &lt; INT &lt; EXT &lt; COM</td>
</tr>
</tbody>
</table>

Note. 1 Gender and mental health care use: Chi-square tests with asymptotic significance set at .01, other: ANOVA main effects for group with $F(3, 2033), p < .01$ and $\eta^2 > .010$ (a group contrasts set at .01). 2 Mean item scores (range 0 - 2). 3 Percentage of children for whom parents have contacted a mental health care facility at least once in the last year on account of their child's maladaptive behavior (type of problems are unknown).
INFORMATION PROCESSING. A variety of information processing capacities were assessed by measures of speed (reaction times, RTs) and accuracy (error rates) derived from five tasks of the well-validated Amsterdam Neuropsychological Tasks program (ANT; De Sonneville, 1999). An extensive description of the tasks and resulting measures is provided in Appendix A. In short, children were tested individually for approximately 70 minutes (short breaks included) by trained undergraduate psychologists in a separate room at their school (or, if this was not feasible, in a nearby community center). They consecutively performed, (1) the Baseline Speed task measuring simple visuo-motor reaction time, (2) the Pattern Recognition task measuring automatic and controlled visuo-spatial pattern recognition, (3) the Sustained Attention task measuring response variability, perceptual sensitivity, response bias, and responsiveness to feedback on errors, (4) the Memory Search task measuring working memory capacity, and (5) the Shifting Set task measuring inhibition of prepotent responses as well as attentional flexibility. Verbal task instructions were given before each task emphasizing both speed and accuracy of performance. To ensure that the children understood these instructions, practice trials were performed preceding task assessment. An overview of the measures can be found in Table 2. Inter-correlations were generally weak suggesting limited overlap between the measures (RT: mean $r = .23$ ranging from $r = .07$ to $r = .54$, accuracy: mean $r = .07$ ranging from $r = .01$ to $r = .46$).

INTELLIGENCE. The Vocabulary and Block Design subtests from the Revised Wechsler Intelligence Scales for Children (WISC-R; Van Haasen et al., 1986; Wechsler, 1974) were used to estimate Full Scale IQ for all children (Sattler, 1992).

ANALYSES
First, scores on each RT- and accuracy measure with an absolute z-score greater than or equal to 4 were defined as outliers (Stevens, 2002, p.16). For each measure separately, these outliers together with participants performing at a chance level of accuracy, i.e., making 50% or more errors on any of the relevant task conditions, were dropped from subsequent analyses. These left-out participants did not differ from the remaining sample with respect to gender, age, IQ, or diagnostic group. Next, accuracy measures were logarithmically transformed to approximate normal distributions.
Table 2. Overview of the information processing measures.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Measurement Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Speed</td>
<td>The ability to detect and respond to a stimulus (simple reaction time).</td>
</tr>
<tr>
<td>Pattern Search</td>
<td>The central cognitive ability to detect a visuo-spatial target pattern among barely distinguishable (similar) visuo-spatial patterns.</td>
</tr>
<tr>
<td>Pattern Detection</td>
<td>The input-related ability to automatically detect a visuo-spatial target pattern sticking out among easily distinguishable (dissimilar) visuo-spatial patterns.</td>
</tr>
<tr>
<td>Fluctuation in Tempo</td>
<td>The central cognitive ability to maintain a stable performance over a prolonged period of time (response variability).</td>
</tr>
<tr>
<td>Feedback Responsiveness</td>
<td>The central cognitive ability to adjust response behavior following feedback on errors.</td>
</tr>
<tr>
<td>T-O-T D’</td>
<td>Time-On-Task perceptual sensitivity, i.e., the input-related ability to discriminate target signals from nontarget signals.</td>
</tr>
<tr>
<td>T-O-T Beta</td>
<td>Time-On-Task response bias, i.e., the output-related ability to inhibit (task-induced) biased response tendencies.</td>
</tr>
<tr>
<td>WM Capacity</td>
<td>The central cognitive ability to maintain and compare increasing information load in working memory (WM).</td>
</tr>
<tr>
<td>Inhibition of Prepotent Responses</td>
<td>The output-related ability to inhibit an inappropriate, habitual response tendency.</td>
</tr>
<tr>
<td>Attentional Flexibility</td>
<td>The central cognitive ability to mentally switch between two competing and unpredictable response sets.</td>
</tr>
</tbody>
</table>

Group differences in information processing performance were then tested by a series of univariate analyses of covariance (GLM, ANCOVA, SPSS) with group (respectively NO versus INT, NO vs. EXT, NO vs. COM, INT vs. COM, EXT vs. COM, and INT vs. EXT) and gender as between-subject variables and age as covariate. Additionally, as the INT group shows some externalizing behavior and the EXT group some internalizing behavior, externalizing and internalizing problem scores were entered as a covariate in, respectively, the NO vs. INT and NO vs. EXT comparisons. Furthermore, as the INT and EXT group differ slightly in severity of problems (see Table 1), CBCL Total Problems score was used as a
covariate in the INT vs. EXT comparisons. Finally, in a separate run of the analyses, IQ was entered as a covariate (in addition to above-mentioned covariates). All tests were two-tailed using a $p < .05$ level of statistical significance. Because of our large sample and the use of multiple tests, statistically significant group differences were considered meaningful only if the accompanying effect size was at least small (i.e., Cohen’s $d \geq 0.20$) (Cohen, 1988, pp. 24-26). Cohen’s $d$ was computed with a version of Cohen’s formula suitable for comparing covariate adjusted group means, while simultaneously accounting for the potential effect of unequal group sizes (Lipsey & Wilson, 2001, pp. 180 and 198).

Group performances were visualized by first converting the RT- and accuracy measures into gender-specific age-adjusted (and in a separate run age- and IQ-adjusted) z-scores and subsequently plotting the group means in a line chart. The correction for potential main effects of gender and age enhances the interpretability of these charts through a focus on merely problem behavior-related differences in performance.
RESULTS

INFORMATION PROCESSING CAPACITIES related to the SEVERITY of PROBLEM BEHAVIOR

Figure 1 shows the gender-specific age-adjusted group means for the RT- and accuracy measures respectively. The univariate tests comparing the groups differing most in severity but not in type of problem behavior, i.e., NO vs. COM, revealed statistically significant differences with small effect sizes for five of the RT- and one of the accuracy measures. As compared to the NO group, the COM group demonstrated a lower baseline speed of responding (Baseline Speed, $F(1, 1606)= 6.80, p = .009, d = 0.21$), needed more time for the controlled serial search process necessary when processing hardly distinguishable visuo-spatial patterns (Pattern Search, $F(1, 1594)= 9.39, p = .002, d = 0.27$), and was less able to maintain a stable performance over a prolonged period of time (Fluctuation in Tempo, $F(1, 1604)= 31.80, p < .001, d = 0.48$). Furthermore, the COM group showed a longer delay in responses following feedback on errors (Feedback Responsiveness, $F(1, 1601)= 5.61, p = .018, d = 0.22$), needed more time to process increased informational load in their working memory (WM Capacity, $F(1, 1608)= 20.77, p < .001, d = 0.38$), and displayed a greater time-on-task dependent decline in perceptual sensitivity (Time-On-Task D', $F(1, 1579)= 4.95, p = .026, d = 0.21$).

In line with decreasing severity of problem behavior, the EXT and INT group performed intermediate to the COM and NO group on these six measures (see Figure 1). However, the EXT group differed from the NO group on only the RT-measures Pattern Search ($F(1, 1627)= 7.05, p = .008, d = 0.22$) and Fluctuation in Tempo ($F(1, 1637)= 11.21, p = .001, d = 0.26$) and did not differ from the COM group. In contrast, the INT group did not differ from the NO group but differed from the COM group on the RT-measures Fluctuation in Tempo ($F(1, 378)= 13.05, p < .001, d = 0.38$) and WM Capacity ($F(1, 378)= 4.85, p = .028, d = 0.23$).

Most group differences lost significance ($p \geq .05$ and/or $d < 0.20$) after additional adjustment for IQ, with the exception of the NO vs. COM and INT vs. COM differences on Fluctuation in Tempo (respectively, $F(1, 1603)= 22.66, p < .001, d = 0.40$ and $F(1, 377)= 6.92, p = .009, d = 0.28$) and the NO vs. COM difference on WM Capacity ($F(1, 1607)= $).
Figure 1. Information processing profiles.
Note. Group differences at p < .05 and d ≥ 0.20 are marked by letter combinations, i.e., NI: NO vs. INT, NE: NO vs. EXT, NC: NO vs. COM, IC: INT vs. COM, EC: EXT vs. COM, and IE: INT vs. EXT. Differences observed for Baseline Speed do not account for differences on other RT-measures as this was automatically corrected for in the computation of these measures.
15.99, \( p < .001, \ d = 0.33 \) (see Figure 2). Although boys and girls were unevenly distributed across groups, none of the group comparisons showed a significant interaction with gender.

**INFORMATION PROCESSING CAPACITIES related to the DIRECTION of PROBLEM BEHAVIOR**

The univariate tests comparing the two groups differing in type of problem behavior, i.e., INT vs. EXT, resulted in only one RT-measure showing a significant though small group effect. Children scoring high on externalizing problems were less able to quickly inhibit prepotent responses as compared to children with high internalizing problems (Inhibition of Prepotent Responses, \( F(1, 407) = 4.04, \ p = .045, \ d = 0.20 \)). This effect was independent of gender but it was no longer significant after additional adjustment for IQ (\( p = .257, \ d = 0.08 \)) (see Figure 2).
Figure 2. Information processing profiles after controlling for IQ. Note. Group effects are indicated as in Figure 1.
DISCUSSION

This study presented information processing profiles and comparisons of ten- to twelve-year-olds differing in severity as well as type of parent-rated behavior problems. With respect to the severity of problem behavior, children with co-occurring internalizing and externalizing problems performed least efficiently on six aspects of information processing. In contrast, the performance of children with only externalizing problems was less deviant and confined to only two of these capacities, whereas the children with only internalizing problems did not differ at all from the children without problems. Furthermore, the ability to inhibit prepotent responses was found to be related to the direction of behavior problems, discriminating the children with internalizing problems from those with externalizing problems. Noteworthy, virtually all of the markers concerned speed rather than accuracy of information processing. Considering the self-paced and simple character of our tasks, this indicates that the children in our problem groups are capable of performing accurately provided that they are given sufficient time to respond. Daily life, however, necessitates quick and complex (re)actions, and needing more processing time than children without behavior problems places the affected children at a clear disadvantage in which they most likely will resort to trading accuracy for speed.

Consistent with previous population-based studies (Anderson et al., 1989; Frost et al., 1989; Kusché et al., 1993), more and most pronounced cognitive processing deficits were found for the children with co-occurring internalizing and externalizing problems as compared to children with either internalizing or externalizing problems. These children showed the most marked deficit in the ability to keep up a stable performance over a prolonged period of time. Intra-individual response variability is suggested to reflect difficulties in consistently applying the amount of effort necessary for a stable and efficient task performance (Oosterlaan & Sergeant, 1996) and is increasingly put forward as an important marker of brain pathology (e.g., Bellgrove, Hester, & Garavan, 2004). Our findings suggest that increasing severity of symptomatology is marked by greater variability in speed of responding. This is consistent with results from Swaab-Barneveld and colleagues (2000) who administered the same task paradigm and found that 6- to 13-year-olds with various types of psychiatric diagnoses showed greater response variability than control children. During continuous task performance, albeit less pronounced, children
with co-occurring problems also showed a stronger decrease in perceptual sensitivity and delayed responses following feedback on errors. Further research is needed to investigate how these deficiencies observed during continuous performance might relate to each other.

The second pronounced severity marker concerns the ability to maintain and compare increasing informational load in working memory. The same pattern, though to a lesser extent, was seen for visuo-spatial pattern search which also strains the working memory ability of serially comparing information. Working memory is a crucial aspect of all complex cognitive functions and deficits in working memory have been reported across the psychiatric domain, yet with most studies focusing on externalizing type disorders (e.g., Cauffman, Steinberg, & Piquero, 2005; Séguin, Boulerice, Harden, Tremblay, & Phil, 1999).

The present study is the first to examine the effects of ‘pure’ internalizing and ‘pure’ externalizing behavior and found that the processing deficits were less severe and confined to fewer capacities for the children with only externalizing problems, whereas no deficits were found for children with only internalizing problems. It may be that the children with only internalizing problems showed no deficits because their problems are less severe than externalizing and co-occurring internalizing and externalizing problems as is corroborated here by lower mean problem scores and mental health care utilization rates. Additionally, these findings may imply that internalizing problems, at least when not co-occurring with {many} other problems, are unrelated to deficits in fundamental information processing capacities that do not demand evaluation and interpretation of emotionally meaningful information (see also, Werry, Elkind, & Reeves, 1987).

Unlike previous population-based studies, the present study identified the ability to inhibit inappropriate behavioral responses as a cognitive direction marker of problem behavior. This is in line with studies on response inhibition as measured with the Stop Signal Task (Logan, Cowan, & Davis, 1984), finding children with externalizing problems to need more time to inhibit responses, whereas some support for enhanced response inhibition - though less consistent - was found for internalizing children (Kooijmans, Scheres, & Oosterlaan, 2000; Oosterlaan & Sergeant, 1998). This finding bears clinical relevance considering that internalizing and externalizing problems can also be characterized in terms of, respectively, over-controlled and under-controlled behavior.
After controlling for group differences in IQ, only response variability and working memory performance remained significant severity markers. However, as was stated earlier, the appropriateness of statistically controlling for IQ is a complex theoretical issue (see also, Doyle, Wilens, et al., 2005; Kuntsi, Oosterlaan, & Stevenson, 2001). On the one hand, it can be argued that IQ is an index of general ability, the effect of which should be removed to ensure that information processing deficits are not attributable to low general ability. On the other hand, it is also possible that deficits in information processing contribute directly or indirectly to poor performance on measures of IQ. Controlling for IQ would then unduly remove variance that is inherent to information processing itself. Although this debate remains unresolved, IQ and information processing have been found to share a common genetic basis (Plomin & Spinath, 2002) indicating that correction for IQ might jeopardize studying information processing as core cognitive processing. Moreover, considering our findings, we argue that even the processing capacities that share variance with IQ are informative when investigating the relationships between cognitive processing and problem behavior, because specific information processing capacities may have more explanatory value than IQ.

Greater response variability and deficits in working memory and response inhibition have also frequently been associated with Attention-Deficit/Hyperactivity Disorder (ADHD; e.g., Barkley, 1999; Castellanos & Tannock, 2002; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005) suggesting that these deficits are characteristic of all disruptive behavior problems. Yet, as aggressive and rule-breaking behavior problems often co-occur with attention and activity problems, further research is needed to investigate the (lack of) specificity of these findings as processing deficits reported in ADHD might be due to co-occurring externalizing problems and conversely, the deficits found in children with externalizing problems might be due to co-occurring ADHD-symptomatology.

**LIMITATIONS**

The findings of the present study should be interpreted in light of the following limitations. First, groups were formed on the basis of parent-reported behavior problems only. Additional insights may be obtained by making use of other informants. Second, as the neuropsychological tasks were administered in a fixed order, we cannot entirely rule out
potential influences of order effect or fatigue. Group differences were nonetheless found at the beginning, middle, and end of the battery suggesting that these factors did not bias the findings. Third, although we found several relationships between information processing and problem behavior, our cross-sectional data preclude causal inferences.

**CLINICAL IMPLICATIONS**

This comprehensive investigation of the relationships between multiple aspects of information processing and the broad-band internalizing and externalizing behavior dimensions identified specific information processing capacities as markers of the severity and type of problem behavior within a large unselected general population sample of preadolescents. Overall, more severity than direction markers could be identified suggesting that cognitive processing deficits are more strongly related to the degree of maladaptive behavior per se than to the type of problems. More specifically, results suggest that response variability and working memory may serve as potential markers for identifying high-risk children, whereas response inhibition may serve as a marker of the type of maladaptive behavior.

**ACKNOWLEDGEMENTS**

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CHAPTER 4

ADH and OD/C PROBLEMS in a GENERAL POPULATION SAMPLE of PREADOLESCENTS:
SPECIFIC INFORMATION PROCESSING DEFICITS?

OBJECTIVE: This study investigated how several input-, central cognitive-, and output-related information processing capacities are related to Attention-Deficit/Hyperactivity (ADH) and Oppositional Defiant/Conduct (OD/C) problems in a population-based sample of ten- to twelve-year-olds. METHODS: DSM-IV-oriented ADH and OD/C problems were assessed by the Child Behavior Checklist and the efficiency of various information processing capacities was evaluated by measures of speed and accuracy of the Amsterdam Neuropsychological Tasks program. Information processing profiles were examined in children with (1) neither ADH nor OD/C problems \((n = 1378)\), (2) only ADH problems \((n = 151)\), (3) only OD/C problems \((n = 243)\), and (4) both ADH and OD/C problems \((n = 261)\). RESULTS: A lower baseline speed, less efficient visuo-spatial pattern recognition, greater response variability, and lower working memory capacity were uniquely related to the presence of ADH problems. No deficiencies were found for the OD/C group. Inhibition of prepotent responses, perceptual sensitivity, and attentional flexibility also discriminated the ADH from the ‘neither symptoms’ yet not from the OD/C group. Results were similar for boys and girls, age and co-occurring internalizing problems were taken into account. CONCLUSIONS: It is the presence of ADH and not OD/C symptomatology that accounts for information processing deficits.
INTRODUCTION

Attention-Deficit/Hyperactivity Disorder (ADHD), Oppositional Defiant Disorder (ODD), and Conduct Disorder (CD) are common disruptive behavior disorders, estimated to affect 1 to 14% of children and adolescents from the general population (American Psychiatric Association, 1994; Faraone, Sergeant, Gillberg, & Biederman, 2005; Maughan, Rowe, Messer, Goodman, & Meltzer, 2004). As these disruptive behaviors frequently co-occur, i.e., in 30 to 50% of cases (e.g., Angold, Costello, & Erkanli, 1999; Biederman, Newcorn, & Sprich, 1991), considerable debate has risen about their distinctive properties. A key aspect in this debate concerns the specificity of the cognitive deficits associated with these disorders.

Studies of cognitive functioning generally focus on so-called ‘Executive Functioning (EF)’, which is an umbrella term referring to a range of higher-order cognitive processes such as cognitive flexibility, response inhibition, verbal fluency, working memory, and planning that allow for goal-oriented behavior (Pennington & Ozonoff, 1996). A recent review of the extensive literature on EF in ADHD concludes that children and adolescents with ADHD exhibit significant impairments across all EF domains but show the strongest and most consistent deficits on measures of response inhibition, vigilance, working memory, and planning (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005; see also Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Sergeant, Geurts, & Oosterlaan, 2002). EF has been studied relatively less in ODD and CD, here denoted as ODD/CD. Yet, although findings are less equivocal, analogous EF deficits have been associated with ODD/CD (for reviews, see Moffitt, 1993; Pennington & Ozonoff, 1996; Sergeant et al., 2002; see also Oosterlaan, Logan, & Sergeant, 1998; Séguin, Boulerice, Harden, Tremblay, & Phil, 1999; Swaab-Barneveld et al., 2000; Toupin, Déry, Pauzé, Mercier, & Fortin, 2000). To date, however, it remains unclear whether the same cognitive processing deficits underlie both disorders or whether specific processing deficits are uniquely associated with the presence of either ADHD or ODD/CD.

One reason for this lack of information may be that the majority of previous studies have not considered the possible impact of co-occurring problems on their findings (Angold et al., 1999; Sergeant et al., 2002). Studies reporting EF deficits in children with ODD/CD have rarely controlled for the effect of co-occurring attention and activity...
problems, thereby allowing for the possibility that the presence of co-occurring (subthreshold) ADH problems accounted for the EF deficits found (Pennington & Ozonoff, 1996) and vice versa for studies focusing on ADHD. Nevertheless, several studies have compared the EF performance of children with ADHD, ODD/CD, and co-occurring ADHD and ODD/CD problems and found deficits only for the ADHD and ADHD + ODD/CD, but not the ODD/CD, groups suggesting that EF deficits are uniquely associated with the presence of ADHD (Clark, Prior, & Kinsella, 2000; Klorman et al., 1999; Schachar, Mota, Logan, Tannock, & Klim, 2000; Oosterlaan, Scheres, & Sergeant, 2005). Furthermore, the few studies that did adjust for subthreshold ODD/CD problems found that the ADHD-related EF deficits were independent of ODD/CD (Nigg, 1999; Oosterlaan et al., 2005; Seidman, Biederman, Faraone, Weber, & Ouelette, 1997). Conversely, some studies have found ODD/CD to still be associated with deficits in working memory and planning after statistically controlling for ADHD (Séguin et al., 1999; Toupin et al., 2000). Moreover, even though it has been demonstrated that ADHD as well as ODD/CD also show considerable overlap with internalizing disorders (Biederman et al., 1991; Bird, Gould, & Staghezza, 1993), this type of co-occurring problems has rarely been taken into account either.

A second factor that may obscure the specificity of cognitive deficits is the typical operationalization of executive functions. Executive functions are often measured with neuropsychological tests that assess the product of multiple more elementary cognitive processes (Nigg, 2005). Decomposition of this product may be realized by adopting reaction time (RT) paradigms that incorporate simple within-task manipulations enabling the selective measurement of specific cognitive processes also referred to as information processing capacities (Sergeant, Oosterlaan, & Van der Meere, 1999). These paradigms, moreover, provide rigorous control over task administration (e.g., stimulus presentation) and a fine-grained collection of data on processing speed and accuracy, thereby reducing measurement error and enabling the assessment of even subtle inter-individual differences in information processing (see also, Doyle, Faraone et al., 2005; Sergeant et al., 2002).

Third and finally, a clear-cut interpretation is further complicated by the fact that most previous studies have compared highly-selected samples such as referred versus non-referred or delinquent vs. non-delinquent children. Moreover, these samples were small and encompassed wide age ranges, thereby lacking sufficient statistical power to
adequately examine confounding effects. Large general population samples have been suggested to be preferable over small and highly-selected samples as referral biases make such populations unrepresentative of the general population of disordered children and often contain an overrepresentation of subjects with more severe and comorbid symptomatology (Caron & Rutter, 1991; Goodman et al., 1997).

The present study adds to previous research in that it used a large, unselected population sample of ten- to twelve-year-olds which allowed for taking possible confounding effects of gender, age and co-occurring behavior problems into account. Moreover, because daily life continuously requires us to perceive, evaluate, and react to information, the present study provides data of several RT-paradigms assessing input-related processes (detection, discrimination, and selection), as well as more central cognitive (serial search, sustained attention, and feedback-related effort allocation), and output-related processes (response organization and response inhibition) (Mulder, 1986; Sanders, 1983; Sergeant, 2005).

This study was designed to address three issues: (1) to investigate whether, within the general population of preadolescents, children with only ADH problems as well as children with only OD/C problems and children with co-occurring ADH and OD/C problems encounter performance deficiencies when compared to children with neither ADH nor OD/C problems, (2) to determine whether the only ADH and only OD/C problem group differ in the type and/or severity of these deficits, and (3) to examine whether children with co-occurring ADH and OD/C problems can be discriminated from children with either ADH or OD/C problems on the basis of their information processing performance. This typological approach of identifying groups of persons based on the presence or absence of problem behavior is closely related to clinical practice and provides a straightforward and easily interpretable alternative to the more common variable-centered approach (Mandara, 2003). As there is an ongoing debate on whether one should control for general cognitive ability when investigating specific cognitive processes (see discussion in Doyle, Wilens et al., 2005), we analyzed our data both with and without controlling for IQ. To our knowledge, this study is unique in its attempt to establish specificity within the disruptive behavior problems domain at a fundamental information processing level in a general population sample.
METHODS

SAMPLE
The present study reports data from the first assessment wave of the TRacking Adolescents’ Individual Lives Survey (TRAILS), an ongoing cohort study investigating the development of mental health from preadolescence into adulthood. From March 2001 to July 2002, 3145 ten- to twelve-year-olds living in five municipalities in the North of the Netherlands, including both urban and rural areas, were approached for enrollment in the study. Children were excluded if they were incapable to participate due to mental retardation or a serious physical illness or handicap; or if no Dutch-speaking parent or parent surrogate was available, and it was not feasible to administer part of the measurements in the parent’s language ($N = 210, 6.7\%$). Of the remaining 2935 children, 76.0\% ($N = 2230, \text{mean age} = 11.09, SD = 0.55, 50.8\% \text{ girls}$) agreed to participate. Written parental consent was obtained before participation. Responders and non-responders did not differ with respect to the prevalence of teacher-rated problem behavior, nor regarding associations between socio-demographic variables and mental health outcomes (De Winter et al., 2005). The present study selected those children for whom both parent-reported behavior problems and information processing data were available ($n = 2033$, i.e., 91.2\% of the TRAILS sample).

TRAILS is approved by the Dutch Central Committee on Research Involving Human Subjects. Detailed information on sample selection and characteristics is provided elsewhere (De Winter et al., 2005; Oldehinkel, Hartman, De Winter, Veenstra, & Ormel, 2004).

PROCEDURE and MEASURES
BEHAVIOR PROBLEMS. Parent-reported (96\% mothers) behavior problems were assessed by means of the Child Behavior Checklist (CBCL/6-18; Achenbach & Rescorla, 2001). In addition to the original syndrome scales, Achenbach and colleagues (Achenbach, Dumenci, & Rescorla, 2003) developed several DSM-IV-oriented problem scales that correspond to the following clinical diagnostic categories: i.e., the Affective Disorders, Anxiety Disorders, Somatoform Disorders, Attention-Deficit/Hyperactivity Disorder, Oppositional Defiant Disorder, and Conduct Disorder (American Psychiatric Association, 1994). For the present study, the Affective, Anxiety, and Somatic Problem scales were
combined to form the broad-band Internalizing Problems dimension, whereas the Oppositional Defiant and Conduct Problems scales were combined to form an Oppositional Defiant/Conduct Problems dimension. On the basis of the Attention-Deficit/Hyperactivity Problems and Oppositional Defiant/Conduct Problems dimensions, children were assigned to one of the following four groups: (1) no problems (NO: Attention-Deficit/Hyperactivity < P80 and Oppositional Defiant/Conduct < P80), (2) only Attention-Deficit/Hyperactivity problems (ADH: Attention-Deficit/Hyperactivity ≥ P80 and Oppositional Defiant/Conduct < P80), (3) only Oppositional Defiant/Conduct problems (OD/C: Attention-Deficit/Hyperactivity < P80 and Oppositional Defiant/Conduct ≥ P80), (4) co-occurring Attention-Deficit/Hyperactivity and Oppositional Defiant/Conduct problems (ADH + OD/C: Attention-Deficit/Hyperactivity ≥ P80 and Oppositional Defiant/Conduct ≥ P80). Group characteristics are presented in Table 1.

Table 1. Group Characteristics.

<table>
<thead>
<tr>
<th>Measures</th>
<th>NO (N)</th>
<th>ADH (A)</th>
<th>OD/C (O)</th>
<th>ADH+OD/C (C)</th>
<th>Pairwise group comparisons ¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>n = 1378</td>
<td></td>
<td>n = 151</td>
<td>n = 243</td>
<td>(C) n = 261</td>
<td></td>
</tr>
<tr>
<td>Gender ( % boys)</td>
<td>42.09</td>
<td>60.93</td>
<td>62.55</td>
<td>65.52</td>
<td>N &lt; A, O, C</td>
</tr>
<tr>
<td>Age (M (SD))</td>
<td>11.34</td>
<td>11.28</td>
<td>11.39</td>
<td>11.41</td>
<td>n.s.</td>
</tr>
<tr>
<td>(0.56)</td>
<td>(0.58)</td>
<td>(0.54)</td>
<td>(0.56)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IQ (M (SD))</td>
<td>99.56</td>
<td>93.91</td>
<td>97.96</td>
<td>91.33</td>
<td>C, A &lt; O, N</td>
</tr>
<tr>
<td>(14.55)</td>
<td>(14.21)</td>
<td>(14.65)</td>
<td>(13.49)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADH Problems (M (SD))</td>
<td>-0.48</td>
<td>1.33</td>
<td>0.04</td>
<td>1.72</td>
<td>N &lt; O &lt; A &lt; C</td>
</tr>
<tr>
<td>(0.60)</td>
<td>(0.43)</td>
<td>(0.50)</td>
<td>(0.65)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OD/C Problems (M (SD))</td>
<td>-0.49</td>
<td>0.11</td>
<td>1.06</td>
<td>1.67</td>
<td>N &lt; A &lt; O &lt; C</td>
</tr>
<tr>
<td>(0.51)</td>
<td>(0.46)</td>
<td>(0.49)</td>
<td>(0.99)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internalizing Problems (M (SD))</td>
<td>-0.25</td>
<td>0.18</td>
<td>0.38</td>
<td>0.86</td>
<td>N &lt; A, O &lt; C</td>
</tr>
<tr>
<td>(0.82)</td>
<td>(1.00)</td>
<td>(1.05)</td>
<td>(1.19)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mental health care use (%)</td>
<td>2.18</td>
<td>5.96</td>
<td>4.94</td>
<td>19.54</td>
<td>N &lt; O, A &lt; C</td>
</tr>
</tbody>
</table>

Note. ¹ Gender and mental health care use: Chi-square tests with asymptotic significance set at .01, other: ANOVA main effects for group with F(3, 2029), p < .01, and η² > .010 (a group contrasts set at .01). ² Mean item z-scores. ³ Percentage of children for whom parents have contacted a mental health care facility at least once in the last year on account of their child’s maladaptive behavior (type of problems are unknown).
INFORMATION PROCESSING. A variety of information processing capacities were assessed by measures of speed (RTs) and accuracy (error rates) derived from five tasks of the well-validated Amsterdam Neuropsychological Tasks program (ANT; De Sonneville, 1999). An extensive description of the tasks and resulting measures is provided in Appendix A. Children were tested individually for approximately 70 minutes (short breaks included) in a separate room at their school or, if this was not feasible, in a nearby community center. Tasks were administered by trained undergraduate psychologists who were ‘blind’ with respect to the children’s behavior problem scores. The children performed the following tasks in fixed order: (1) Baseline Speed measuring simple visuo-motor reaction time, (2) Pattern Recognition measuring automatic as well as controlled visuo-spatial pattern recognition, (3) Sustained Attention measuring response variability, perceptual sensitivity, response bias, and responsiveness to feedback on errors, (4) Memory Search measuring working memory capacity, and (5) Shifting Set measuring inhibition of prepotent responses as well as attentional flexibility. Before each task, children were shown a screenshot of relevant task characteristics and received verbal instructions, emphasizing both speed and accuracy of performance. Furthermore, practice trials were run prior to the administration of the test trials to ensure that the children understood the instructions. An overview of the measures can be found in Table 2. Inter-correlations were generally weak suggesting limited overlap between the measures (RT: mean $r = .23$ ranging from $r = .07$ to $r = .54$, accuracy: mean $r = .07$ ranging from $r = .01$ to $r = .46$).

INTELLIGENCE. The Vocabulary and Block Design subtests from the Revised Wechsler Intelligence Scales for Children (WISC-R; Van Haasen et al., 1986) were used to estimate Full Scale IQ for all children (Sattler, 1992).
Table 2. Overview of the information processing measures.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Measurement Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Speed</td>
<td>The ability to detect and respond to a stimulus (simple reaction time).</td>
</tr>
<tr>
<td>Pattern Search</td>
<td>The central cognitive ability to detect a visuo-spatial target pattern among barely distinguishable (similar) visuo-spatial patterns.</td>
</tr>
<tr>
<td>Pattern Detection</td>
<td>The input-related ability to automatically detect a visuo-spatial target pattern sticking out among easily distinguishable (dissimilar) visuo-spatial patterns.</td>
</tr>
<tr>
<td>Fluctuation in Tempo</td>
<td>The central cognitive ability to maintain a stable performance over a prolonged period of time (response variability).</td>
</tr>
<tr>
<td>Feedback Responsiveness</td>
<td>The central cognitive ability to adjust response behavior following feedback on errors.</td>
</tr>
<tr>
<td>T-O-T D’</td>
<td>Time-On-Task perceptual sensitivity, i.e., the input-related ability to discriminate target signals from nontarget signals.</td>
</tr>
<tr>
<td>T-O-T Beta</td>
<td>Time-On-Task response bias, i.e., the output-related ability to inhibit (task-induced) biased response tendencies.</td>
</tr>
<tr>
<td>WM Capacity</td>
<td>The central cognitive ability to maintain and compare increasing information load in working memory (WM).</td>
</tr>
<tr>
<td>Inhibition of Prepotent Responses</td>
<td>The output-related ability to inhibit an inappropriate, habitual response tendency.</td>
</tr>
<tr>
<td>Attentional Flexibility</td>
<td>The central cognitive ability to mentally switch between two competing and unpredictable response sets.</td>
</tr>
</tbody>
</table>

ANALYSES

First, scores on each RT- and accuracy measure with an absolute z-score ≥ 4 were defined as outliers (Stevens, 2002, p.16). For each measure, these outliers and participants performing at chance level of accuracy, i.e., making 50% or more errors on any of the relevant task conditions, were dropped from subsequent analyses. These left-out participants did not differ from the remaining sample with respect to gender, age, IQ, or diagnostic group. Next, accuracy measures were logarithmically transformed to approximate normal distributions.
Group differences in information processing performance were tested by a series of univariate analyses of covariance (GLM, ANCOVA, SPSS) with group (respectively NO versus ADH, NO vs. OD/C, NO vs. ADH + OD/C, ADH vs. ADH + OD/C, OD/C vs. ADH + OD/C, and ADH vs. OD/C) and gender as between-subject variables, and age and internalizing problems as covariates. Additionally, because the ADH group shows some (subthreshold) oppositional defiant/conduct behavior as well (see Table 1), Oppositional Defiant/Conduct problems was entered as a covariate (in addition to age and internalizing problems) in the NO vs. ADH comparisons. Finally, in a separate run, IQ was entered as a covariate in addition to above-mentioned covariates. All tests were two-tailed using a $p < .05$ level of statistical significance. Because of our large sample and the use of multiple tests, statistically significant group differences were considered meaningful only if the accompanying effect size was at least small (i.e., Cohen’s $d \geq 0.20$) (Cohen, 1988, pp. 24-26).

Group performances were visualized by first converting the RT- and accuracy measures into gender-specific z-scores adjusted for age and internalizing problems (and IQ, added in a separate run) and then plotting the various group means in a line chart. The correction for potential effects of gender, age, and internalizing problems enhances the interpretability of these charts by focusing merely on disruptive behavior-related differences in performance.
RESULTS

ADH, OD/C, ADH + OD/C vs. NO PROBLEMS

The children with only ADH problems showed performance deficiencies on six RT-measures and two accuracy measures (see Figure 1). As compared to the NO group, the ADH group was generally slower (Baseline Speed, $F(1, 1516)= 9.32$, $p = .002$, $d = 0.24$) and demonstrated a slower automatic (Pattern Detection, $F(1, 1500)= 11.53$, $p = .001$, $d = 0.30$), as well as controlled (Pattern Search, $F(1, 1503)= 10.26$, $p = .001$, $d = 0.25$) visuo-spatial pattern recognition. They additionally exhibited a greater response variability during continuous task performance (Fluctuation in Tempo, $F(1, 1513)= 18.94$, $p < .001$, $d = 0.32$) and needed more time to maintain and compare increased informational load in working memory (WM Capacity, $F(1, 1515)= 7.84$, $p = .005$, $d = 0.24$) as well as to inhibit inappropriate behavioral responses (Inhibition of Prepotent Responses, $F(1, 1512)= 4.43$, $p = .036$, $d = 0.20$). Furthermore, the ADH group showed a greater time-on-task-dependent decrease in perceptual sensitivity (Time-On-Task D', $F(1, 1491)= 5.59$, $p = .018$, $d = 0.20$) and was less accurate when switching between two competing and unpredictable response sets (Attentional Flexibility, $F(1, 1479)= 6.90$, $p = .009$, $d = 0.21$).

In contrast, the children with only OD/C problems performed closely around the sample mean and did not differ from the children with neither ADH nor OD/C problems (all $p$s $\geq .05$ and/or $d$s $< 0.20$). The children with co-occurring ADH and OD/C problems did perform worse than the children without behavior problems on three RT-measures, i.e., Pattern Search ($F(1, 1610)= 24.35$, $p < .001$, $d = 0.31$), Fluctuation in Tempo ($F(1, 1624)= 49.77$, $p < .001$, $d = 0.43$), and WM Capacity ($F(1, 1627)= 17.81$, $p < .001$, $d = 0.23$).

Most group differences lost significance ($p \geq .05$ and/or $d < 0.20$) after additionally covarying for IQ, with the exception of the NO vs. ADH differences on Pattern Detection and Fluctuation in Tempo (respectively, $F(1, 1499)= 4.46$, $p = .035$, $d = 0.20$ and $F(1, 1512)= 10.34$, $p = .001$, $d = 0.22$) and the NO vs. ADH + OD/C difference on Fluctuation in Tempo ($F(1, 1623)= 25.96$, $p < .001$, $d = 0.29$) (see Figure 2). Although boys and girls were unevenly distributed across groups, none of the group comparisons showed a significant interaction with gender.
Figure 1. Information processing profiles.
Note. Group differences at \( p < .05 \) and \( d \geq 0.20 \) are marked by letter combinations, i.e., NA: NO vs. ADH, NO: NO vs. OD/C, NC: NO vs. ADH + OD/C, AC: ADH vs. ADH + OD/C, OC: OD/C vs. ADH + OD/C, and AO: ADH vs. OD/C. Differences observed for Baseline Speed do not account for differences on other RT-measures as this was automatically corrected for in the computation of these measures.
CHAPTER 4

ADH vs. OD/C PROBLEMS

Group contrasts between the ADH and OD/C group showed that five of the eight measures discriminating between the ADH and NO group, also distinguished the OD/C from the ADH group, i.e., Baseline Speed ($F(1, 386)= 9.72, p = .002, d = 0.30$), Pattern Detection ($F(1, 385)= 7.06, p = .008, d = 0.31$), Pattern Search ($F(1, 386)= 4.73, p = .030, d = 0.23$), Fluctuation in Tempo ($F(1, 386)= 8.90, p = .003, d = 0.31$), and Working Memory Capacity ($F(1, 385)= 4.59, p = .033, d = 0.22$). ADH and OD/C groups could not be discriminated on the RT-measure Inhibition of Prepotent Responses and the accuracy measures Time-On-Task D’ and Attentional Flexibility ($0.383 \leq p \leq 0.460$). After additional adjustment for IQ, only Baseline Speed and Fluctuation in Tempo remained discriminating the ADH from the OD/C group (respectively, $F(1, 385)= 5.72, p = .017, d = 0.25$ and $F(1, 385)= 4.88, p = .028, d = 0.24$). Results were similar for boys and girls.

ADH and OD/C vs. ADH + OD/C PROBLEMS

None of the three measures significantly distinguishing the ADH + OD/C from the NO group, discriminated between the ADH + OD/C and ADH group (ps $\geq .05$ and ds $< 0.20$).

In contrast, these measures did discriminate the ADH + OD/C from the OD/C group: Pattern Search ($F(1, 492)= 9.57, p = .002, d = 0.28$), Fluctuation in Tempo ($F(1, 496)= 20.11, p < .001, d = 0.40$), Working Memory Capacity ($F(1, 496)= 5.27, p = .022, d = 0.20$). After controlling for IQ, only Fluctuation in Tempo still discriminated significantly between the two groups ($F(1, 495)= 10.15, p = .002, d = 0.29$). Again, no gender differences were found.
Figure 2. Information processing profiles after controlling for IQ. Note. Group effects are indicated as in Figure 1.
DISCUSSION

The main finding of the present study is that within the general population of preadolescents, Attention-Deficit/Hyperactivity problems, but not Oppositional Defiant/Conduct problems, are related to several information processing deficits. These results were obtained after controlling for the effects of age and co-occurring internalizing problems and were similar for boys and girls.

The deficiencies found to be specific for ADH problems in our sample correspond with frequently reported deficiencies in clinical samples with ADHD. Children with ADHD have been found to exhibit motor problems (Pitcher, Piek, & Hay, 2003) which may be reflected in a lower baseline speed of responding. Furthermore, although there is less support for a deficit in automatic visuo-spatial pattern detection (Huang-Pollock & Nigg, 2003), greater intra-individual variability of performance in ADHD has been observed across a wide variety of cognitive tasks and is considered to be a potentially important candidate cognitive endophenotypic marker for ADHD (e.g., Castellanos & Tannock, 2002). Moreover, the observed reduced ability to maintain and quickly compare verbal information in working memory as well as the slower pattern search straining the ability to compare visuo-spatial information in working memory corroborate findings from a meta-analysis on verbal and visuo-spatial working memory impairments in ADHD (Martinussen et al., 2005).

The present study also found children with only ADH problems to be deficient in inhibiting prepotent responses, perceptual sensitivity, and the accuracy of attentional flexibility which is also in line with the results of ADHD studies (e.g., Oosterlaan, Logan, & Sergeant, 1998; Slaats-Willemse, Swaab-Barneveld, De Sonneville, Van der Meulen, & Buitelaar, 2003; Swaab-Barneveld et al., 2000). These capacities, however, did not discriminate between the ADH and OD/C problems suggesting that compared to above-mentioned capacities, these capacities have relatively less discriminative value in the disruptive behavior domain.

After controlling for group differences in IQ, only response variability remained discriminating significantly. The appropriateness of statistically controlling for IQ is, however, a complex theoretical issue (see also, Doyle, Wilens et al., 2005; Kuntsi, Oosterlaan, & Stevenson, 2001). On the one hand, it can be argued that IQ is an index of general ability,
the effect of which should be removed to ensure that information processing deficits are not attributable to low general ability. On the other hand, it is also possible that deficits in information processing contribute to poor performance on measures of IQ. Controlling for IQ would then unduly remove variance that is inherent to information processing itself. Although this debate remains unresolved, IQ and information processing have been found to share a common genetic basis (Plomin & Spinath, 2002) indicating that correction for IQ might jeopardize studying information processing as core cognitive processing.

Considering our findings, we argue that even the processing capacities that share variance with IQ are informative when investigating the relationships between cognitive processing and problem behavior, as these specific processing deficits may be of greater value in elucidating the phenotype than IQ. In this context, it is noteworthy that the majority of the performance deficiencies concerned the speed rather than the accuracy of information processing. Considering the self-paced and simple character of our tasks, this suggests that children with ADH problems are capable of performing accurately provided that they are given sufficient time. Daily life, however, necessitates quick and complex (re)actions, and needing more processing time than children with no or OD/C problems places the affected children at a clear disadvantage in which they most likely will resort to trading accuracy for speed.

The present study did not find OD/C problems to be related to deficiencies in information processing. Furthermore, the performance of the children with co-occurring ADH and OD/C problems support that the presence of ADH, rather than OD/C, problems accounted for the deficiencies. This corroborates results obtained by recent EF studies (Clark et al., 2000; Oosterlaan et al., 2005). Moreover, our study shows that it is unlikely that these findings merely reflect group differences in symptom severity, as the children with both ADH and OD/C problems were the most severely affected but did not demonstrate the most prominent cognitive impairment.

LIMITATIONS

The findings of the present study should be interpreted in light of the following limitations. First, groups were formed on the basis of parent-reported behavior problems only. Additional insights may be obtained by making use of other informants. Second, the ADH
problems of the present study are ADHD-Combined Type symptoms (American Psychiatric Association, 1994). More research is needed to determine whether our findings are equally valid for children with only ADHD-Inattentive Type and only ADHD-Hyperactive/Impulsive Type symptoms. Third, the DSM-IV conceptualizes ODD and CD as separate disorders characterized by, respectively, a pattern of negativistic, hostile, and defiant behavior and a pattern of behavior that violates the basic rights of others or major age-appropriate societal norms and rules (American Psychiatric Association, 1994). Yet, despite this distinction, ODD and CD are often combined in research as ODD is suggested to be a ‘developmental precursor’ or a ‘milder variant’ of CD (see e.g., Rowe, Maughan, Pickles, Costello, & Angold, 2002; Schachar & Wachsmuth, 1990). The present study found that a combination of ODD and CD symptoms was unrelated to information processing deficits. Future studies that investigate oppositional defiant and conduct problems separately, however, are needed to support this finding.

CLINICAL IMPLICATIONS
The findings of the present study suggests that the presence of ADH, but not OD/C, problems accounts for information processing deficiencies within a large, unselected sample of ten- to twelve-year-olds. Results corroborate recent findings on EF measures in clinical samples and indicate that despite the high co-occurrence of ADH and OD/C symptomatology, both disorders have distinctive cognitive features. Taken the study’s limitations into account, our findings may facilitate the targeting of interventions and provide information in support of theory construction as within the diagnostic criteria of DSM-IV, the concept of attention is not formally defined in cognitive terms.
ACKNOWLEDGEMENTS

This research is part of the TRacking Adolescents’ Individual Lives Survey (TRAILS). The authors are grateful to all participating children, parents, and teachers. Furthermore, the authors thank Prof. dr. T.A.B. Snijders for his statistical advice. Collaborating centers of TRAILS include various Departments of the University of Groningen, the Erasmus Medical Center of Rotterdam, the University of Nijmegen, the Trimbos Institute, and the University of Utrecht, The Netherlands. TRAILS is financially supported by grants from the Netherlands Organization for Scientific Research (GB-MW 940-38-011, GB-MAG 480-01-006, ZonMw 100.001.001, NWO 175.010.2003.005), the Department of Justice (WODC), and by the participating centers.
CHAPTER 5

DIFFERENTIATING INFORMATION PROCESSING PROFILES of ATTENTION-DEFICIT/HYPERACTIVITY SUBTYPES within a GENERAL POPULATION SAMPLE of PREADOLESCENTS

This chapter has been submitted as: Brunnekreef, J.A., De Sonneville, L.M.J., Althaus, M., Minderaa, R.B., Verhulst, F.C., & Ormel, J. Differentiating Information Processing Profiles of Attention-Deficit/Hyperactivity Subtypes within a General Population Sample of Pre-adolescents.
ABSTRACT

This study compared the information processing performance of ten- to twelve-year-olds from the general population showing (1) no Attention-Deficit/Hyperactivity (ADH) problems (NO, \( n = 1266 \)), (2) only attention problems (ADH-I, \( n = 116 \)), (3) only hyperactivity/impulsivity problems (ADH-H, \( n = 150 \)), and (4) combined attention and hyperactivity/impulsivity problems (ADH-C, \( n = 202 \)). ADH problems were assessed by the Child Behavior Checklist and Teacher Checklist of Psychopathology, and multiple information processing capacities were evaluated by the Amsterdam Neuropsychological Tasks program. After controlling for co-occurring internalizing and externalizing problems, ADH-I exhibited a lower baseline speed, greater response variability, and a less efficient working memory as compared to both NO and ADH-H. No deficiencies were found for ADH-H, not even on response inhibition, which instead showed a trend for ADH-I. ADH-C did not differ from the ADH-I group, although ADH-C appeared somewhat less affected. Findings were similar for both genders and indicate that symptoms of inattention, rather than of hyperactivity/impulsivity, are related to information processing deficits suggesting that the Hyperactive/Impulsive Type may be etiologically different from the Inattentive and Combined Types.
INTRODUCTION

Current clinical practice conceptualizes Attention-Deficit/Hyperactivity Disorder (ADHD) as comprising three distinct subtypes: a predominantly Inattentive, a predominantly Hyperactive/Impulsive, and a Combined Inattentive and Hyperactive/Impulsive Type (DSM-IV; American Psychiatric Association, 1994). Validating support for this subdivision comes from studies showing these subtypes to differ significantly in behavioral and demographic characteristics, level of social and academic impairment, and rate of co-occurrence with other childhood disorders (Carlson, Shin, & Booth, 1999; Faraone, Biederman, Weber, & Russel, 1998; Gaub & Carlson, 1997; Graetz, Sawyer, Hazell, Arney, & Baghurst, 2001; Lahey et al., 1994). Yet to date, little is known about the potential differences among the three subtypes in cognitive processing.

The majority of extant literature has attempted to identify the dysfunctions in aspects of attention and higher-order cognitive processes subserving the co-occurrence of inattention and hyperactivity/impulsivity symptoms (e.g., Barkley, 1997; Castellanos, Sonuga-Barke, Milham, & Tannock, 2006; Douglas, 1983; Nigg, 2005; Sergeant, Geurts, Huijbregts, Scheres, & Oosterlaan, 2003; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Yet increasingly, it is suggested that the inattention symptoms of the Inattentive Type are qualitatively different from those of the Combined Type and that the Inattentive Type may be better classified as a separate, different disorder (Barkley, 1997; Milich, Balentine, & Lynam, 2001). On a cognitive level, it has been postulated that the inattention symptoms of the Inattentive Type are characterized by a general deficit in speed of cognitive processing and a specific deficit in focused or selective attention, whereas the inattention symptoms of the Combined Type are marked by a deficit in sustained attention (Barkley, DuPaul, & McMurray, 1990; Barkley, 1997). However, studies comparing the Combined and Inattentive Types, or the somewhat comparable DSM-III ADD with and without Hyperactivity subtypes (Morgan, Hynd, Riccio, & Hall, 1996), on these processes have provided highly inconsistent results (compare e.g., Collings, 2003; Goodyear & Hynd, 1992; Sergeant & Scholten, 1985; with Huang-Pollock & Nigg, 2003; Huang-Pollock, Nigg, & Carr, 2005; Hynd et al., 1989).

With respect to the hyperactivity/impulsivity symptoms, Barkley (1997; 1999) proposed that both the Hyperactive/Impulsive and Combined Type are characterized by a
core deficit in response inhibition which causes secondary impairments in other aspects of higher-order cognitive functioning (i.e., Executive Functioning or EF such as cognitive flexibility, verbal fluency, working memory, and planning). As the behavior of patients with lesions in the frontal lobes, which are thought to underlie EF, exhibits great similarities with the behavioral characteristics of ADHD, EF dysfunction has become the dominant paradigm in ADHD research over the last decade. Yet, available data comparing clinically diagnosed children with the Combined and Inattentive Types found only partial support for this model. The children with the Combined Type showed deficient response inhibition relative to controls but the children with the Inattentive Type often also performed deviant from controls or their performance could not be differentiated from that of the children with the Combined Type (Geurts, Verté, Oosterlaan, Roeyers, & Sergeant, 2005; Houghton et al., 1999; Nigg, Blaskey, Huang-Pollock, & Rappley, 2002).

Moreover, results are limited as only few studies have included the Hyperactive/Impulsive Type. Chhabildas and colleagues (2001), for example, found that symptoms of inattention, rather than symptoms of hyperactivity/impulsivity, are associated with impairments in response inhibition, vigilance, and processing speed with Inattentive and Combined Type showing similar profiles of impairment. These findings are corroborated by two studies that included both symptom dimensions in a regression model predicting executive dysfunction; each study found that inattention was significantly associated with EF weaknesses, whereas hyperactivity/impulsivity was not when the influence of inattention was controlled (Nigg et al., 2005; Oosterlaan, Scheres, & Sergeant, 2005).

All in all, there is currently no consensus as to which processing deficits are related to the co-occurrence of inattention and hyperactivity/impulsivity or are specific to either inattention or hyperactivity/impulsivity symptoms. This may in part be because inferences from one type of study to the other must be made with caution as studies often excluded female participants and included participants of wide age ranges or with co-occurring internalizing and externalizing behavior problems. Moreover, as not all children with ADH problems receive mental health care (Hoagwood, Kelleher, Feil, & Comer, 2000), clinical study samples often contain an overrepresentation of children with more severe and comorbid symptomatology (Caron & Rutter, 1991; Goodman et al., 1997). Further
hampering a clear-cut interpretation of ADHD subtype research may be the typical operationalization of cognitive processing in EF research. Executive functions are often measured with neuropsychological tests that assess the product of multiple cognitive processes (Nigg, 2005). It has been suggested that greater specificity may arise when dysfunctions in the contributing, more elementary, cognitive processes can be delineated (Klorman et al., 1999; Oosterlaan et al., 2005; Willcutt et al., 2005).

The present study assesses the specificity of information processing performance of DSM-IV subtypes of Attention-Deficit/Hyperactivity (ADHD) problems in a general population of preadolescents. To this end, the information processing performances were compared of ten- to twelve-year-olds with (1) no Attention-Deficit/Hyperactivity problems (n = 1266), (2) only Attention problems (n = 116), (3) only Hyperactivity/Impulsivity problems (n = 150), and (4) Combined Attention and Hyperactivity/Impulsivity problems (n = 202). Two key features distinguish this study from past investigations. First, our large and unselected sample is representative of the full population of children with ADHD problems and afforded the opportunity to apply stringent controls for possible confounders such as age and co-occurring (subthreshold) internalizing and externalizing problems. Because each subtype is more prevalent among boys but the proportion of girls is relatively higher in the Inattentive than in the other two subtypes (Wolraich, Hannah, Pinnock, Baumgaertel, & Brown, 1996), we additionally checked whether relationships were similar for boys and girls. Furthermore, as there is an ongoing debate on whether or not one should control for general cognitive ability when investigating specific cognitive processes (see discussion in Doyle, Wilens, et al., 2005), we analyzed our data both with and without controlling for IQ. Second, because daily life continuously needs us to perceive, evaluate, and react to information, we administered neuropsychological tasks assessing elementary input-, as well as more central cognitive-, and output-related processes that are assumed to form the basis of complex cognitive functions (Mulder, 1986; Sanders, 1983; Sergeant, 2005). These neuropsychological tasks are based on reaction time (RT) paradigms which offer a useful alternative to the product measures as they incorporate simple within-task manipulations that enable the selective measurement of relatively specific cognitive component processes also referred to as information processing capacities (De Sonnevile & Njokiktjien, 1993; Sergeant, Oosterlaan, & Van der Meere, 1999). Moreover, these tasks provide rigorous control over
task administration (e.g., stimulus presentation) and a fine-grained collection of data on processing speed and accuracy, thereby reducing measurement error and enabling the assessment of even subtle inter-individual differences in information processing (see also, Doyle, Faraone et al., 2005; Sergeant, Geurts, & Oosterlaan, 2002). Subtype-specific information processing profiles would not only provide external validity to the subtypes, but may also shed some light on the potential differential etiology and outcome of the different subtypes.
METHODS

SAMPLE
The present study reports data from the first assessment wave of the TRacking Adolescents’ Individual Lives Survey (TRAILS), an ongoing population cohort study investigating the development of mental health from preadolescence into adulthood. From March 2001 to July 2002, 3145 ten- to twelve-year-olds living in five municipalities in the North of the Netherlands, including both urban and rural areas, were approached for enrollment in the study. Children were excluded if they were incapable to participate due to mental retardation or a serious physical illness or handicap; or if no Dutch-speaking parent or parent surrogate was available, and it was not feasible to administer part of the measurements in the parent’s language (N = 210, 6.7%). Of the remaining 2935 children, 76.0% (N = 2230, mean age = 11.09, SD = 0.55, 50.8% girls) agreed to participate. Responders and non-responders did not differ with respect to the prevalence of teacher-rated problem behavior, nor regarding associations between socio-demographic variables and mental health outcomes (De Winter et al., 2005). The present study selected those children for whom both parent- and teacher-reported behavior problems and information processing data were available (n = 1734, i.e., 77.8% of the TRAILS sample). Detailed information on sample selection and characteristics is provided elsewhere (De Winter et al., 2005; Oldehinkel, Hartman, De Winter, Veenstra, & Ormel, 2004).

PROCEDURE and MEASURES

ATTENTION-DEFICIT/HYPERACTIVITY PROBLEMS. Parent-reported behavior problems were assessed by means of the Child Behavior Checklist (CBCL/6-18; Achenbach & Rescorla, 2001) with 96% of parental informants being mothers. The CBCL consists of 120 behavior problems to be scored on a 3-point scale based on the occurrence of the behavior during the preceding 6 months: 0 if the problem was not present, 1 if the item was somewhat or sometimes present, and 2 if it was very or often present. In addition to the original syndrome scales, Achenbach and colleagues (Achenbach & Dumenci, 2001; Achenbach, Dumenci, & Rescorla, 2003) developed several DSM-IV-oriented problem scales that correspond to the following clinical diagnostic categories: Affective Disorders, Anxiety Disorders, Somatoform Disorders, Attention-Deficit/Hyperactivity Disorder, Oppositional
Defiant Disorder, and Conduct Disorder (American Psychiatric Association, 1994). For the present study, an Internalizing Problems dimension was constructed from the Affective, Anxiety, and Somatic Problem scales and an Externalizing Problems dimension was constructed from the Oppositional Defiant Problems and Conduct Problems scales. Furthermore, the Attention-Deficit/Hyperactivity problems scale was subdivided into an ADH-Attention Problems and an ADH-Hyperactivity/Impulsivity Problems scale. Additionally, teacher-reported behavior problems were assessed by means of the Teacher Checklist of Psychopathology containing nine descriptions of problems behaviors which correspond with the empirically derived syndrome scales of the Teacher’s Report Form (TRF/4-18; Achenbach, 1991), i.e., Anxious/Depressed Behavior, Withdrawn Behavior, Somatic Complaints, Social Problems, Thought Problems, Attention Problems, Activity/Impulsivity Problems, Aggressive Behavior, Rule-Breaking Behavior. For each scale, teachers rated the children on a 5-point scale based on the occurrence of the behavior during the preceding 2 months; 0 if the problem item was not present, 1 if the item was rarely present, 2 if it was somewhat or sometimes present, 3 if it was present or often present, and 4 if it was very often present. Congruent to the parent ratings, Internalizing and Externalizing Problems dimensions were constructed. Subsequently, parent- and teacher-ratings were made comparable by converting them into z-scores and averaged in the construction of the following problem dimensions: Internalizing Problems, Externalizing Problems, Attention Problems, and Hyperactivity/Impulsivity Problems. On the basis of the Attention Problems and Hyperactivity/Impulsivity Problems dimensions, the children were assigned to one of the following four groups: (1) neither attention nor hyperactivity/impulsivity problems (NO: Attention Problems < P80 and Hyperactivity/Impulsivity Problems < P80), (2) only attention problems (ADH-I: Attention Problems ≥ P80 and Hyperactivity/Impulsivity Problems < P80), (3) only hyperactivity/impulsivity problems (ADH-H: Attention Problems < P80 and Hyperactivity/Impulsivity Problems ≥ P80), (4) co-occurring attention and hyperactivity/impulsivity problems (ADH-C: Attention Problems ≥ P80 and Hyperactivity/Impulsivity Problems ≥ P80). Group characteristics are presented in Table 1.
Table 1. Group Characteristics.

<table>
<thead>
<tr>
<th>Measures</th>
<th>NO (N) n = 1266</th>
<th>ADH-I (I) n = 116</th>
<th>ADH-H (H) n = 150</th>
<th>ADH-C (C) n = 202</th>
<th>Pairwise group comparisons 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (% boys)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N &lt; I, H, C</td>
</tr>
<tr>
<td>Age (SD)</td>
<td>11.31 (0.54)</td>
<td>11.36 (0.55)</td>
<td>11.31 (0.53)</td>
<td>11.35 (0.55)</td>
<td>n.s.</td>
</tr>
<tr>
<td>IQ (SD)</td>
<td>99.83 (14.60)</td>
<td>91.66 (14.69)</td>
<td>95.83 (12.23)</td>
<td>90.01 (13.05)</td>
<td>C, I, H &lt; N with C &lt; H</td>
</tr>
<tr>
<td>Attention Problems</td>
<td>-0.44 (0.63)</td>
<td>1.43 (0.43)</td>
<td>0.26 (0.54)</td>
<td>1.75 (0.50)</td>
<td>N &lt; H &lt; I &lt; C</td>
</tr>
<tr>
<td>Activity Problems</td>
<td>-0.45 (0.53)</td>
<td>0.09 (0.50)</td>
<td>1.29 (0.53)</td>
<td>1.83 (0.76)</td>
<td>N &lt; I &lt; H &lt; C</td>
</tr>
<tr>
<td>Internalizing Problems 2 (SD)</td>
<td>-0.18 (0.88)</td>
<td>0.46 (1.08)</td>
<td>0.23 (1.06)</td>
<td>0.70 (1.18)</td>
<td>N &lt; H, I, C with H &lt; C</td>
</tr>
<tr>
<td>Externalizing Problems 2 (SD)</td>
<td>-0.32 (0.67)</td>
<td>0.05 (0.82)</td>
<td>0.78 (0.96)</td>
<td>1.37 (1.31)</td>
<td>N &lt; I &lt; H &lt; C</td>
</tr>
<tr>
<td>Mental health care use 3 (%)</td>
<td>2.45</td>
<td>7.76</td>
<td>8.00</td>
<td>20.79</td>
<td>N &lt; I, H &lt; C</td>
</tr>
</tbody>
</table>

Note. 1 Gender and mental health care use: Chi-square tests with asymptotic significance set at .01, rest: ANOVA main effects for group with $F(3, 1730)$, $p < .01$, and $\eta^2_p > .010$ (a group contrasts set at .01). 2 Mean item z-scores averaged over parent- and teacher-report. 3 Percentage of children for whom parents have contacted a mental health care facility at least once in the last year on account of their child’s maladaptive behavior (type of problems are unknown).

INFORMATION PROCESSING. A variety of information processing capacities were assessed by measures of speed (RTs) and accuracy (error rates) derived from five subtasks of the computer-aided Amsterdam Neuropsychological Tasks program (ANT; De Sonneville, 1999). Since the introduction of the program in 1985, numerous studies have proven the ANT to be a sensitive and valid tool in non-referred samples (e.g., De Sonneville et al., 2002; Groot, De Sonneville, Stins, & Boomsma, 2004; Stins et al., 2005) as well as in referred samples of various clinical domains, such as phenylketonuria (e.g., Burgard, Rey, Rupp, Abadie, & Rey, 1997; Huijbregts, De Sonneville, Van Spronsen, Licht, & Sergeant, 2002), minor neurological dysfunction (e.g., De Sonneville, Geeraets, & Woestenburg, 1993),
attention-deficit disorders (e.g., Hanisch, Konrad, Günther, & Herpertz-Dahlmann, 2004; Slaats-Willemse, Swaab-Barneveld, De Sonneville, Van der Meulen, & Buitelaar, 2003), and autism-related disorders (e.g., Althaus, De Sonneville, Minderaa, Hensen, & Til, 1996a, 1996b; Serra et al., 2003). For the present study, children were tested individually for approximately 70 minutes (short breaks included) by trained undergraduate psychologists in a separate room at their school (or, if this was not feasible, in a nearby community center). The children performed the following tasks in fixed order: (1) Baseline Speed measuring simple visuo-motor reaction time, (2) Pattern Recognition measuring automatic as well as controlled visuo-spatial pattern recognition, (3) Sustained Attention measuring response variability, perceptual sensitivity, response bias, and responsiveness to feedback on errors, (4) Memory Search measuring working memory capacity, and (5) Shifting Set measuring inhibition of prepotent responses as well as attentional flexibility. Before each task, children were shown a screenshot of relevant task characteristics and received verbal instructions, emphasizing both speed and accuracy of performance. Furthermore, practice trials were run prior to the administration of the test trials to ensure that the children understood the instructions. An overview of the measures can be found in Table 2. Inter-correlations were generally weak suggesting limited overlap between the measures (RT: mean $r = .23$ ranging from $r = .07$ to $r = .54$, error rates: mean $r = .08$ ranging from $r = .01$ to $r = .46$).

INTELLIGENCE. The Vocabulary and Block Design subtests from the Revised Wechsler Intelligence Scales for Children (WISC-R; Van Haasen et al., 1986; Wechsler, 1974) were used to estimate Full Scale IQ for all children. This two-subtest short-form has a high multiple correlation with Full Scale IQ ($r = .90$) (Sattler, 1992).
Table 2. Overview of the information processing measures.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Measurement Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Speed</td>
<td>The ability to detect and respond to a stimulus (simple reaction time).</td>
</tr>
<tr>
<td>Pattern Search</td>
<td>The central cognitive ability to detect a visuo-spatial target pattern among barely distinguishable (similar) visuo-spatial patterns.</td>
</tr>
<tr>
<td>Pattern Detection</td>
<td>The input-related ability to automatically detect a visuo-spatial target pattern sticking out among easily distinguishable (dissimilar) visuo-spatial patterns.</td>
</tr>
<tr>
<td>Fluctuation in Tempo</td>
<td>The central cognitive ability to maintain a stable performance over a prolonged period of time (response variability).</td>
</tr>
<tr>
<td>Feedback Responsiveness</td>
<td>The central cognitive ability to adjust response behavior following feedback on errors.</td>
</tr>
<tr>
<td>T-O-T D’</td>
<td>Time-On-Task perceptual sensitivity, i.e., the input-related ability to discriminate target signals from nontarget signals.</td>
</tr>
<tr>
<td>T-O-T Beta</td>
<td>Time-On-Task response bias, i.e., the output-related ability to inhibit (task-induced) biased response tendencies.</td>
</tr>
<tr>
<td>WM Capacity</td>
<td>The central cognitive ability to maintain and compare increasing information load in working memory (WM).</td>
</tr>
<tr>
<td>Inhibition of Prepotent Responses</td>
<td>The output-related ability to inhibit an inappropriate, habitual response tendency.</td>
</tr>
<tr>
<td>Attentional Flexibility</td>
<td>The central cognitive ability to mentally switch between two competing and unpredictable response sets.</td>
</tr>
</tbody>
</table>

ANALYSES

First, scores on each RT- and accuracy measure with an absolute z-score ≥ 4 were defined as outliers (Stevens, 2002, p.16). For each measure, these outliers and participants performing at chance level of accuracy, i.e., making 50% or more errors on any of the relevant task conditions, were dropped from subsequent analyses. These left-out participants did not differ from the remaining sample with respect to gender, age, IQ, or diagnostic group. Next, accuracy measures were logarithmically transformed to approximate normal distributions.
Group differences in information processing performance were then tested by a series of univariate analyses of covariance (GLM, ANCOVA, SPSS) with group (respectively NO versus ADH-I, NO vs. ADH-H, NO vs. ADH-C, ADH-I vs. ADH-C, ADH-H vs. ADH-C, and ADH-I vs. ADH-H) and gender as between-subject variables, and age, internalizing problems, and externalizing problems as covariates. Additionally, because the ADH-I group shows some (subthreshold) hyperactive/impulsive behavior as well (see Table 1), Hyperactivity/Impulsivity scores were entered as a covariate (in addition to age, internalizing, and externalizing problems) in the NO vs. ADH-I comparisons. Finally, in a separate run, IQ was entered as a covariate in addition to above-mentioned covariates. All tests were two-tailed using a $p < .05$ level of statistical significance. Because of our large sample and the use of multiple tests, a statistically significant group difference was considered meaningful only if the accompanying effect size was at least small (i.e., Cohen’s $d \geq 0.20$) (Cohen, 1988, pp. 24-26). Cohen’s $d$ was computed with a version of Cohen’s formula suitable for comparing covariate adjusted group means, while simultaneously accounting for the potential effect of unequal group sizes (Lipsey & Wilson, 2001, pp. 180 and 198).

Group performances were visualized by first converting the RT- and accuracy measures into gender-specific standardized residuals (i.e., $z$-scores adjusted for age, internalizing problems, and externalizing problems and, in a separate run also for IQ) and then plotting the various residual group means in a line chart. The correction for potential effects of gender, age, internalizing problems, and externalizing problems enhances the visual interpretability of these charts by focusing merely on subtype-related differences in performance.
RESULTS

ADH-I, ADH-H, ADH-C vs. NO PROBLEMS

The children with Inattentive Type problems showed performance deficiencies on four RT-measures and none of the accuracy measures (see Figure 1). As compared to the NO group, the ADH-I group was generally slower (Baseline Speed, $F(1, 1368) = 19.64, p < .001$, $d = 0.43$), demonstrated a slower visuo-spatial working memory (Pattern Search, $F(1, 1361) = 7.23, p = .007, d = 0.27$), a greater response variability during continuous performance (Fluctuation in Tempo, $F(1, 1368) = 29.78, p < .001, d = 0.53$), and needed more time to maintain and compare increased (verbal) informational load in working memory (WM Capacity, $F(1, 1369) = 17.45, p < .001, d = 0.43$).

In contrast, the children with only Hyperactive/Impulsive Type problems performed closely around the sample mean and did not differ from the children with neither Inattention nor Hyperactivity problems (all $p$'s $\geq .05$ and/or $d$'s $< 0.20$).

The children with Combined Type problems performed worse than the children without behavior problems on only two RT-measures, i.e., Pattern Search ($F(1, 1447) = 9.98, p = .002, d = 0.26$) and Fluctuation in Tempo ($F(1, 1456) = 27.05, p < .001, d = 0.37$).

Most group differences remained significant ($p \geq .05$ and/or $d \leq 0.20$) after additional adjustment for IQ, except for the group differences on Pattern Search (NO vs. ADH-I: $p = .123, d = 0.14$; NO vs. ADH-C: $p = .086, d = 0.15$; ADH-H vs. ADH-C: $p = .114, d = 0.14$) (see Figure 2). Although boys and girls were unevenly distributed across the groups, none of the group comparisons showed a significant interaction with gender indicating that boys and girls did not differ in the associations between problem behavior and information processing.
Figures 1 (left) and 2 (right). Information processing profiles respectively before and after controlling for IQ. Note. Group differences at $p < .05$ and $d \geq 0.20$ are marked by letter combinations, i.e., NI: NO vs. ADH-I, NH: NO vs. ADH-H, NC: NO vs. ADH-C, IC: ADH-I vs. ADH-C, HC: ADH-H vs. ADH-C, IH: ADH-I vs. ADH-H. Differences observed for Baseline Speed do not account for differences on other RT-measures as this was automatically corrected for in the computation of these measures.
SPECIFICITY of ADH-I and ADH-H related DEFICIENCIES

Group contrasts between the ADH-I and ADH-H groups show that three of the four measures distinguishing between the ADH-I and NO problems group, also discriminated the ADH-I from the ADH-H group, i.e., Baseline Speed ($F(1, 256)= 7.66, p = .006, d = 0.42$), Fluctuation in Tempo ($F(1, 255)= 5.77, p = .017, d = 0.48$), and Working Memory Capacity ($F(1, 255)= 7.81, p = .006, d = 0.45$). ADH-I and ADH-H groups could not be discriminated on Pattern Search ($p = .245, d = 0.26$), although the effect size was small. After additional adjustment for IQ, these three measures remained discriminating the ADH-I from the ADH-H group, i.e., Baseline Speed ($F(1, 255)= 5.61, p = .019, d = 0.36$), Fluctuation in Tempo ($F(1, 254)= 4.44, p = .036, d = 0.40$), and Working Memory Capacity ($F(1, 254)= 6.45, p = .012, d = 0.40$). Results were similar for both genders.

ADH-I and ADH-H vs. ADH-C PROBLEMS

Both measures distinguishing between the ADH-C and NO problems group, also discriminated the ADH-C from the ADH-H group (Pattern Search $F(1, 340)= 6.03, p = .015, d = 0.22$) and Fluctuation in Tempo ($F(1, 342)= 9.26, p = .003, d = 0.27$). Conversely, the ADH-I group could not be discriminated from the ADH-C group on these or any of the measures. After correction for IQ, only the ADH-C vs. ADH-H difference on Fluctuation in Tempo remained significant ($F(1, 341)= 5.21, p = .023, d = 0.21$), whereas Pattern Search no longer discriminated significantly ($p = .114, d = 0.14$). Again, boys and girls did not differ in these associations.
DISCUSSION

The findings of the present study suggest that it is the presence of inattention symptoms, and not of hyperactivity/impulsivity symptoms, that is associated with deficits in specific information processing capacities. These results were obtained in a large, unselected sample of 10- to 12-year-olds while controlling for the effects of age and co-occurring internalizing and externalizing problems. Moreover, no differences were found between boys and girls and most deficiencies remained once group differences in IQ were controlled for. Although it should be noted that the appropriateness of statistically controlling for IQ is in fact a highly debated issue in which it has been argued that this type of control may unduly remove variance that is inherent to information processing itself (see also, Brunnekreef et al., in press; Doyle, Wilens, et al., 2005, for a more elaborate discussion).

In line with Barkley’s hypotheses (1990; 1997), we found that a lower baseline speed of information processing discriminated the Inattentive Type from both the no ADH problems as well as the Hyperactive/Impulsive Type. Yet, a trend for lower baseline speed could also be observed for the Combined Type. Furthermore, to the extent that ‘late’ selective attention, i.e., the ability to differentiate between relevant and irrelevant information, is dependent on (visuo-spatial and verbal) working memory, our findings indeed suggest that the Inattentive Type is related to a deficient selective attention. Our results, however, do not support a differential selective attention deficit for the Inattentive versus Combined Type, as the Combined Type also showed a less efficient, albeit predominantly visuo-spatial, working memory. Moreover, both the Inattentive and Combined Type exhibited a deficiency in sustaining attention over a prolonged period of time as demonstrated by their greater response variability during continuous task performance.

Although the type of processing deficiencies are in line with previous expectations, our results do not provide support for the discriminant validity of Inattentive and Combined Types at the neuropsychological level as the Inattentive and Combined Type showed similar deficiencies and could not be differentiated from each other. This latter finding corroborates the results of previous studies (Geurts et al., 2005; Houghton et al., 1999) and is also in line with studies reporting equal impairments on measures of intelligence and academic achievement in Inattentive and Combined Types (e.g., Faraone et al., 1998).
Also contrary to Barkley’s (1997; 1999) theory, no processing deficiencies were found for the Hyperactive/Impulsive Type, not even on response inhibition where instead a trend was observed for the Inattentive Type. These findings corroborate results obtained by Chhabildas and colleagues (2001) in their comparison of all three subtypes and suggest that the Hyperactive/Impulsive Type may not share the same etiologic mechanism as the Inattentive and Combined Types. In his two-process model of ADHD, Sonuga-Barke (2002) postulated that hyperactivity/impulsivity symptoms may stem from problems in reward-response contingency rather than from structural cognitive deficits which contribute primarily to symptoms of inattention. As neither the Chhabildas and colleagues’ nor our study included a reward manipulation in our tasks, we may thus not have been able to measure potential deficiencies in the Hyperactivity/Impulsive Type.

Increasingly, reports are published challenging the etiological primacy of inhibitory and executive deficits in ADHD and advocating a shift towards a focus on response variability (see e.g., Castellanos et al., 2006; Lijffijt, Kenemans, Verbaten, & Van Engeland, 2005). At a subtype level, our results likewise suggest that response inhibition may be of less value as compared to response variability, baseline speed, and working memory in attempts to unravel the etiological mechanisms underlying the Inattentive and Combined Type. Response variability, for example, has previously been found to be highly heritable (Kuntsi & Stevenson, 2001) and may therefore be useful as a cognitive endophenotype for molecular genetic studies of ADHD (Castellanos & Tannock, 2002; Slaats-Willemse, Swaab-Barneveld, De Sonneville, & Buitelaar, 2005).

In interpreting the results of the present study, it should be considered that we identified ADH subtypes on the basis of standardized symptom checklists that do not take into account other essential DSM-IV criteria such as symptom onset, pervasiveness, or impairment thereby complicating a direct comparison with findings obtained in clinical samples. Yet, although our groups are most probably not as severely affected as clinically referred groups, our study was able to identify several cognitive markers that may be valuable in the search for the etiological mechanisms in ADHD.
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CHAPTER 6

GENERAL CONCLUSIONS and DISCUSSION
INTRODUCTION

The empirical studies presented in the preceding chapters investigated the relationships between multiple aspects of information processing and multiple types of problem behavior within a general population sample of preadolescents. This final chapter provides an overview of the main findings and discusses the contribution of this dissertation to the field of child and adolescent psychopathology using Seidman and colleagues’ (1997, 1999) tripartite view of the clinical value of neuropsychological measures: i.e., (1) as aids to treatment by identifying etiological mechanisms and evaluating treatment effects; (2) as aids to the diagnostic process; and (3) as measures of change over time.

CONCLUSIONS

In this dissertation, information processing deficiencies proved to be uniquely related to the (co-)presence of inattentive behavior symptoms. Most pronouncedly, a greater response variability differentiated children with ‘pure’ as well as (co-)occurring inattentive behavior symptoms from both children without behavior problems and from children with, respectively, ‘pure’ hyperactivity/impulsivity, ‘pure’ oppositional defiant/conduct, and ‘pure’ internalizing* problems. This discriminative value, moreover, appeared resistant to statistical control for IQ. Furthermore, a lower baseline speed and a deficient visuo-spatial as well as verbal working memory could also be pinpointed to parent- and teacher-reports of ‘pure’ inattentive behavior. Yet, these deficiencies were less pronounced and thus did not discriminate children with co-occurring inattentive behavior problems as consistently as response variability nor did these deficiencies withstand statistical control for IQ. No specific deficiencies were found in visuo-spatial pattern detection, responsiveness to auditory feedback, inhibition of prepotent responses, attentional flexibility, perceptual sensitivity, and response bias (see Appendix B for a schematic overview). Furthermore, this dissertation found no evidence of information processing deficiencies in preadolescents with behavior problems other than inattentive problems, i.e., ‘pure’ internalizing, ‘pure’ oppositional defiant/conduct, and ‘pure’ hyperactivity/impulsivity problems.

* Although it was not mentioned in Chapter 3, response variability significantly discriminated the EXT from the INT group (p < .05, d = 0.22) without the (perhaps too) stringent statistical control for severity of problem behavior (i.e., CBCL Total Problemsscore).
DISCUSSION

STRENGTHS and LIMITATIONS

The main findings of this study should be interpreted in light of the strengths and limitations inherent to its methodology. First, the large and unselected nature of our sample of preadolescents has several assets for investigating the relationships between information processing and problem behavior. Because population-based samples are not liable to referral biases, they are more representative of the full population of children with behavior problems as opposed to clinical samples, which generally contain an overrepresentation of children with more severe and more complex symptomatology (Caron & Rutter, 1991; Goodman et al., 1997). This afforded the opportunity to study more homogeneous categories of problem behavior which, in turn, facilitated the identification of behavior-specific processing deficiencies. Furthermore, the large sample size provided sufficient power to additionally take into account effects of gender and age as well as simultaneously explore the relationship between information processing and IQ. To closely relate to clinical practice, we adopted a person-centered (typological) approach to analyze our data by comparing the information processing profiles of clinically relevant groups that were formed on the (probable) presence or absence of problem behavior (Mandara, 2003). A drawback of the typological categorization of continuous variables, however, is that it may involve loss of information as children scoring just below the designated cut-off are regarded as having ‘no problems’ even though they may be quite similar to the ‘problem’ children who score at or above the cut-off. We, therefore, used very lenient cut-off criteria (i.e., borderline clinical range) in our studies. As a consequence, the behavior problems in our problem groups are, on average, not as severe as those of clinical samples. To illustrate, only 5 to 22% of children in our problem groups had contacted a mental health care facility in the preceding year.

Second, we assessed multiple types of problem behaviors by means of two of the most commonly used standardized questionnaires in child and adolescent psychiatric research. These checklist provides evidence of good (construct and discriminant) validity and reliability (Achenbach & Rescorla, 2001, pp. 99-135) and, moreover, offer the possibility to combine reports of several informants and to control for co-occurring subthreshold problems. These symptom checklists, however, are not an exact copy of the symptoms
described by the *Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR, American Psychiatric Association, 2000)* and do not assess other essential DSM-criteria such as symptom onset, pervasiveness, or impairment, thereby further complicating the clinical implications of our findings. Nevertheless, strong associations between CBCL scores and DSM diagnoses have frequently been reported (e.g., Edelbrock & Costello, 1988; Kasius, Ferdinand, Van den Berg, & Verhulst, 1997; Kazdin & Heidish, 1984).

A third strength is the comprehensive assessment of multiple information processing capacities. These capacities were assessed with computerized RT-paradigms that have a number of assets: (1) the incorporation of simple within-task manipulations enables the selective measurement of specific cognitive processes also referred to as information processing capacities (Sergeant, Oosterlaan, & Van der Meere, 1999), (2) the rigorous control over task administration (e.g., stimulus presentation) and (3) the fine-grained collection of data on processing speed and accuracy reduce measurement error and enable the assessment of even subtle inter-individual differences in information processing (see also Doyle et al., 2005; MacDonald III & Carter, 2002; Sergeant, Geurts, & Oosterlaan, 2002). Moreover, while for most other neuropsychological tests little is known about the test-retest reliability of findings (Doyle et al., 2005), Althaus and colleagues (submitted), recently reported adequate to high test-retest reliabilities (i.e., intra-class correlations > .6) for our RT-measures. These results substantiate the relevance of our main findings that all pertain to the speed of information processing. Poor test-retest reliabilities (i.e., intra-class correlations < .6), however, were found for our accuracy measures, indicating that we can not decisively rule out that problem behavior is related to the accuracy of information processing.
NEUROPSYCHOLOGICALLY IMPAIRED vs. NON-IMPAIRED TYPES of PROBLEM BEHAVIOR: INDICATIONS for a DIFFERENTIAL ETIOLOGY?

First and foremost, our findings that fundamental information processing deficiencies are uniquely related to the (co-)presence of inattentive behavior symptoms suggests that the etiological mechanisms underlying ‘pure’ internalizing, ‘pure’ oppositional defiant/conduct, and ‘pure’ hyperactivity/impulsivity behavior problems are different from those underlying the (co-)presence of inattentive behavior problems. An alternative argument to explain the lack of effects for these three types of behavior problems could be that the mean behavior problems of these groups were not severe enough to reveal information processing deficiencies. This argument, however, seems unlikely as these groups demonstrated clear behavioral impairments relative to the no problem groups (large effect sizes) that were comparable in degree to the impairments demonstrated by the groups with (co-occurring) inattentive behavior symptoms. Moreover, the current lack in existing literature of clinical and population-based studies reporting deficits in these aspects of information processing in children with internalizing, oppositional defiant/conduct, or hyperactivity/impulsivity while taking due recognition of co-occurring problems, further reinforces our conclusion.

In contrast to Barkley’s (1997, 1999) theory of ADHD that assigns a primary role to response inhibition and other processing deficits in the development of hyperactivity/impulsivity problems, this dissertation adds to increasing reports linking information processing deficits to the inattention dimension, rather than the hyperactivity/impulsivity dimension of ADHD (e.g., Castellanos, Sonuga-Barke, Milham, & Tannock, 2006; Chhabildas, Pennington, & Willcutt, 2001; Willcutt & Carlson, 2005). Moreover, our findings suggest that the discriminative value of inhibition of prepotent responses is limited as compared to that of response variability, baseline speed and working memory. The adequate to high test-retest reliabilities for these specific measures strengthen this difference (Althaus et al., submitted). Additional support comes from recent reports challenging the etiological primacy of inhibitory and executive deficits in ADHD and advocating a shift towards intra-individual variability (see e.g., Castellanos et al., 2006). In a recent meta-analytic review, for example, effect sizes for group differences on within-subject variability of
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responding were larger than those for response inhibition (Lijffijt, Kenemans, Verbaten, & Van Engeland, 2005).

On a neurological level, these processing deficits have been associated with the dorsolateral prefrontal cortex (DLPFC) (Bellgrove, Hester, & Garavan, 2004; Haber, 2003; Stuss, Murphy, Binns, & Alexander, 2003; Zelazo & Mueller, 2002). Castellanos and colleagues (2006) proposed that inattention symptoms may stem from deficits that on a neurological level have been associated with the dorsolateral prefrontal cortex, whereas hyperactivity/impulsivity problems may reflect deficits in abilities that have been traced back to the orbital and medial prefrontal cortex (OMPFC) such as the appraisal of the affective significance of stimuli. Additionally, the importance of catecholamines (dopamine and norepinephrine) in the regulation of motor control and cognitive functions has become increasingly appreciated (Solanto, 2002). A lower baseline speed, greater response variability, and a deficient working memory may thus be hypothesized to be the result of structural anomalies and/or neurochemical dysfunctions in the DLPFC. Differences in anatomical brain structures between ADHD and controls have indeed been documented, among which a decreased volume and hypoperfusion of the right prefrontal cortex (Filipek et al., 1997; Krain & Castellanos, 2006). Also, several studies have suggested that catecholaminergic deficiency may explain the less-than-optimum waking DLPFC activation in ADD (Cabral, 2006; Oades et al., 2005; Pliszka, 2005; Solanto, 2002). Interestingly, Huijbregts and colleagues (2002) demonstrated a strong relationship between greater response variability, as measured with the same ANT parameter as in our study, and higher Phenylanaline concentrations and thereby lower concentrations of Tyrosine, which is the metabolic precursor of dopamine and norepinephrine.

The processing deficiencies we observed in children with (co-occurring) inattentive behavior symptoms may thus reflect a difficulty in achieving and consistently maintaining a physical state of alertness or activation for incoming information. Our findings thereby add support for one of the most influential theories of ADHD, as in his cognitive-energetic model of ADHD, Sergeant (2000) suggests that processing deficits in ADHD may be a reflection of differences in state regulation mechanisms (i.e., vigilance, arousal, effort, or activation). Likewise, Van Zomeren & Brouwer (1994) suggested that lower and more variable speed of processing might be explained by insufficient ‘intensity’ of general
attention which is related to the individual’s general state of alertness and which has great resemblance to Posner’s alerting network of attention (Posner & Raichle, 1994).

A remaining question, however, is how this theory applies to children who exhibited both inattentive and hyperactivity/impulsivity problems. In Chapter 5, we found that although the task performance of children with Combined Type problems did not differ from that of children with Inattentive Type problems, their processing deficiencies appeared to be somewhat less pronounced in spite of their more severe inattentive behavior symptoms. Could it be that the hyperactivity/impulsivity problems of these children reflect a compensatory mechanism that is only to a certain extent successful in fine-tuning their suboptimal level of arousal or activation to the task conditions at hand? Although this dissertation can not provide the answers to these questions, it was found that even children with less severe, i.e., subthreshold (co-occurring) inattentive behavior symptoms show specific processing deficiencies. This dissertation thereby supports the view that ADHD is best conceptualized as the extreme of a behavior that varies in severity of expression throughout the general population rather than as disorder with discrete determinants (Levy, Hay, McStephen, Wood & Waldman, 1997). It is argued that it is necessary for future etiological studies to pay due recognition to these subthreshold inattentive problems. These studies may benefit, for example, from going beyond the DSM in defining relevant groups by assessing the degree or ratio of inattentive to hyperactivity/impulsivity in their samples. Such an approach would be preferable over the categorisation of individuals on the basis of meeting a certain number (but not all) of specified DSM criteria, which will result in affected groups that are still too heterogeneous (DSM-IV; American Psychiatric Association, 1994, p. xxii).

Furthermore, this dissertation identified four aspects of information processing that may be valuable for future research. The most pronounced processing deficiency, i.e., response variability, has previously been found to be highly heritable (Kuntsi & Stevenson, 2001) and may therefore be useful as a cognitive endophenotype for molecular genetic studies of ADHD (Castellanos & Tannock, 2002; Slaats-Willemse, Swaab-Barneveld, De Sonneville, & Buitelaar, 2005). On a neurological level, these processing measures might serve as a way to further examine the contribution of different brain areas and neurotransmitters to problem behavior using advanced neuro-imaging techniques such as
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event-related fMRI or PET. A caveat of these methods, however, is that they are expensive and because PET uses an intravenous radioactive isotope, research in children is difficult because of children’s known greater sensitivity to radiation and risk of radiation induced cancer (see e.g., Saad et al., 2006). A less expensive and less invasive alternative may be to use RT-tasks as a bridge between brain and behavior by evaluating treatment effects of ADHD psychopharmacas (e.g., Methylphenidate, Atomoxetine) that block the reuptake of dopamine and norepinephrine (Purper-Ouakil, Fourneret, Wohl, & Reneric, 2005; Sevecke, Battel, Dittman, Lehmkuhl, & Dopfner, 2006). Eventually, more insights into the etiology of problem behavior may result in more targeted treatment strategies for clinical practice. For example, children with ADHD currently receive identical treatments regardless of their specific subtype. Our results suggest that the subtypes possibly might benefit from different treatments.

RESPONSE VARIABILITY, BASELINE SPEED, and WORKING MEMORY: SPECIFIC COGNITIVE MARKERS as AIDS to the DIAGNOSTIC PROCESS?

Clinicians currently predominantly make use of parent- and, to a lesser extent, teacher-reports of problem behavior. Yet, these behavioral reports depend heavily upon the informants’ experienced burden as well as on their norms and expectations of what behavior is (in)appropriate considering the context and the child’s level of development. Inattentive behavior, for example, may be expressed in social situations as frequent shifts in conversation, not listening to others, and not following details or rules of games or activities. In school, inattentive behavior may be marked by a failure to give close attention to details, careless mistakes in school work or tasks, messy homework and difficulties in persisting with tasks until completion (DSM-IV-TR, American Psychiatric Association, 2000). It has been suggested that neuropsychological measures may serve as important, more objective, validating criteria for clinical practice (Seidman, Biederman, Faraone, Weber, & Ouelette, 1997).

Explicitly contributing to the diagnostic potential, the neuropsychological data of our TRAILS sample have been incorporated in the recently launched Windows version of the ANT program (ANT 3.0), serving as important representative normative data for testing
individual children. Furthermore, this dissertation showed that a lower baseline speed, greater response variability, and a less efficient visuo-spatial as well as verbal working memory capacity discriminated groups of children with (co-occurring) inattentive behavior symptoms from groups of children with ‘pure’ Hyperactive/Impulsive Type, ‘pure’ OD/C, and to a lesser extent ‘pure’ internalizing problems.

The fact that group differences were only small was to be expected considering the fact that we compared different problem groups based on very low cut-off criteria. Furthermore, the processing measures and questionnaires assess functioning on very different levels (cognitive vs. behavioral) and are based on different types of informants (parents and teachers vs. children) in two very different settings (home and classroom vs. test situation). Yet, although these small effects may indicate that all children with (co-)inattentive problems demonstrate a similar degree of processing deficiency as compared to other children, it is more likely that they indicate that children with (co-)inattentive behavior demonstrate processing deficiencies to varying degrees (Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). For the classification of individual children, the latter implies that these measures - as most other neuropsychological measures - will have good specificity (i.e., few false positives) in that processing deficiencies are likely to be shown only by a child with (co-occurring) inattentive problems but poor sensitivity (i.e., more false negatives) in that normal task performance cannot be used to rule out the presence of behavior problems (Barkley & Grodzinsky, 1994; Doyle, Biederman, Seidman, Weber, & Faraone, 2000; Grodzinsky & Barkley, 1999). Furthermore, as the behavior problems of clinically referred children are more complex, most children will probably show some degree of inattentive symptoms. The diagnostic value of processing deficiencies in making differential diagnoses will then be limited.

On the basis of the studies presented in this dissertation, we argue instead that baseline speed, response variability, and visuo-spatial as well as verbal working memory may be most valuable to the diagnostic process as objective markers of the degree of inattentive behavior. These information processing markers may improve insights into the specific problems of a child alongside traditional behavioral reports in a way that does justice to the subtle degrees to which these deficits can be present. Clinical practice as well as parents and teachers would benefit from knowing whether a child processes
information at a slower pace; is less able to keep up a stable performance over a prolonged
period of time; and has difficulty holding ‘on-line’ and comparing complex visuo-spatial as
well as verbal information in working memory. Additionally, valuable insights may be
provided by studies investigating the relationships between these processing deficiencies,
as observed in self-paced and simple tasks, and everyday cognitive skills that demand
complex integration of several processes under less structured and more time-demanding
circumstances (Chaytor & Schmitter-Edgecombe, 2003). Furthermore, research is needed
to examine the extent to which these deficiencies are unique to inattentive problems when
compared to other types of preadolescent problem behavior such as autism related
disorders (Geurts, Verté, Oosterlaan, Roeyers, & Sergeant, 2004).

STABILITY or CHANGE? TOWARDS an INTEGRATIVE,
DEVELOPMENTAL CONCEPTUALIZATION of the
RELATIONSHIPS between INFORMATION PROCESSING and
PROBLEM BEHAVIOR.

The findings of this dissertation are restricted to the narrow developmental period of
preadolescence. More research is needed to establish whether the relationships are similar
in childhood and adolescence. It would be ideal to chart the developmental trajectories of
these relationships in a longitudinal design. A great advantage of the ANT program is that
it is suitable for use from age 4 upwards. Furthermore, it would be valuable if such studies
could shed light upon the predictive value of these processing deficiencies for later
functioning. As information processing deficiencies cannot account for the full
phenomenology of problem behavior, it is important for such studies to examine the
relationships more comprehensively. We recommend that future studies combine
neuropsychological and behavioral factors with environmental and biological (genetic,
psychophysiological) factors in order to unravel the multiple developmental pathways to
ADHD (Sonuga-Barke, 2005).