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NEUROLOGY AND PRECLINICAL NEUROLOGICAL STUDIES - REVIEW ARTICLE

Cognitive characterization of adult attention deficit hyperactivity disorder by domains: a systematic review

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Abstract

Attention deficit hyperactivity disorder (ADHD) is reportedly the most frequent neurodevelopmental disorder diagnosed during childhood, and it is recognized as a common condition in adulthood. We review the evidence to help identify cognitive domains associated to deficits in adult ADHD. A systematic review with narrative synthesis was performed, assessing studies on adult ADHD, neuropsychology and research on involved cognitive domains in adults 18+ years old with an established diagnosis of ADHD, in seven electronic databases (PubMed, PsychInfo, WebOfScience, Embase, Scopus, OvidSPMedline, and Teseo), and Worldcat and OpenGrey grey literature databases. 93 studies were included for this review, encompassing findings from a total 5574 adults diagnosed only with ADHD, medication-naïve or non-medicated at the moment of the assessment and 4880 healthy controls. Adults diagnosed with ADHD may show, when compared to healthy controls, a cognitive profile characterized by deficits across all attention modalities, processing speed, executive function (mainly working memory and inhibition with emphasis on reward delay and interference control), verbal memory, reading skills, social cognition and arithmetic abilities. A cognitive characterization of adult ADHD by domains is established beyond the sole consideration of attention and executive function problems. Along with these, verbal memory, language (mainly reading), social cognition and arithmetic abilities may also contribute to a more comprehensive characterization of the cognitive profile in adult ADHD.

Keywords Adult ADHD · Neuropsychological assessment · Cognitive domains · Cognitive profile · Cognitive deficits

Introduction

Attention deficit hyperactivity disorder (ADHD) is reportedly the most frequent neurodevelopmental disorder diagnosed during childhood, and is increasingly being recognized as a common condition in adulthood (Aboitiz et al. 2014). According to Ginsberg et al. (2014), reports show an estimated prevalence of 2.5%–5% in adults of the general population, a prevalence that significantly increases when pointing to specific populations such as imprisoned men and adults who attend psychiatric outpatient facilities for conditions different than ADHD (17–22%). For incarcerated populations, Young et al. (2015) suggested a fivefold increase in prevalence of ADHD in youth prison populations (30.1%) and a ten-fold increase in adult prison populations (26.2%).

According to Waite (2007), individuals with ADHD may be encountered in clinical settings in one of the following ways: (a) a patient with established ADHD (diagnosed as a child), (b) those who were diagnosed and treated in childhood but stopped care as adults, and (c) those who have never been diagnosed or treated for ADHD. The latter may imply, for general adult population, up to 90% of the cases (i.e., 90% of adult ADHD individuals with no treatment), according to Culpepper and Mattingly (2010), which may have a serious impact on the life of these individuals. Ginsberg et al. (2014) found that, although adults with ADHD often experience chaotic lifestyles, with impaired educational and vocational achievement and higher risks of substance abuse and imprisonment, many remain undiagnosed and/or untreated.

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As it can be inferred, properly defining the limits of what is and what is not adult ADHD is both complex and controversial. For Dowson and Blackwell (2011), the level of dysfunction required for a diagnosis is arbitrary and, in part, usually reflects a clinician's judgment. Fischer et al. (2012) states that, even in the context of late-life cognitive disorders, memory clinics may not adequately identify and address ADHD. According to Faraone et al. (2006), differentiating ADHD from other clinical disorders is often the most difficult part of making an ADHD diagnosis in adults, given the high comorbidity between ADHD and other psychiatric disorders such as major depressive and anxiety disorders (Paek et al. 2016), internet addiction (Bielefeld et al. 2017; Wang et al. 2017), bipolar disorder (Klassen et al. 2010; Mucci et al. 2019), borderline personality disorder (Xenaki and Pehlivanidis 2015), substance abuse (Fatseas et al. 2012), gambling disorders (Marmet et al. 2018), or alcohol abuse (Grazioli et al. 2019). Ginsberg et al. (2014) remark that adults with ADHD are more likely to seek psychiatric services to obtain treatment for their other comorbid disorders than for ADHD, which adds more confusion and challenge for the clinicians that may fail to properly identify and distinguish ADHD symptoms from symptoms of the other comorbidities that appear as the primary reason for consultation. However, leaving ADHD untreated, even if comorbidities are treated, leads to poor clinical and functional outcomes. Asherson et al. (2012), in a review of cultural influences on the diagnosis of ADHD, found that ADHD could be detrimental to many areas of life including work, daily activities, social and family relationships and psychological and physical well-being. Patient-reported impairments in productivity due to poor time management, procrastination, and distractibility can translate into significant indirect costs and decreased quality of life, and into increased accidents, medical resource utilization, antisocial behaviour and drug or alcohol abuse. For all these reasons, as Paris, Bhat and Thombs (2015) state in their review, diagnosis of adult ADHD should be made cautiously, making use of multiple sources of information, including self-report, clinical interviews, collateral information, childhood documentation, and neuropsychological testing, including an exhaustive cognitive study.

In terms of how neuropsychology may contribute to differential diagnosis of adult ADHD, there is scarce but increasing literature in the characterization of cognitive domains that specifically distinguish adult ADHD from other comorbid or concurrent disorders.

Driving from a more general overview to more specific findings, we need to refer first to the meta-analysis developed by Bridgett and Walker (2006), who found that adults with ADHD scored lower than adults without ADHD on WAIS intelligence tests, but that this difference could be attributable to those adults who have a diagnosis of ADHD with comorbid disorders or past head trauma (in other words, ADHD alone could not be referred as the reason for a lower IQ). Faraone and Ansthel (2008) remark how Barkley developed his executive functioning theory of ADHD, stating that the main symptoms that differentiated ADHD from adults with other types of psychopathology were mainly related to decision-making, more specifically, to making decisions impulsively and having difficulty stopping activities or behaviour when one should; while hyperactivity, so common as a core feature in childhood ADHD, may not distinguish adults with ADHD from normal adults or adults with other clinical disorders.

These findings match with the review performed by Dowson and Blackwell (2011), who observed that most common cognitive deficits in adult ADHD tend to show on tests with known sensitivity to a dysfunction in frontal lobes, and reported different findings that have linked a range of neurocognitive domains involving attention, behavioural inhibition, memory (both verbal and visual), set shifting, speed of visuomotor search, working memory and interference control, although further research is needed to properly identify primary or core deficits, and differentiate them from those arising from other comorbid conditions or from factors related to age, gender and estimated premorbid IQ.

In subsequent years, different studies have tried to summarize main research findings in terms of cognitive domains affected in adult ADHD, with confusing or mixed results. Aboitiz et al. (2014) identified the inability to suppress irrelevant or distractive stimuli as a main salient feature in ADHD. Xenaki et al. (2015), in an attempt to differentiate ADHD from Borderline Personality Disorder, stated that ADHD shows a more outwardly expressed symptomatology, with the main focus on difficulties in inhibition control, but without a clear cut-point between the two disorders, which share features of impulsivity, emotional dysregulation, attention and decision making.

One of the most comprehensive reviews of cognitive domains performed so far was developed by Leroy et al. (2019), but their focus was on the distinction of already established ADHD subtypes and, as their main outcome, they found that, while four domains were informative in differentiating ADHD subtypes from controls, only memory was helpful to distinguish between inattentive and combined subtypes. However, Skodzik et al. (2017) previously reported in their meta-analysis that these differences are restricted to verbal memory (but not to visual long-term memory) with problems related to memory acquisition but not to retrieval, suggesting a learning deficit induced at the stage of encoding. Separately, on another meta-analysis on decision-making and attention in ADHD, Mowinckel et al. (2015) supported the existence of similar magnitude deficits of attention and decision-making in adult ADHD, without prevailing one type of deficit over the other, but with a need of further research to understand the underlying neurocognitive mechanisms. Fuermaier et al. (2018) added another piece to this puzzle by performing a systematic review on perceptual functions in ADHD, finding that individuals with ADHD have increased perceptual functions with regards to olfactory detection thresholds, cold pain and bitter taste, while they show reduced perceptual functions for visual and speech perception, showing greater discomfort to sensory stimuli at lower levels of intensity. These perceptual problems, which seem to be moderated by pharmacological treatments, cognitive functions and symptom severity, may aggravate symptoms of inattention, so the mixture between perception and cognition appears as an additional challenge. In other words, it is crucial to disentangle perception and cognitive functions in ADHD as much as possible to better understand mechanisms underlying clinical symptoms in ADHD.

Subsequently, with all these previous consideration in mind, the goal of the current study is to perform a systematic review on the identification of cognitive domains associated to deficits in adult ADHD, regardless of pre-established distinctions of clinical presentations or subtypes in clinically established guidelines like the DSM-5, with an aim to provide further clarity in the delimitation of which and how are those cognitive domains mainly affected in adult ADHD.

Methods

Searching strategy

The method of this systematic review was developed in accordance to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) criteria (Liberati et al. 2009). Given the wide variety of measurements used in extant studies reviewed, and the broad nature of the review, we decided that meta-analysis would not be useful given the high level of methodological heterogeneity.

Scientific studies were identified by searching electronic databases (PubMed, PsychInfo, WebOfScience, Embase, Scopus, OvidSPMedline, and Teseo) using the following syntaxis adapted to the searching requirements in each database: ("adult ADHD" or "adult attention hyperactivity disorder") AND ("neuropsychology" or "cognition" or "executive functions" or "attention" or "memory" or "language" or "visuospatial" or "visuoconstructive" or "social cognition" or "dysexecutive syndrome" or "impulsivity" or "inhibition" or "motor" or "reasoning"). Additionally, the search was performed in Worldcat and OpenGrey grey literature databases. The timeframe was established to capture the research performed in the last 15 years, ranging from 1st January 2006 to 31st March 2020. No specific exclusion terms were added to extend the scope of the review as much as possible.

Selection strategy, screening and extraction

Combination of electronic databases with the examination of grey literature raised a total of 11,571 references, which were subsequently filtered to remove 7306 duplicates. That led to a total of 4265 studies to be screened as potential to be included in the results. At this point, only studies in English and Spanish were included and an exhaustive exclusion strategy was followed to narrow the scope into the study goals, thus leading to the exclusion of the following studies:

- All studies in a language other than English or Spanish.
- Genetic studies on ADHD.
- Studies with a primary focus on fMRI, EEG and ERP.
- Studies with mixed samples of children, adolescents and adults with ADHD that did not provide separate data for adults with ADHD.
- Studies focused on ADHD with comorbidities, when the main focus of the study and reported outcomes were mainly focused on those comorbidities, or when outcomes attributable to ADHD were not distinguishable from those attributed to the comorbidities. This may include alcohol or other drug consumption, other psychiatric disorders (e.g., schizophrenia, bipolar disorder, eating disorders, gambling, internet addiction…) and personality disorders (mainly, antisocial or borderline personality disorders).
- Studies focused on the effects of specific interventions, both pharmacological and non-pharmacological.
- Editorials, letters to editors, abstracts in conferences, erratums, corrigendums, and book reviews.

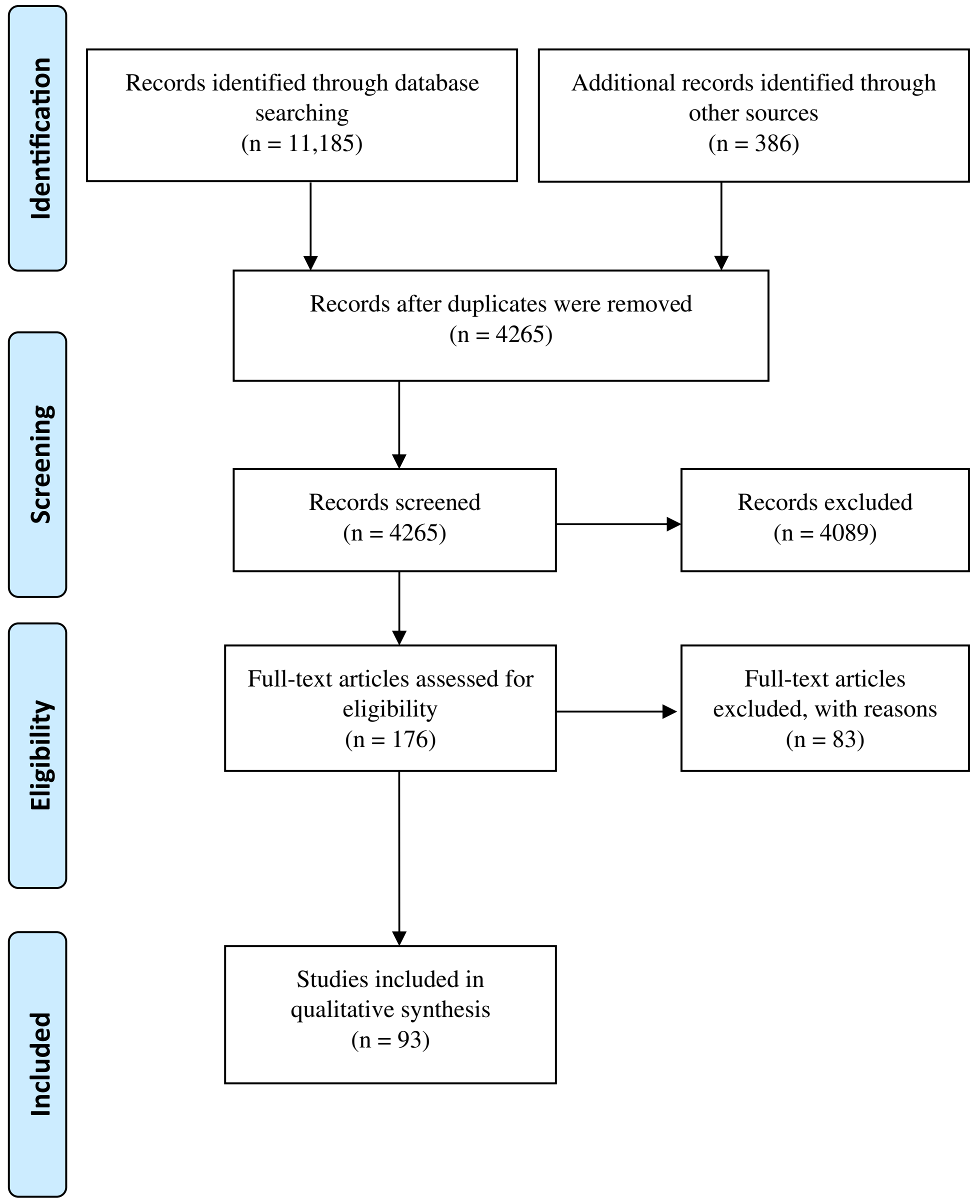
Each of the authors reviewed a total of two-thirds of the selected articles (2844) so each study was screened independently by at least 2 out 3 researchers to avoid selection biases, and the conflicts were solved by all the 3 research team members. This selection and exclusion strategy led to the exclusion of another 4089 studies, leading to a final selection of 176 articles to be assessed for quality purposes.

Quality review strategy

The quality review led to the exclusion of 83 studies that, despite focusing on adult ADHD, did not achieve enough quality in the following terms:

- Studies that focused on samples with ADHD symptoms, without a confirmed diagnosis.
- Studies that claimed focusing on cognitive domains but which did not report cognitive measures (i.e., saccades, gait, motor aspects, driving abilities…).
- Studies with no control group to which compare results on different cognitive domains.

Fig. 1 PRISMA flow diagram



- Studies with psychiatric populations and thus showing complex profiles with comorbidities.
- Studies with ADHD mixed samples of individuals with and without comorbidities, or individuals with and without medication at the time of the study, that report results as a unique, joint, non-differentiated ADHD group.
- Studies with ADHD samples with a primary focus on other target conditions (e.g., PTSD).
- Studies with ADHD samples that included special features such as bilingualism or individuals with high IQ only, as well as individuals on special institutions for learning disabilities, who would not be representative of an average ADHD profile.

This quality review strategy led to a final number of 93 studies finally included in the systematic review.

Results

Figure 1 shows the PRISMA Diagram with the search and filtering process followed from the initial identification of potential eligible studies to the final selection of 93 studies included in this systematic review, encompassing findings from a total 5574 adults diagnosed only with ADHD, medication-naïve or non-medicated at the moment of the assessment, 4880 healthy controls, and 1323 adults with other conditions, from other clinical/psychiatric conditions to individuals with ADHD under medication at the time of the study and/or comorbidities that made it difficult to establish an ADHD-only cognitive profile. The selected pool of articles consisted of 92 case–control studies and 1 longitudinal study, as the approach undertaken in this systematic review excluded those cross-sectional studies lacking a healthy control group.

For a structured review of these studies, we categorized them into different cognitive domains, based on outcomes related to individual cognitive domains. Initially, we created a section called miscellaneous to include studies on adult ADHD reporting on more than one cognitive domain, and then we divided each reported set of results into one of the following categories, so some of those miscellaneous studies may repeat throughout the different sections. We decided this to provide further clarity on the specific results obtained for each cognitive domain, developing one specific section for each as follows: (1) attention, (2) executive functions (including working memory or similar theoretical constructs), (3) learning and memory, (4) language, (5) social cognition, and (6) arithmetic.

Attention and processing speed

Table 1 summarizes the 47 studies that have been found in relation to a characterization of attention and processing speed features in individuals with adult ADHD.

General results reflecting a worse attentional performance in ADHD versus healthy controls were reported by Biederman et al. (2010) and Mostert et al. (2018). Fuermaier et al. (2015) reported results based on both self-reported and neuropsychological testing, indicating significant worse self-reported performance in attention in terms of experiences of deficits ($d = 2.23$) and complaints ($d = 2.65$) and worse neuropsychological performance in selective attention ($d = 0.57$) and vigilance ($d = 0.52$). The most comprehensive results were obtained by Fuermaier et al. (2016) and Tucha et al. (2017), where ADHD patients showed significant, medium sized effect, *deficits across all attentional modalities*, such as alertness, selective and sustained attention (vigilance). A similar pattern of comprehensive attentional differences was found even when more ecologically, close to real situations, were used to evaluate all attentional modalities. Thus, Groen et al. (2019), showed reduced attention scores with large effect sized on all nine *situations of everyday life* (reading a book, watching a movie or documentary, or attending a lecture, among others) when compared to matched healthy controls, and showed specific attention difficulties when compared also to individuals with other psychiatric disorders in reading a book, doing an assignment, performing an indoor activity or having a conversation.

Inattention problems, usually measured as omission errors across different tests, have been reported as more significant for ADHD individuals by Studerus et al. (2018) ($p < 0.0001$). Kalanthroff et al. (2013) showed that irrelevant stimuli, both at a local and global level, produced similar interference in ADHD participants, but an alerting cue could make global processing in ADHD participants comparable to that of healthy controls. Pretus et al. (2020) reported a significantly higher susceptibility to distractors in ADHD versus controls. Similarly, Pelletier et al. (2013) reported a greater susceptibility to distraction and worse performance under irrelevant sound conditions for individuals with ADHD, indicative of impaired *selective attention*, while Salomone et al. (2020) did not report significant differences. Kallweit et al. (2019) also showed adult ADHD individuals exhibiting a slower performance in a selective attention task while displaying higher hyperactivity and feeling less calm than controls, while Lin and Gua (2020) reported worse selective attention in both early and late onset adult ADHD groups when compared to controls. Previously, Pazvantoglu et al. (2012) had reported that ADHD persisters showed worse inattention problems than both remitters and controls, while for omission errors of the CPT, these were high both in persisters and remitters.

With regards to *impulsivity*, Torres et al. (2017) reported impulsivity measures as significantly higher for individuals with ADHD versus healthy controls, as shown by higher number of commission errors and a worse response style score in the CPT-II, although Marx et al. (2013) reported ADHD patients were able to exhibiting longer reaction times as a strategy to prevent impulsivity errors. Millioni et al. (2014) described impulsivity (in the form of commission errors) in ADHD patients as worse than controls as the only measure of an extensive neuropsychological battery that could not be masked by individuals with a high IQ.

As a reflection of both this inattention and impulsivity, Sethi et al. (2018) showed that ADHD patients were significantly more persistent in selecting novel stimuli after their initial introduction and showed a trend towards a lower selection of familiar options. These outcome was also in line with Tatar and Cansiz (2019), who reported worse performance both in terms of inattention (lower correct answers and higher omission scores, $d = 0.93$) and impulsivity ($d = 0.74$); and with Grane et al. (2014), who had shown both significant more omission and commission errors in individuals with ADHD as compared to healthy controls.

For *divided attention*, Muller et al. (2007) showed that patients reflected worse slower performance than controls, especially for auditory stimuli, as well as Salomone et al. (2020), who reported ADHD group showing impaired performance in the form of significantly higher dual task decrement scores compared to healthy controls. Similar results had previously been reported by Roberts et al. (2012) who showed that ADHD patients performed slower than controls in a dual task and this slowing was more pronounced when inter-task intervals were shortened.

Table 1 Studies showing results for attention and processing speed domains

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Adams et al. (2011)	ADHD (n = 30) HC (n = 28)	ADHD = 21.1 (1.7) HC = 22 (1.7)	Delayed oculomotor response (DOR) task	ADHD displayed more premature saccades (i.e., greater distractibility). Greater variability in RT was associated with increased distraction on the DOR task but only in ADHD participants
Aycicegi-Dinn et al. (2011)	ADHD (n = 13) HC (n = 19)	ADHD = 28.31 (6.89) HC = 27.11 (7.77)	Auditory continuous performance test Go/No-Go task Stroop colour-word test Trail Making Test -A	ADHD demonstrated performance deficits on the auditory CPT in comparison with HC (U = 51.5, p = .007). Groups differed significantly on the first (U = 65.0, p = .038) and third (U = 59.0, p = .02) blocks of the CPT. ADHD displayed significantly slower response times during the non-conflict block of the Go/No-Go task (U = 57.0, p = .01) and during three of the four non-conflict blocks of the Stroop Colour-Word Test, including colour-word naming (block 2; U = 67.0, p = .03), colour naming (blocks printed in different colours; block 3; U = 47.5, p = .003), and colour naming (*n*on-colour words printed in different colours; block 4; U = 40.0, p = .002). Stroop task performance was relatively error free and group differences did not approach significance with the following exception: ADHD made a significantly greater number of self-corrected errors during the colour naming condition (i.e., non-colour words printed in different colours; U = 63.0, p = .039) ADHD demonstrated slower response times during part A of the TMT (U = 69.5, p = .037)
Biederman et al. (2010)	ADHD (n = 116) HC (n = 146)	ADHD = 37.8 (9.8) HC = 30.3 (8.7)	WAIS-III (vocabulary, digit span, symbol search)	ADHD was associated with lower scores on all cognitive measures assessed across the adult life cycle when compared to non-ADHD controls in a natural course of adult cognitive development
Bisch et al. (2016)	ADHD (n = 23) HC (n = 31)	ADHD = 27.6 (9.3) HC = 29.3 (8.2)	Testbatterie zur Aufmerksamkeitspruefung (TAP, Zimmermann and Fimm 2009), sustained attention and alertness subtests	Significantly more errors and misses in the subtest "sustained attention" (TAP) and higher variation of reaction times (alertness constancy) during the subtest "alertness"' (both p < .01). Moreover, differences between reaction times without and those with reaction time during the subtest ''alertness'' were higher in ADHD, representing a higher ''phasic alertness'' The parameters for intrinsic alertness of the subtest ''alertness'' failed to reach significance in the group comparison
Carr et al. (2006)	ADHD (n = 72) HC (n = 67)	ADHD = 23.1 (4.0) HC = 24.2 (4.9)	Antisaccade task Attentional blink task GAF	ADHD committed more errors in both baseline and dual-task conditions, but no consistent evidence was found that they differed reliably from HC with respect to the pattern or magnitude of the attentional blink phenomenon
Deliste and Braun (2011)	ADHD (n = 30) HC (n = 30)	ADHD = 39.03 (10.7) HC = 40 (9.84)	CPT-II	Despite statistical control for depression and anxiety, the ADHD group made more errors of commission than controls on the CPT-II (56 (13) vs 46 (10), F = 7.54, p = .008) and detectability index for sustained attention (55 (9) vs 50 (8), F = 6.66, p = .012)
Dobson-Patterson, et al. (2016)	ADHD (n = 32), 16 ADHD-I, 16 ADHD-C HC (n = 30)	ADHD-I = 40.7 (13.2) ADHD-C = 35 (12.9) HC = 39.6 (12.9)	CPT-II, Digit Span Forward of the WMS-III	No clear differences between ADHD subtypes and healthy controls
Finke et al. (2011)	ADHD (n = 30) HC (n = 30)	ADHD = 35.5 (9.49) HC = 35.96 (10.39)	TVA model based computerized task	No significant differences in perceptual processing speed
Fried et al. (2012)	ADHD (n = 56) HC (n = 63)	ADHD = 28.3 (8.5) HC = 30.8 (10.2)	Digit Span, DKEFS, Trail Making Test Workplace simulation tasks	Significant observable differences between groups on the video task, which required the most vigilance and sustained attention. Math Fluency task and editing task significantly impaired in ADHD: task under timed conditions and high level of attention to detail are key weakness in ADHD individuals (this in the structured periods). Less discriminating performance in the unstructured period

Table 1 (continued)

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Fried et al. (2016)	ADHD (n = 26) HC (n = 52) Other: ASD (n = 26)	ADHD = 28.2 (5.6) HC = 27.5 (4.1) ASD = 27.5 (6.2)	WAIS-III, DKEFS, Trail Making Test	No significant differences in attention between ADHD and HC
Fried et al. (2019)	ADHD (n = 474) HC (n = 163)	ADHD = 31.6 (11.1) HC = 30.8.(9.9)	CANTAB attention subtests (RT, shifting of attention, sustained visual attention and arousal)	No significant differences in attention between groups. Results failed to show any diagnostic utility for the CANTAB, even when using the most robust tests (AGN Total Commissions and RTI Simple Reaction Time) identified from stepwise logistic regression (forward selection; $p > 0.05$ for entry). Differences between groups in Total Commissions (Affective Go/No-Go)
Fuermaier et al. (2015)	ADHD (n = 55) HC (n = 66)	ADHD = 34.6(10.7) HC = 31.9 (10.2)	Questionnaire for experiences of attention deficits (FEDA) Questionnaire for Complaints of Cognitive Disturbances (Attention Subscale – FLei-Ad) Selective attention and Vigilance (Test Battery for Attentional Performance)	Significant worse self-reported performance in attention: FEDA: ADHD 3.27(0.74) vs HC 1.95 (0.43), t(119) = 12.29, $p < .001$, Cohen's $d = 2.23$, % of patients with impairment: 85 FLei-Ad: ADHD 2.56 (0.66) vs HC 0.87 (0.66), t(119) = 14.31, $p < .001$, Cohen's d = 2.65, % of patients with impairment: 85.2 Selective Attention: ADHD: 5.49 (1.60) vs 4.62 (1.49), t(119) = 3.06, $p = .003$, Cohen's $d = 0.57$, % of patients with impairment: 38.2 Vigilance: ADHD: 2.56 (3.67) vs 1.12 (1.75), t(119) = 2.83, $p = .005$, Cohen's $d = 0.52$, % of patients with impairment: 42.9 ADHD showed a significantly decreased performance in all neuropsychological tests, and self-reported attention deficits in 92% of cases, while objective attention measures showed significant differences but with lower size effects
Fuermaier et al. (2017a, b)	ADHD (n = 36) off-medication ADHD (n = 31) on medication HC (n = 36)	ADHD off = 34.1 (10.5) ADHD on = 33.9 (9.6) HC = 34.1 (10.9)	Test battery for Attentional Performance (Zimmermann and Fimm 2008): alertness, selective attention, vigilance	Significant group differences of medium size were found on all measures of attention, including tonic alertness (F(2,97) = 6.43, p = .002, $\eta^2 = .117$), phasic alertness (F(2,97) = 5.10, $p = .008$, $\eta^2 = .095$), selective attention (F(2,97) = 5.37, $p = .006$, $\eta^2 = .100$), vigilance (F(2,97) = 3.20, $p = .045$, $\eta^2 = .062$), and inhibition (F(2,97) = 4.82, $p = .010$, $\eta^2 = .090$). Post hoc analysis revealed a significant decreased performance of patients with ADHD not-treated with MPH when compared to HC in all measures of attention, that is, tonic alertness ($p = .005$, $d = 0.73$), phasic alertness ($p = .017$, $d = 0.59$), selective attention ($p = .006$, $d = 0.76$), vigilance ($p = .047$, $d = 0.70$), and inhibition ($p = .012$, $d = 0.75$)
Grane et al. (2014)	ADHD Combined subtype (n = 36) HC (n = 35)	ADHD = 31.8 (10) HC = 32.2 (9.5)	ASR, TOVA (CPT & Go/No-Go), BRIEF-A	Less speedy reactions in the ADHD and significantly greater reaction time variability; ADHD group made significantly more omission errors to Go signals across conditions; tended to make more omission errors relative to controls in the 2nd half of the task, as well as more commission errors during the entire task
Groen et al. (2019)	ADHD (n = 80) HC (n = 80) Other psychiatric disorders (n = 56)	ADHD = 32.2 (10.7) HC = 32.3 (11.2) Others = 31.4 (8.8)	ELAS Scale: Nine sketches of situations of everyday life: reading a book (*Reading*), watching a movie or documentary (*Movie*), performing an indoor activity (*Activity*), attending a lecture or open evening (*Lecture*), having a conversation (*Conversation*), doing an assignment/administration (*Assignment*), preparing a meal (*Cooking*), cleaning up the house (*Cleaning up*), and driving a car (*Driving*)	ADHD have clearly reduced attention scores (with large effect sizes) on all nine situation scales of the ELAS and showed particularly strong attentional difficulties in comparison to both the control and the mixed clinical group in the following situations: Reading, Assignment, Activity, and Conversation. More than half of the patients with ADHD indicated impaired attention scores in five situations or more

Table 1 (continued)

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Hopwood and Morey (2008)	ADHD (n = 26) HC (n = 27)	Total 22.62 (5.80)	CPT-II; WAIS-III Personality Assessment Screener (PAS)	The increase in partial correlations between the CPT-II and ADHD when PAS scores were controlled suggested that emotional problems were suppressing the relation between CPT performance and ADHD
Holst nd Thorell (2017)	ADHD (n = 57) HC (n = 53)	ADHD = 26.8 (5.9) HC = 25.5 (5)	Reaction time variability: two non-set-shifting trials of the Navon like task	For RT variability, the ADHD group showed significantly higher variability compared with the controls, with a small effect size (ADHD: 1,848 (0.574) vs 1,630 (0.04), ANCOVA = 0.53 (0.01)
Kalanthroff et al. (2013)	ADHD (n = 20) HC (n = 20)	ADHD = 25.01 (2.05) HC = 22.8 (0.95)	Global–local Navon task in which they were asked to respond to the large stimulus or the small component stimuli, and to a Navon-like task with an alerting cue	Unlike controls, adults with ADHD did not have global precedence Irrelevant global stimuli (when asked to respond to the local level) and irrelevant local stimuli (when asked to respond to the global level) produced similar interference in ADHD Appearance of an alerting cue increased global processing bias (i.e., increased interference from global stimuli in the local block and reduced interference from local stimuli in the global block) for both groups, such that global processing in ADHD was comparable to that of controls
Kallweit et al. (2019)	ADHD (n = 36) HC (n = 36)	ADHD = 31.3 (8.88) HC = 31.7 (9.45)	Selective attention task	ADHD were significantly slower and HC reported substantially more concentration on Auction. For every manipulation factor/task, the ADHD group reported significantly more inattention and hyperactivity and felt substantially less calm than did the controls
Lin and Shur-Fen (2020)	ADHD (n = 183, 142 early, 41 late) HC (n = 148)	Early onset ADHD = 27.6(6.23) Late onset ADHD = 28.74(6.12) HC = 24.74(5.03)	CANTAB (RT, sustained attention/signal detectability RVP)	The early-onset ADHD group had longer reaction time than HC in the simple analysis Both the early- and late-onset ADHD groups were impaired in the probability of hit (sustained attention), A′, and mean latency (signal detectability) of RVP in both the simple analysis and the first model of multiple analysis. Only the early-onset ADHD group showed significant impairment in the probability of hit, and A′ and both ADHD groups showed impairment in mean latency in the second model of multiple analysis
Low et al. (2019)	ADHD (n = 42) HC (n = 42)	ADHD = 26.9 (7.37) HC = 26.7 (5.6)	Bundesen's Theory of Visual Attention (TVA)	ADHD had significantly higher levels of ADHD symptomatology on both self-report and clinician-rated rating scales; on average, the patients were rated as having moderate to severe ADHD symptomatology. Significant differences were found between patients and controls for three of the five TVA parameters For the variables of primary interest, K and C, patients had a significantly smaller VSTM capacity K, t(82) = −3.306, p = .001, and a significantly slower processing speed C, t(82) = −2.776, p = .007 When the analyses were undertaken excluding the ten patients screening positive for dyslexia, group differences regarding processing speed were reduced to trend level, t(72) = −1.696, p = .094; findings initially remained significant for VSTM capacity K, t(72) = −2.163, p = .034, but was reduced to trend when controlling for IQ (p = .071). For the three other TVA variables, a significant difference was found between the groups for parameter t0, reflecting that patients had a significantly higher threshold of conscious perception than controls (U = 520.5, p = .001) Differences between groups were not significant for efficiency of top–down control of attention (α), or spatial bias of attention. The analyses were very similar when excluding participants screening positive for dyslexia

Table 1 (continued)

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Luna-Rodriguez et al. (2018)	ADHD (n=38) HC (n=39)	ADHD=36.14 (12.17) HC=33.61 (9.18)	TAP; WAIS-IV; ad hoc created battery with a task switch protocol without proactive interference (The experiment combined orthogonally task-switch vs. repetition, and attentional set shift vs. no shift. Each experimental stimulus had global and local features (Hierarchical/ "Navon" stimuli), associated with corresponding attentional sets)	ADHD patients were slower than controls in task switch trials with a simultaneous shift of attention between global/local attentional sets ADHD is associated with a deficit in flexible deployment of attention to varying sources of stimulus information
Lundervold et al. (2011)	ADHD (n=58) HC (n=56)	ADHD=33.60 (9.3) HC=29.2 (7.1)	Attention Network Test (ANT) Mood Disorder Questionnaire (MDQ)	Adults with ADHD did not differ on ANT measures of the three attention networks, but they showed a lower accuracy, a higher intra-individual variability, and lower vigilance across the task. The effect sizes were mainly moderate, but only the accuracy measures retained statistical significance when controlled for age and intellectual function In a subgroup of ADHD with affective fluctuations, it was found an impact on the alerting and control networks, and on the measure of hit reaction time. The subgroup was significantly more distracted by conflicting stimuli and slower to respond, and their results on the measure of the alerting network suggest that they were more alert. Furthermore, the total ASRS and IQ scores had a major impact on the RT and the control network in this ADHD subgroup, while the alerting network was left unaffected
Marchetta et al. (2008)	ADHD (n=28) HC (n=28) Others: ADHD with comorbidities (n=68)	ADHD=33.80 (9.64) HC=32.22 (10.49) ADHD with comorbidities= 32.36 (8.23)	Amsterdam Neuropsychological tasks	Adults with ADHD only and with comorbidity display a specific deficit in sustained attention compared with HC. It pertains to specific regulatory problems in maintaining a consistent level of performance, suggesting a less optimal effort allocation in adult ADHD. The ADHD adults with comorbidity show additional deficits on the focused attention task (i.e., lower accuracy), a finding that was specific to this group, suggesting higher vulnerability to (complex) controlled processing demands and difficulty in inhibiting foils. These findings provide evidence for a specific deficit in sustained attention control, irrespective of comorbidity, rather than a deficient response inhibition
Maruta et al. (2017)	ADHD (n=23) HC (n=23)	ADHD=37.3 (20–54) HC=36.8 (21–55)	ANT;Spatial Span subtest of the WMS-III Visual tracking testing protocol was implemented on an integrated stimulus presentation-eye tracking apparatus (EyeLink CL, SR Research, Ontario, Canada)	Even when on medication, patients performed more poorly than controls on visual tracking and simple reaction time tasks immediately following other attention-demanding tasks Patients' visual tracking performance degraded while off-medication in a manner consistent with reduced vigilance
Marx et al. (2013)	ADHD (n=38) HC (n=40)	ADHD=25.1 (2.05) HC=22.8 (0.95)	Continuous performance task (CPT)	Impaired performance in the ADHD group was observed for RT variability in the CPT Furthermore, when rewarded, subjects with ADHD exhibited longer reaction times and fewer false positives in the continuous performance task, which suggests the use of strategies to prevent impulsivity errors
Mehren et al. (2019)	ADHD (n=23) HC (n=23)	ADHD=29.9 (9.5) HC=29 (7.4)	Flanker Task; Visual task	Slowed processing speed both in Flanker congruent and incongruent tasks in ADHD group, that improved with exercise and paired with HC. So, exercise improved attention processes and interference

Table 1 (continued)

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Millioni et al. (2014)	ADHD IQ ≥ 110 (n = 20) ADHD IQ < 110 (n = 31) HC (n = 33)	ADHD IQ ≥ 110 = 27.84 (6.54) ADHD IQ < 110 = 28 (6.11) HC = 26.82 (5.49)	WCST; Stroop; TMT; CPT; COWAT; WASI	The ADHD group with high IQ underperformed the control group only in an impulsivity score (commission errors)
Mostert et al. (2015)	ADHD = 155 HC = 143	ADHD = 35.56 (10.4) HC = 36.30 (11.75)	DS (WAIS III); Flanker task; SA-dots); SART; TMT	The largest effect sized were observed for measures of performance variability, both in terms of fluctuations in errors as in reaction times
Mostert et al. (2018)	ADHD (n = 133) HC (n = 132)	ADHD = 35.56 (10.40) HC = 30.3 (7.7)	Measures tapping into EF (WM, attention, inhibition, set-shifting, fluency) and delay discounting	The best-fitting six-factor solution produced a superior fit over competing models: $\chi^2(104) = 167.81$, CFI = 0.925, TLI = 0.901, RMSEA = 0.048, 66 free parameters. Six factors were labelled as "reaction time and reaction time variability, "delay discounting," "verbal fluency," "working memory, "attention," and "inhibition." Patients with ADHD performed significantly worse than healthy controls on all six factors
Muller et al. (2007)	ADHD (n = 30) HC (n = 27)	ADHD = 33.8 (8.2) HC = 20 (1.17)	TMT-A, Test of Attentional Performance (TAP): divided attention ask and covered orienting of attention	A difference in performance between groups was found in TMT. Relative to HC [23.8 (7.3)], patients [34 (9.1)] took more time in the visual scanning of numbers [$F(1,55) = 21.5$, $p < .001$, partial Eta = 0.28 (medium) In the divided attention task patients showed slowing tended to be slightly larger in the visual as compared to the auditory domain. However, the multivariate analysis of variance did not show a significant group (ADHD/control) x domain (auditory/visual) effect ($F(1,55) = 1.8$, $p = .187$). The number of errors to auditory stimuli was higher in patients than HC, but there was no difference between patients and controls in errors to visual stimuli In the covered orienting of attention task, overall slowed RT were found in patients with persistent ADHD. Invalid cues led to higher RT in patients. In a multivariate analysis of variance combining group, laterality, and validity of cues, a significant two-way interaction between group and cue validity was found ($F(1,55) = 8.1$, $p = .006$). No significant effects were found with regard to other interaction effects involving the group factor. Patients made more errors on valid cued targets on the right than on valid left or invalid left or right cued targets
Nikolas et al. (2019)	ADHD (n = 109) HC (n = 52) Other: Depression (n = 85)	ADHD = 24.8 (6.2) HC = 23.6 (5.4) Depression = 22.9 (4.5)	PASAT-100; the Salthouse Listening Span Test; TOVA; the Dot Counting Test	While single test measures provided performed poorly in identifying ADHD participants, analyses revealed that a combined approach using self and informant symptom ratings, positive family history of ADHD, and a RT variability measure correctly classified 87% of cases
Paucke et al. (2019)	ADHD (n = 18) HC (n = 54) Other: ADHD + Depression (n = 26) Depression (n = 23)	ADHD = 29.9 (1.7) HC = 29.3 (1.1) ADHD + Depression = 33.0 (1.8) Depression = 41.5 (2.8)	CAARS Test of Attentional Performance (TAP)	A reduced alertness and higher variations in reaction times measured by performance tests indicated problems in sustained attention in ADHD patients compared with HC
Pazvantoglu et al. (2012)	ADHD persisters (n = 30) ADHD remitters (n = 35) HC (n = 30)	ADHD persisters = 37.0 (6.5) ADHD remitters = 39.3 (5.7) HC = 37.7 (5.5)	Turkish version of verbal and non-verbal Cancellation Test (CT); CPT; TMT; Stroop Test	Significant differences among the three groups in tests of attention; omission error scores of CT-random letters, CT-random figures, omission error score of CPT, and the 4th subtest score of Stroop Test. On three of these four measures, persisters showed worse performance than both HC and remitters, while in omission error score of the CPT, there was a significant difference only between persisters and HC. No significant difference among groups in other tests or subtests (omission error scores of CT-organized letters and of CT-organized figures scores; 1st, 2nd, and 3rd subtest scores of Stroop Test; TMT-A score) that measure attention functions

Table 1 (continued)

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Pelletier et al. (2013)	ADHD ($n=32$) HC ($n=32$)	ADHD = 34.44 (11.23) HC = 35.44 (11.10)	WAIS-III, vocabulary and matrix reasoning subtests; BRIEF; Experimental task E-Prime software on a PC	The effect of interference—comparison between quiet and irrelevant sound conditions—was significant for both control participants, $t(31)=2.08$, $p<.05$, $d=0.21$, and ADHD, $t(31)=4.89$, $p<.001$, $d=0.58$, though the effect size was greater for the group of adults with ADHD ADHD have a greater susceptibility to distraction (impaired selective attention), despite a preserved ability of sustained attention. The impact of irrelevant sound also shows a positive relationship with inattentive symptoms reported by ADHD in a clinical questionnaire
Pettersson et al. (2018)	ADHD ($n=60$) HC ($n=48$)	ADHD = 28.18 (9.09) HC = 32.75 (10.61)	Diagnostic Interview of ADHD in Adults (DIVA 2.0) Digit Symbol—Coding (WAIS-IV), D-KEFS, PASAT, QBTest Plus and CPT II	With the ADHD group performing poorly in comparison with the non-ADHD group, overall, all tests showed a very poor ability to classify patients into the correct group. Total classification accuracy was 53% to 66%—hardly better than chance. The majority of the tests showed relatively good specificity but very low sensitivity with the exception of the variables QBTest cardinal variable Activity and QBTest Omission errors, which showed the opposite pattern Most of the neuropsychological tests appeared to be related to age and especially to levels of estimated full-scale IQ (e.g., the PASAT test), as many of the differences between the groups disappeared when controlling for these variables. The only tests found to be relatively insensitive to differences in IQ were the two continuous performance tests: QBTest Plus and CPT II
Pretus et al. (2020)	ADHD ($n=21$) HC ($n=24$)	ADHD = 36.48 (6.90) HC = 34.33 (7.73)	WURS, CAARS	Time estimation error measures were not significantly different in ADHD. However, the absolute difference in performance between distractor and non-distractor trials was significantly larger, $t(43)=-2.213$, $p=.032$, in the ADHD group ($M=3.29$; $SD=2.11$) than HC ($M=2.06$; $SD=1.62$), that is, the ADHD patients were more susceptible to distractors
Roberts et al. (2012)	ADHD = 38 HC = 33	ADHD = 21.3 (1.7) HC = 22.1 (1.7)	Dual task (PRP task)	ADHD group was slower to response overall to task 2 of the dual task when compared to controls, as well as more pronounce slowing as the intertask interval shortened
Salomone et al. (2020)	ADHD ($n=51$) HC ($n=28$)	ADHD = 32.78 (10.96) HC = 30.6 (10.3)	The Telephone Search While Counting from the Test of Everyday Life Attention (TEA); SART; Auditory oddball task; Hotel task; ARCEQ	ADHD group showed significantly higher dual task decrement's scores ($t(77)=2.19$, $p=.04$), indicating impaired performance Selective attention. No significant differences between groups in the two selective attention subtests—Elevator Counting With Distraction: $t(77)=1.66$, $p=.67$, and Telephone Search: $t(77)=1.85$, $p=.39$
Segal et al. (2015)	ADHD ($n=26$) HC ($n=24$)	ADHD = 26.42 (3.18) HC = 25.33 (3.18)	CCPT; CVST; a Go/No-go response inhibition task for response inhibition	Sustained attention: ADHD were more variable in their RT on the CCPT (standard deviation of 80.59 ms) than HC (standard deviation of 56.44 ms); this two-tailed independent samples t-test was significant ($t(32)=-3.48$, $p<.01$, Cohen's $d=0.97$) Selective spatial attention and Go/No-go: non-significant differences

Table 1 (continued)

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Sethi et al. (2018)	ADHD ($n=30$) HC ($n=30$)	ADHD = 33.7 (9.51) HC = 32.6 (9.54)	Conners self-report Adult ADHD Rating Scale (CAARS) Novelty Processing Computerized Task	Unmedicated ADHD participants were significantly more likely than HC to choose novel compared to familiar options on their first presentation [Group Familiarity: F(1,58) = 8.83, $p=.030$] with a heightened salience of intrinsically 'novel' stimuli rather than an increased propensity to choose all newly introduced stimuli [% novel items selected: ADHD: 16.8 (± 1.23); control: 12.3 (± 1.09), F(1,58) = 8.83, $p=.004$; % familiar items selected: ADHD: 15.3 (± 1.03); control: 14.0 (± 1.05); F(1,58) = 0.72, $p=.399$) When ADHD participants were unmedicated, poorer performance was associated with greater persistence in selecting novel stimuli after their initial introduction and a trend towards lower persistence in selecting familiar options. Novelty/reward-related behavioural features explain up to 41% of the variance in clinical ADHD phenotype
Studerus et al. (2018)	ADHD ($n=123$) HC ($n=109$) Other: At-Risk mental State for psychosis ($n=168$)	ADHD = 31.6 (9.83) HC = 25 (5.28) ARMS = 25.4 (7.23)	CPT	Significant differences were found between ADHD and controls in CPT measures like False alarms (ADHD: 3.8 (12.3) vs. HC 1.1 (2.2), p < .0001), Omissions (ADHD: 1.9 (4.4) vs. HC 0.4 (0.8), $p<.0001$) and Reaction Time (ADHD: 531 (137.4) vs. HC 391.3 (82.7), $p<.0001$)
Tatar and Cansiz (2019)	ADHD ($n=50$) HC ($n=50$)	ADHD = 21.56 (3.94) HC = 22.22 (3.11)	TMT CPT	ADHD group had a lower number of correct answers in the CPT (mean = 46.06, SD = 7.91 and mean = 51.86, SD = 3.79, respectively; t(98) = 4.67, $p<.001$), higher omission scores (7.94 ± 7.91 and 2.16 ± 3.79, respectively; t(98) = − 4.656, $p<.01$, Cohen's $d=0.93$) and higher commission scores (5.82 ± 6.29 and 2.28 ± 2.841, respectively; t(98) = − 3.713, $p<.001$, Cohen's $d=0.74$). No group differences were found on TMT A time
Torres et al. (2017)	ADHD ($n=50$) HC ($n=86$) Other: ADHD + BD = 23 Bipolar Disorder ($n=70$)	ADHD = 37.08 (12.3) HC = 43.31 (13.8) ADHD + BD = 41.52 (9.6) Bipolar Disorder = 46.34 (10.5)	TMT-A, SCWT, Symbol search and digit symbol of WAIS-III CPT-II	All the clinical groups had poorer performance than the HCs in the attentional domain Differences in favour of HC versus ADHD in number of commission errors and response style score in the CPT
Tucha et al. (2017)	ADHD ($n=29$) HC ($n=30$)	ADHD = 33.5 (11.11) HC = 33.4 (12.5)	Vienna Test System (VTS)	Compared to healthy individuals, patients with ADHD showed significant deficits of medium size in selective attention and divided attention. Furthermore, medium sustained attention deficits was observed in measures of alertness, selective attention and divided attention
Vekaria and Peverly (2018)	ADHD ($n=22$) HC ($n=50$)	ADHD = 23.63 (4.17) HC = 22.18 (3.40)	TEA; The listening span test is based on one used by Daneman and Carpenter	There were no reliable differences between groups on sustained attention
Weyandt et al. (2013)	ADHD ($n=24$) HC ($n=26$)	ADHD = 20.17 (1.20) HC = 20(1.17)	Conners' Continuous Performance Test (CPT-II; Conners 2000)	Students with ADHD demonstrated greater variability in the Standard Error of RT [ADHD: 50.76 (13.80) vs HC 41.65 (8.65), $d=0.798$ (0.217, 1.372), F(1,46) = 7.921, $p=.007$], but did not differ on the other six CPT II scales

In terms of *sustained attention*, Marchetta et al. (2008) reported a specific deficit in sustained attention control for ADHD patients, regardless of whether it was their only diagnosis or showed comorbidities, suggesting specific regulatory problems to maintain a consistent level of performance. Deliste and Braun (2011) reported differences for commission errors with the addition of a worse performance in sustained attention**,** as measured by the CPT-II detectability index. Moreover, Adams et al. (2011) showed that ADHD group showed a greater variability in reaction time associated with an increased distraction when performing a delayed oculomotor response task. Fried et al. (2012) showed, by means of different workplace simulation tasks, that ADHD participants exhibited worse performance than controls in those tasks requiring most vigilance and sustained attention, suggesting working under timed conditions and high demands of attention to detail as key weaknesses in ADHD individuals. Mostert et al. (2015) presented largest effect sizes in the comparison between ADHD and controls in measures of performance variability, both in terms of fluctuations and reaction times, showing problems in reaction time variability, representative of sustained attention, as one of the most robust features of ADHD; results which are similar to those reported by Segal et al. (2015). Bisch et al. (2016) confirmed significantly more errors and misses in sustained attention and a higher variation of reaction times in ADHD compared to controls. Luna-Rodriguez et al. (2018) partially reported more variable reaction times in ADHD participants, but performance improved when the attention set was kept constant. Mehren et al. (2019) showed that reaction time variability, significantly more pronounced in ADHD patients, could decrease with exercise. Sustained attention deficits as compared to controls were also reported by Weyandt et al. (2013), as represented by the CPT II Standard Error of reaction time (*Cohen's* $d = 0.798$), as well as by Grane et al. (2014) on the TOVA test; by Holst and Thorell (2017) on a Navon like task (ANCOVA = 0.53); by Maruta et al. (2017) when measuring visual tracking performance with the Attention Network Test and Spatial Span of the WMS-III, and by Paucke et al. (2019), with reduced alertness and higher variations in reaction times measured by the TAP test. More recently, Lin and Gua (2020), who went further by detailing specific differences for early-onset and late-onset ADHD participants when compared to healthy controls, showed that only early-onset individuals showed significant impairment in the CANTAB probability of hit (sustained attention) in a second model of multiple analysis, while initially both early and late onset groups had showed impairment. For Nikolas et al. (2019), there is a need to go beyond single test measures and suggest that a combined approach using self and informant symptom ratings, together with family history and reaction time variability for sustained attention could help correctly classify 87% of cases.

In relation to *processing speed*, significantly slower response or reaction times in adults with ADHD have been repeatedly reported across examined studies. Muller et al. (2007) reported ADHD individuals needing significantly more time than controls for TMT-A and slower reaction times in the covered orienting of attention task of the TAP. Aycigegi-Dinn et al. (2011) reported worse performance deficits in ADHD participants for the auditory part of the CPT, for the non-conflict block of a go/no-go task, for non/conflict blocks of the Stroop Colour-Word Test and also slower response times during Trail Making Test part A. Studerus et al. (2018) reported a significant slower reaction times for individual with ADHD versus controls ($p < 0.001$), similar to Grane et al. (2014). Maruta et al. (2017) reported that patients with ADHD performed more poorly than controls on visual tracking and simple reaction time tasks, even when on medication. Low et al. (2019) also reported significant slower processing speed levels for individuals with ADHD, but those differences were reduced to trend level after excluding a subgroup of ADHD patients positive for dyslexia. Separately, for the trail Making Test part A, Tatar and Cansiz (2019) reported no group differences on Trail A time ($p > 0.05$).

With regards to negative or non-conclusive results, four studies (Dobson-Patterson et al. 2016; Finke et al. 2011; Fried et al. 2016; Vekaria and Peverly 2018) did not report any significant difference between adult ADHD patients and healthy controls across a different range of measures, both paper-based (Digit Span Forward, TMT-A, or Test of Everyday Attention, among others) or computer based (Conners' CPT/II or TVA model based computerized task). Carr et al. (2006) documented the lack of convincing evidence of an abnormal worse attentional filtering in adult ADHD versus healthy controls. Hopwood and Morey 2008) only reported correlations between CPT-II and ADHD self-reported symptoms when emotional symptoms were not considered, suggesting the need of both cognitive and affective evaluations in ADHD. Lundervold et al. (2011) found only moderate results with a great influence of age and intellectual function. Pettersson et al. (2018) reported significant sensitivity problems in neuropsychological tests, with great influence form age and IQ, showing that only continuous performance tests (e.g., QBTest Plus and CPT-II) showed relative insensitivity to these variables. Fried et al. (2019) only showed discrete results showing higher impulsivity in adult ADHD versus controls in impulsivity measures (i.e., total commissions in the CANTAB affective go/no-go task).

In general, the use of the attentional domain as a way to clearly differentiate between adults with ADHD and healthy controls has shown more positive than negative results. Although only 7 of the reported studies seem to have large sample sizes of more than 100 per group (Biederman et al. 2010; Fried et al. 2019; Lin and Gua 2020; Mostert et al.

2018; Nikolas et al. 2019; Studerus et al. 2018), outcomes point to a considerable clear attention profile in terms of inattention deficits, higher distractibility to irrelevant stimuli resulting in problems of selective attention, high impulsivity regardless of age and IQ, difficulties to manage with multiple simultaneous sources of information (divided attention), significant variability of the reaction time as a robust manifestation of sustained attention problems and a general profile of slower processing speed (in some studies, even when medication was on).

Overall, this profile, which some studies were able to establish combining both self-reports and neuropsychological tests, should be kept in mind as a way to start defining a more characteristic distinct attentional profile for individuals with ADHD as compared with other learning difficulties or conditions.

Executive Functions (including working memory or similar theoretical constructs)

There are several studies analysing Executive Functions (EF), a total of 62 out of 93 in the current review (see Table 2). First, we are presenting those obtaining general results from EFs, or through constructs with an indirect relationship. Aycicegi-Dinn et al. (2011) and Stern et al. (2017) observed that although a higher degree of frontal symptoms was self-reported by the ADHD group, no clear differential deficits were noticed with respect to the healthy control (HC) group. However, Barkley and Murphy (2011) found just the opposite: the ADHD group had a more severe EF rating on all scales, using both self- and other-reports questionnaires. Moreover, they referred to a higher level of severity in these reported measures than what was found using just objective measures. Furthermore, patients reported a higher number of dysfunctions than what objective measures showed by themselves. In the same line, Grane et al. (2014) reported a greater degree of executive difficulties in ADHD patients (being clinically preeminent in the BRIEF-A the initiation, working memory (WM), plan/organize and task monitor, and Metacognition and Behavioural Regulation indexes) and Weyandt et al. (2013) reported greater overall executive dysfunction on all 12 BRIEF scales, similar to Stern et al. (2017), who found a greater deficit in the metacognitive components of EF.

The *abstraction ability* appeared to be impaired in one study (Millioni et al. 2014) and executive dysfunctions in *Theory of Mind* (ToM) in ADHD have been shown (Tatar and Cansiz, 2020). Regarding the measures of IQ, Biederman et al. (2010) had seen ADHD associated with different scores on these measures: 6.9 full-scale IQ points, 5.1 performance IQ points and 7.2 verbal IQ points. Faraone et al. (2006) were more specific comparing "full ADHD" (f-ADHD) and late-onset ADHD (lo-ADHD) subjects, and they noticed f-ADHD had a higher verbal, performance and full-scale score, while lo-ADHD had a lower performance IQ among late-onset subjects compared with ADHD-subthreshold (ADHD-s) subjects. Likewise, the onset age had a negative effect on full-scale IQ among ADHD groups, in the same way that all ADHD groups differed in EF deficits (EFD): ADHD-s and f-ADHD had the highest frequency, and lo-ADHD had the lowest, only above the HC group. Notwithstanding, there were no significant differences between the ADHD groups. Similarly, ADHD-s and f-ADHD showed the highest average number of impaired tests, followed by lo-ADHD and HC the last. Again, no differences between ADHD groups were found. In conclusion, late-onset ADHD may be the most cognitively impaired form of adult ADHD.

On the other hand, tests performed by ADHD patients tend to be biased by global–local processing style, different from what happened with the HC group (Cohen and Kalanthroff 2019). Similarly, they preferred novel options on the presentation of stimuli, heightening salience in their decision-making processes, and this salience explained 41% of the variance (Sethi et al. 2018).

Either way, FE ratings contribute significantly to the variance in ADHD symptoms and severity (Kamradt et al. 2014), especially, ratings of inattentive symptoms provided by late-onset ADHD patients (Lin and Gua 2020).

According to *functional measures*, EF deficits underlie the adaptive impairment associated with ADHD, but EF do not predict impairment independently of ADHD (Stavro et al. 2007). When EF are assessed by ratings of daily life activities, they make some contribution to occupational impairments (Barkley and Murphy 2010) and deficits in daily life activities are shown (Barkley and Murphy 2011).

Finally, some studies have found evidence of lowered performance in the general EF scope (Muller et al. 2007; Salomone et al. 2020), whilst other have found no differences in the typically deteriorated EF (In de Braek and Dijkstra 2011; Petersson et al. 2018; Saboya et al. 2009; Semrud-Clickemand and Harder 2010; Studerus et al. 2018), although in some cases and in other cognitive domains they do find deficits (Torres et al. 2017). No robust evidence of academic impairment is shown in ADHD group (Gropper and Tannock 2009).

Regarding neuropsychological domains, between 73 and 82% adults with ADHD refer a large dysfunction in all domains of EF from a small to large size effect, with the exception of fluency tests (Fuermaier et al. 2015).

Separately, bilingualism has not been an advantage to compensate deficiencies in EF measures, contrary to IQ, which improves performance in EF tasks (Milioni et al. 2017). Equally, the greater or lesser cognitive demand of the experimental task seems to be a relevant variable, so that the greater the cognitive demand, the worse the ADHD performance (Muller et al. 2007; Pazvantoglu et al. 2012;

Roberts, Milich and Fillmore 2012). This performance is worse when demands specifically relate to Working Memory (Hudec et al. 2014), resulting in ADHD individuals behaving more actively and showing ubiquitous hyperactivity, despite the fact that overall cognitive performance in ADHD typically suffers an unusual variability (Mostert et al. 2015; Nikolas et al. 2019). Moreover, these difficulties to manage demands may relate to results showing that ADHD individuals attempt a lower number of tasks than HC (Salomone et al. 2020).

Regarding the results obtained in different specific functions, we are going to start with *Working Memory* (WM). Some studies showed deficits in the WM global measure (Abdel-Hamid et al. 2019; Boonstra et al. 2010; Clark et al. 2007; Cohen and Kalanthroff 2018; Kamradt et al. 2014; Lineweaver et al. 2012; Mette et al. 2015; Mostert et al. 2015, 2018; Nikolas et al. 2019; Thorell et al. 2017; Torralva et al. 2011, 2013; Torres et al. 2017; Weyandt et al. 2013), and also in both verbal and visuospatial types (Alderson et al. 2013), so that Finke et al. (2011) establish that it is depleted by 20% of its capacity in a medium-to-large effect sizes (Rohlf et al. 2012). Nevertheless, Fuermaier et al. (2017a, b) observed only a small number of ADHD subjects exhibiting impairments in verbal WM, as well as a significantly lower performance in visuospatial WM; contrary to Gropper and Tannock (2009), who found just the opposite: an stronger deficit in auditory-verbal WM than in visuospatial WM. Kim et al. (2014) and Lin and Gua (2020) showed lower scores on spatial WM and Lineweaver et al. (2012) in auditory WM. Holst and Thorell (2017) showed a poorer performance in both WM subtypes, but when controlling for short-term memory and/or IQ, results did not show significance. Similarly, practice did not produce a facilitation effect (Lineweaver et al. 2012). Deficits in WM seem to be the same in young and old ADHD population. Although most do, some studies have not been able to verify deficits in WM (Roberts, Milich and Fillmore 2012; Vekaria and Peverly 2018), suggesting that deficits in this type of task are due to problems in other functions.

In terms of *inhibition capacity* and impulsivity, some studies have shown higher deficits in ADHD population compared to HC (Abdel-Hamid et al. 2019; Fried et al. 2016; Grane et al. 2014; Halleland et al. 2012; Holst and Thorell 2017; Kamradt et al. 2014; Lampe et al. 2007; Milioni et al. 2017; Mostert et al. 2018; Muller et al. 2007; Neely et al. 2017; Roberts et al. 2011, 2016; Sebastian et al. 2012; Stavro et al. 2007; Thorell et al. 2017; Torralva et al. 2013; Weyandt et al. 2013) with a medium effect size (Holst and Thorell 2017). ADHD patients exhibit a slowdown when trying to inhibit prepotent responses (Boonstra et al. 2010; Lampe et al. 2007), especially in medication-naive adults with persistent ADHD. ADHD groups, overall, make more commission errors than controls (Deliste and Braun 2011; Dobson-Patterson et al. 2016; Grane et al. 2014), especially in an affective inhibition test (Fried et al. 2016), regardless of their IQ. However, other studies have not found an inhibition deficit (Bueno et al. 2017; Pazvantoglu et al. 2012).

In relation to delay aversion, ADHD reported to be significantly more sensitive to delay aversion (with a medium size effect) when compared to HC and more prone to increase their response variability (Holst and Thorell 2017; Mostert et al. 2015, 2018; Thorell et al. 2017), and this performance showed to be independent from inhibition scores (Lampe et al. 2007; Mostert et al. 2015). Thus, ADHD have higher urgency, lower premeditation and lower perseverance (and higher self-reported impulsivity behaviours), with combined subtype of ADHD showing higher scores than inattentive subtype on urgency and sensation seeking dimensions of impulsivity (Lopez et al. 2015; Sebastian et al. 2012), and also in susceptibility to boredom (Sebastian et al. 2012). When rewarded, accuracy of performance and CPT tasks improve, which suggests that the use of strategies to prevent impulsivity errors ("stopping and thinking strategies") triggers this improvement (Marx et al. 2013) and that interaction between motivation and cognition has to be considered.

Regarding to interference and its control, deficits in these areas are frequently reported (Abdel-Hamid et al. 2019; Boonstra et al. 2010; Faraone et al. 2006; King et al. 2007; Lampe et al. 2007; Mor et al. 2015; Pazvantoglu et al. 2012), although not in all tasks that seek to measure this construct (Lampe et al. 2007). Although both persisters and remitters underperformed relative to HC, no significant differences were found between two ADHD subgroups (Pazvantoglu et al. 2012).

The ability of *alternating* and *switching* different tasks has been extensively analysed. Thereby, some studies evidenced a variety of deficits in this area (generally a higher average of errors and a pronounced slowing) in different tasks (Boonstra et al. 2010; Bueno et al. 2017; Dobson-Patterson et al. 2016; Halleland et al. 2012; Holst and Thorell 2017; King et al. 2007; Lin and Gua 2020; Luna-Rodríguez et al. 2018; Pazvantoglu et al. 2012; Rohlf et al. 2016; Stavro et al. 2007; Thorell et al. 2017; Torralva et al. 2012; Torres et al. 2017; Weyandt et al. 2013), with a medium size effects in comparison with HC for most studies (and medium-large size effect in Rohlf et al. 2016), but losing statistical significance for those differences when controlling for inhibition (Holst and Thorell, 2017), and especially when there is variety in stimulus sources (Luna-Rodríguez et al. 2018). On the contrary, Kamradt et al. (2014) found differences between ADHD and HC groups in a combined inhibition/switching task. However, other studies did not find any deficit in this area (Mostert et al. 2015). Roberts, Milich and Fillmore (2012) reported inconsistencies in a variety of different tasks, showing a dissociation between WM deficits and those related to response selection capacity in ADHD.

Fluency is another large area of analysis within EF, with deficits reported in some studies either in a general manner or in a variety of specific tasks (Boonstra et al. 2010; Mostert et al. 2018; Petersson et al. 2018), such as phonemic fluency (Bueno et al. 2014; Torres et al. 2017). Holst and Thorell (2017) showed a poorer performance in ADHD than HC on letter fluency, but not in category fluency. Older adults with ADHD perform better in fluency tasks than younger ADHD patients (Thorell et al. 2017). However, some studies have not been able to verify any differences between the ADHD group and the control group (Fuermaier et al. 2015; Mostert et al. 2015).

In other less studied EFs, ADHD participants make planning ability errors (Boonstra et al. 2010; Holst and Thorell 2017; Salomone et al. 2020; Weyandt et al. 2013) with an effect size in the small range (Holst and Thorell 2017). Sometimes, those differences in planning have only been seen in adults with early-onset ADHD (Lin and Gua 2020). Regarding cognitive flexibility, ADHD population have deficits (Dobson-Patterson et al. 2016; King et al. 2007; Milioni et al. 2017; Rohlf et al. 2012; Torres et al. 2017) and perform differently to HC group in a medium-to-large effect size (Rohlf et al. 2012). Finally, deficits in dual tasks have also been verified in adults with ADHD (Roberts, Milich and Fillmore 2012; Salomone et al. 2020).

Next section will focus on progresses to establish learning and memory as an additional cognitive domain to characterize Adult ADHD.

Learning and Memory

In the review of memory domain in ADHD, Table 3 details the outcomes found for this domain. In terms of learning as a general process, overall deficits in adults with ADHD were found in the work by Biederman et al. (2010), Dige et al. (2010), Muller et al. (2007), Pettersson et al. (2018), Sethi et al. (2018), Studerus et al. 2018 and Torres et al. (2017), although Faraone et al. (2016) found these significant memory deficits only for the late-onset ADHD group of patients. In this same trend, research developed by Fried et al. 2019, In de Braek and Dijkstra (2011), and Weyandt et al. (2013) did not find statistically significant differences between ADHD and controls with regards to learning abilities, and, more specifically, in verbal learning.

Verbal memory has shown to be in deficit in the majority of studies reviewed (Aycicegi-Dinn et al. 2011; Biederman et al. 2010; Dige et al. 2010; Dobson-Patterson et al. 2016; Faraone et al. 2016; Fuermaier et al. 2015, 2017a, b; In de Braek and Dijkstra 2011; Muller et al. 2007; Nikolas et al. 2019; Pettersson et al. 2018; Storm and White 2010; Studerus et al. 2018; Torralva et al. 2011, 2013; Torres et al. 2017). From the deficient components mentioned in this learning modality, a lower performance has been found for *short-term memory* elements (Aycicegi-Dinn et al. 2011; Dobson-Patterson et al. 2016; Fuermaier et al. 2017a, b; Nikolas et al. 2019; Torralva et al. 2011; Torralva et al. 2013) as well as *long-term memory* (Aycicegi-Dinn et al. 2010; Dige et al. 2010; Dobson-Patterson et al. 2016; Fuermaier et al. 2017a, b; Nikolas et al. 2019; Pettersson et al. 2018; Torralva et al. 2013).

Other studies have shown difficulties arising in *retrospective and prospective memory*, as Fuermaier et al. (2015, 2017a, b). In de Braek and Dijkstra (2011) remark a larger number of errors in ADHD patients during learning tasks compared to healthy controls. In the work developed by Storm and White (2010) studying retrieval-induced forgetting, they found that ADHD participants performed worse and demonstrated a non-significant effect of retrieval-induced facilitation and significant levels of retrieval-induced forgetting on the category-plus-stem-cued recall test. Moreover, memory deficits were more pronounced when medication is not taken (Fuermaier et al. 2017a, b). Separately, Deliste and Braun (2011) remark the good performance shown by ADHD patients in relation to *incidental memory*.

For *visual memory*, findings remain controversial. While some studies show some issues in this memory modality for adult ADHD patients (Aycicegi-Dinn et al. 2011; Biederman et al. 2010; Muller et al. 2007; Sethi et al. 2018) others do not find any type of alteration in performance (Dobson-Patterson et al. 2016; Torralva et al. 2011, 2013; Torres et al. 2017). The work developed by Aycicegi-Dinn et al. (2011) demonstrates specifically that patients with ADHD displayed performance deficits both in immediate and delayed memory, while in Faraone et al. (2006) these significant deficits were only shown in late-onset ADHD patients in terms of Rey-Osterrieth Complex Figure Test accuracy scores.

In summary, we can state that adult patients with ADHD present some type of memory deficits, mainly of verbal nature, as shown by the majority of analysed studies, while only one study reported on incidental memory and findings in visual memory remain mixed and controversial.

Language

Studies reporting outcomes in the language domain have primarily focused on reading performance (Bierderman et al. 2011; Enghelhardt et al. 2011; Fried et al. 2012, 2016; Laasonen et al. 2010), production (Enghelhardt et al. 2011, 2012; Fried et al. 2012; Laasonen et al. 2010; Segal et al. 2015; Torralva et al. 2013) and writing (Miranda et al. 2013; Vekaria and Peverly, 2018), as well as quality aspects of these processes (Enghelhardt et al. 2011, 2012; Fried et al. 2012; Laasonen et al. 2010; Miranda et al. 2013; Segal et al. 2015; Vekaria and Peverly, 2018).

Table 2 Studies showing results for executive functions, including working memory (or similar theoretical constructs)

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Abdel-Hamid et al. (2019)	ADHD ($N=30$): ADHD-I ($N=1$) ADHD-A ($N=13$) ADHD-C ($N=16$) HC ($N=30$)	34.5 (6.81) 35.83 (11.68)	TMT-A & B Stroop Go/No-Go task (TAP)	Significant differences in all of the three Stroop tasks, with a larger time processing in the third task and more non-corrected mistakes; more significant mistakes also in the Go/No-Go task. ADHD group showed deficits in WM and impulse control
Alderson et al. (2013)	ADHD ($n=21$) HC ($n=16$)	ADHD = 19.57 (1.91) HC = 19.44 (1.09)	KBIT-2; Visuospatial Working Memory Task; Phonological working memory task; Letter-Number Sequencing subtest	Both groups performed significantly better during the phonological task (PH) relative to the visuospatial (VS) task. However, ADHD exhibited significant performance deficits associated with the overall phonological system, but not the overall visuospatial system. With increasing opportunities for correct answers as set size increased, participants with ADHD made disproportionately fewer correct responses in the larger set-size blocks. HC were able to recall a maximum of 6.10 PH stimuli, compared to only 5.41 PH in the ADHD group. Similarly, in the VS condition, HC were able to recall a maximum of 4.94 VS, compared to 4.52 by ADHD. These findings reflect differential demands on the Central Executive (CE) as set sizes increased Overall, the CE and PH storage/rehearsal processes of adults with ADHD were both significantly impaired, while between-group differences on the VS storage/rehearsal variable were not significant. Strong evidence of relatively persistent PH storage/rehearsal impairments, but improved CE and VS storage/rehearsal functioning in adults with the disorder
Aycicegi-Dinn et al. (2011)	ADHD ($n=13$) HC ($n=19$)	ADHD = 28.31 (6.89) HC = 27.11 (7.77)	Auditory CPT; Go/No-Go task; Stroop colour-word test; TMT; WCST; LN sequencing task; ROCFT; FAS test (categorical verbal fluency); Divergent thinking task; Design Fluency Task; Object alternation test; Reading the mind in the eyes test; Frontal Lobe Personality Scale	Although the higher number of frontal self-reported symptoms (dysexecutive and disinhibition), no clear deficits are seen between ADHD and HC groups in task measuring executive functions
Barkley and Murphy (2010)	ADHD ($n=146$) HC ($n=109$) Other groups: Clinical control group (other diagnostic apart ADHD)	ADHD = 32.4 (10.9) HC = 36.4 (12) Clinical control = 37.8 (13.2)	EF rating scale; CPT; Stroop; WCST; Five-Point Test of Design Fluency; Learning and Memory Battery, including Digits	When examined individually and apart from the EF tests, self-ratings on the DEFS subscales were found to contribute significantly to all 11 occupational impairment measures, including self-rated work quality, the percentage of jobs on which these adults had experienced various behavioural and interpersonal problems or had been fired, employer ratings of overall work performance and impairment across a variety of work contexts, and clinician ratings of social and occupational adjustment on the SOFAS. Three DEFS were especially useful in these predictions, being Self-Discipline (Inhibition), Self-Management to Time, and Self-Motivation with each contributing to five different occupational measures

Table 2 (continued)

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Barkley and Murphy (2011)	ADHD (n = 146) HC (n = 109) Other groups: Clinical control group (other diagnostic apart ADHD)	ADHD = 32.4 (10.9) HC = 36.4 (12) Clinical control = 37.8 (13.2)	DEFS; Official Driving Record; Stroop; WCST; Five-Points Test of Design Fluency; LAMB; Digits	EF deficits in daily life activities may be represented by five problem dimensions: Self-Management to Time, Self-Organization and Problem-Solving, Self-Discipline, Self-Motivation, and Self-Activation/Concentration. ADHD group had more severe EF ratings on all 5 scales using both self and other-reported versions Relationships between the EF scales and tests were low and mostly not significant Most ADHD adults were clinically impaired on the EF ratings but only a small minority were so on the tests
Biederman et al. (2011)	ADHD (n = 116) HC (n = 146)	ADHD = 37.8 (9.8) HC = 30.3 (8.7)	WAIS-III (vocabulary, digit span, symbol search) or WISCII (block, arithmetic, coding/digit symbol subtest); CPT; WCST; Stroop	ADHD is associated with lower scores on all six measures: 6,9 full-scale IQ points, 5,1 performance IQ points, 7,2 verbal IQ points, 8,5 WRAT arithmetic points, 3,6 WRAT reading points and 0,26 lower neuropsychological aggregate score. However, after SES was controlled, ADHD was no longer associated with a significantly lower WRAT reading score, but all other findings remained significant. After full-scale IQ was controlled, ADHD was still significantly associated with poorer WRAT arithmetic and neuropsychological aggregate scores, but not WRAT reading scores
Boonstra et al. (2010)	ADHD (n = 49) HC (n = 49)	ADHD = 38.7 (9.7) HC = 38.1 (9.3)	Category Fluency Test; Ruff Figural Fluency Test; ToL; Change Task; CPT, Circle Drawing Test; Stroop; WCST; DS, LN, vocabulary, arithmetic, block design and picture arrangement (WAIS-III); Benton Visual Retention Test; Purdue Pegboard; Finger Tapping Test; The Sorting Subtest (Groninger Int. Test)	ADHD showed larger interference times on the Stroop Color–Word Test. Covarying for IQ did not change this large effect. ADHD were considerably slower in inhibiting their prepotent responses, but after controlling for IQ, this difference was neutralised. A poorer set-shifting was concluded in the ADHD group ADHD performed worse on the Change Response of the Change Task. This effect altered into a medium one after covarying for differences in IQ and alternating movements of the Purdue Pegboard Large differences between stimulant medication–naïve adults with persistent ADHD and normal control adults in the EF domain of inhibition, even after stringent controls for group differences in IQ and non-EF demands Differences in other areas of EF did not prove robust results after controlling for IQ and non-EF measures
Bueno et al. (2017)	Medicated ADHD (n = 48), Non-medicated (n = 14) HC (n = 20)	Medicated ADHD = 30.2 (8.1) Non-Medicated ADHD = 32.4 (6.2) Control = 28.4 (5.4)	Plus–minus task; Dual task; Zoo map test; Verbal Fluency; Random Number Generation	Specific deficits in shifting ($g = -.55$; $p = .04$) and long-term memory access -phonemic fluency- ($g = .5$; $p = .03$) in ADHD population, with medium size effects in both. No changes were found in inhibition measures, confirming that ADHD-induced executive deficits are not related to a decline in this general executive ability A difference tendency with a mean effect size in the dual task was found
Clark et al. (2007)	ADHD (n = 20) ADHD-PI (n = 4), ADHD-HI (n = 2), ADHD-C (n = 10) HC (n = 20) Other group: 40 neurological patients with focal, unilateral lesions to the frontal lobes	ADHD = 28 (8.6) HC = 25.1 (5.4) Right lesion = 56.1 (11.9); Left lesion = 54.5 (10.4)	Stop-Signal test; CANTAB Spatial WM Test	More BSErrors (Spatial WM) in ADHD; when the task required low functioning, ADHD and HC had the same performance, but worse in the difficult task. In WSErrors and the strategy score (Spatial WM), all groups had the same performance ADHD subtypes differences: ADHD-HI have longer SSRTs and more BSE than combined subtypes and inattentive In adult subjects with ADHD, response inhibition (SSRT), was correlated significantly with BSE on a self-ordered SWM task. The same association between response inhibition and WM search errors also was identified in neurosurgical patients with unilateral lesions to the right frontal lobe Compared with healthy volunteers, the adult ADHD group committed more SWM BSE, particularly at the most difficult eight-move stage of the task. However, surprisingly, SSRT was comparable in the adult ADHD group and the healthy controls

Table 2 (continued)

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Cohen and Kalanthroff (2019)	ADHD (n = 30) HC (n = 30)	ADHD = 25.03 (2.16) Control = 24.13 (1.80)	WAIS-IV Rorschach inkblots test	Tests are biased by global–local processing style and might be perceived and conducted differently by individuals with ADHD In the picture completion test and in the block design test, in which local processing was hypothesized to be an advantage, the ADHD group performed significantly better in the former (p = .01), and there are no differences in the latter In the digit symbol-coding test, in which local processing was hypothesized to be a disadvantage, the HC group was significantly more successful than the ADHD group (p = .01) On the Rorschach inkblots test, ADHD participants exhibited more responses that referred to local aspects (part/s) of the stimulus and fewer responses that referred to global aspects (whole) of the stimulus
Deliste and Braun (2011)	ADHD (n = 30) HC (n = 30)	ADHD = 39.03 (10.7) HC = 40 (9.84)	SOA CPT-II	Despite statistical control for depression and anxiety, the ADHD group made more errors of commission than controls on the CPT-II (56 (13) vs 46 (10), F = 7.54, p = .008)
Dobson-Patterson et al. (2016)	ADHD (n = 32), 16 ADHD-I, 16 ADHD-C HC (n = 30)	ADHD-I = 40.7 (13.2) ADHD-C = 35 (12.9) HC = 39.6 (12.9)	Stroop, Digit Span Backwards (WMS-III), Tower of London (4-disc-version), CCPT-II (inhibition with the commissions score)	Significant differences between ADHD and HC groups in the TMT-B score, WCST categories, and CCPT-II commissions

Table 2 (continued)

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Faraone et al. (2006)	Subthreshold ADHD ($n=41$) Late-Onset ADHD ($n=79$) Full ADHD ($n=127$) HC ($n=30$)	Subthreshold ADHD = 35.5 (9.1) Late-Onset ADHD = 36.5 (10.8) Full ADHD = 36.1 (10.8) HC = 29.9 (9)	ROCF; Auditory CPT; WCST; Stroop; Arithmetic and digit span (WAIS-III)	The only significant differences among ADHD subgroups were the higher verbal performance and full-scale IQ scores among full ADHD compared with late-onset ADHD subjects and lower performance IQ among late-onset subjects compared with subthreshold subjects. Late-onset ADHD showed significant deficits on the Stroop test, the WCST and ROCF. In contrast, the subthreshold ADHD group only showed deficits on the WCST Linear regression showed a negative effect of ADHD onset age on full-scale IQ [$F(1,215)=6.73$, $p=.01$] and verbal IQ [$F(1,215)=7.60$, $p=.006$) among the ADHD groups. The four groups also differed significantly in frequencies of subjects showing Executive Function Deficits [$\chi^2(3)=17.2$, $p=.001$], with subthreshold ADHD (34.2% of subjects) and full ADHD (31.5% of subjects) having the highest frequencies. Late-onset ADHD had a lower frequency (26.6%) than subthreshold ADHD or full ADHD. Non-ADHD had the smallest frequency of individuals showing EFD (11.4%). No significant differences between the ADHD subgroups in the frequency of subjects showing EFD [$\chi^2(2)=.90$, $p=.64$] A significant relationship between group membership and the number of neuropsychological tests showing EF impairment, controlling for age of subjects [$\chi^2(4)=13.8$, $p=.003$]: subthreshold ADHD and full ADHD showed the highest average number of impaired tests, with late-onset ADHD showing fewer impaired tests and non-ADHD showing the smallest number of impaired tests. No differences between the three ADHD groups in the number of tests showing EF impairment. Both full and late-onset ADHD showed more impaired neuropsychological test scores than non-ADHD. They also showed more impairment on an index of EF disorder the late-onset ADHD group performed worse than the full ADHD group. This raises the intriguing possibility that late-onset ADHD may be a more cognitively impaired form of adult ADHD
Finke et al. (2011)	ADHD ($n=30$) HC ($n=30$)	ADHD = 35.5 (9.49) HC = 35.96 (10.39)	TVA model based computerized task; TAP	Reduced WM storage capacity imposes the critical constraint on attentional processing in ADHD patients: The normal limitation of the number of items that can be maintained in parallel in WM is further accentuated, by more than 20% in adult ADHD patients, even controlling IQ, age, education, socioeconomic status, occupation and income, and comorbidity
Fried et al. (2016)	ADHD ($n=26$) HC ($n=52$) Other: ASD ($n=26$)	ADHD = 28.2 (5.6) HC = 27.5 (4.1) ASD = 27.5 (6.2)	WAIS-III; D-KEFS; TMT; TOWRE Sight Word and Phonemic decoding	Significant differences between HC and ADHD in inhibition (ADHD had more inhibition problems)
Fried et al. (2019)	ADHD ($n=474$) HC ($n=163$)	ADHD = 31.6 (11.1) HC = 30.8.(9.9)	CANTAB Affective Go/No-Go	Differences between ADHD and controls only in Total Commissions (Affective Go/No-Go)

Table 2 (continued)

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Fuermaier et al. (2015)	ADHD (n = 55) HC (n = 66)	ADHD = 34.6 (10.7) HC = 31.9 (10.2)	Questionnaire for experiences of attention deficits (FEDA); Questionnaire for Complaints of Cognitive Disturbances; Dysexecutive Questionnaire (DEX); Selective attention & Vigilance (Test Battery for Attentional Performance); Delayed task execution, inhibition (Stroop), flexibility (TMT), word fluency (Regensburg Word Fluency Test), IQ (Multiple Choice Vocabulary Test)	The patients' self-reports revealed large dysfunction in adults with ADHD in measures of all neuropsychological domains, including EF: a majority of patients reported impairments in various neuropsychological domains (in EF, between about 73% and 82% of patients) Compared to control, ADHD showed a significantly decreased performance in all neuropsychological tests with the exception of the word fluency test with small to large size. The large effects on retrospective memory (story recall) and prospective memory (delayed task execution) might be explained by the high demands of these tests on a range of executive functions Comparison between subjective and objective measures of cognitive functioning in ADHD demonstrated that reported more severe cognitive impairments than actually found in the objective assessment In addition, based on the subjective assessment, more patients were classified as suffering from cognitive impairment than on the basis of the objective test results
Fuermaier et al. (2017a, b)	ADHD1 (n = 48) ADHD2 (n = 27) HC (n = 48)	ADHD1 = 34.2 (11.3) ADHD2 = 33.5 (11.7) HC = 21.1 (2.2)	Visuospatial WM test (VSWMT); computerized VIGIL test of the Vienna Test System VTS; The N-Back Verbal (NBV) of the VTS; Test of Memory Malingering (TOMM); the Dot Counting Test (DCT); the b Test	Cognitive impairments of ADHD were most prominent in vigilance, with more than half exhibiting impairments. In contrast, only a small number of patients with ADHD displayed impairments in verbal WM The statistical comparison of visuospatial WM revealed a significantly lower performance of large size among ADHD. Univariate comparisons demonstrated medium and significant effects regarding errors and total mean response time of correct responses, indicating a poorer visuospatial WM in ADHD
Grane et al. (2014)	ADHD Combined subtype (n = 36) HC (n = 35)	ADHD = 31.8 (10) HC = 32.2 (9.5)	ASR, TOVA (CPT & Go/No-Go), BRIEF-A	Less speedy reactions in ADHD and significantly greater reaction time variability and more omission errors to Go signals across conditions, tending to make more omission in the 2nd half of the task and more commission during the entire task ADHD group generally reported a greater degree of executive difficulties (BRIEF-A) ADHD self-report resulted in 4 (Initiate, Working Memory, Plan/Organize, Task Monitor) of the 5 scales comprising the Metacognition Index being clinically elevated from the BRIEF-A normative sample. The ADHD group had clinical elevation on 1 (Inhibit) of the 4 scales comprising the Behavioral Regulation Index. Both the Metacognition Index (mean T score = 569.6; SD = 513.2), and the Behavioral Regulation Index (mean T score = 567.7; SD = 512.9) were in the clinically elevated range
Gropper and Tannock (2009)	ADHD (n = 16) HC (n = 30)	ADHD = 21.34 (2.59) HC = 22.48 (2.68)	Digit Span; Letter-Number; PASAT; CANTAB;	WM is impaired in ADHD (strongest for Auditory Verbal WM), strongly related to students' academic achievement at university. Only limited evidence of impairment in VisuoSpatial WM (groups only differ on the measure "spatial span backward and they had a tendency for poorer performance on spatial WM, but didn't doffer on Spatial Span, forward") No robust evidence of academic impairment in ADHD group relative to controls measured by self-reported GPA

Table 2 (continued)

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Halleland et al. (2012)	ADHD ($n=60$) HC ($n=60$)	ADHD = 34.4 (9.9) HC = 29 (6.9)	D-KEFS	ADHD had significantly lower scores on the P-set-shifting score, also after controlling for WM and total IQ ANCOVA with age as a covariate showed a statistically significant difference between the groups on the SR-inhibition/set-shifting score and SR-set-shifting score, with lower scores in the ADHD group, still significant when including total IQ and WM as covariates ADHD have specific difficulties with set-shifting (CWIT), difficulties that probably also reflect problems related to EF in their daily life
Holst and Thorell (2017)	ADHD ($n=57$) HC ($n=53$)	ADHD = 26.8 (5.9) HC = 25.5 (5)	LN and Digit Span (WAIS-IV) Find-the-Phone Task D-KEFS Navon task Quick Delay Questionnaire (QDQ)	For WM, ADHD performed more poorly with regard to two of the tasks: one verbal (i.e., the Letter-Number Sequencing Task) and one spatial (i.e., Find-the-Phone Task). When controlling for short-term memory, the results showed that the group difference found for the Letter-Number Sequencing Task was no longer significant. The effect for the spatial WM task just missed significance ($p=.52$) when controlling for short-term memory and was non-significant when controlling for IQ For inhibition, the results showed a significant medium effect size group difference for the Color-Word task. For set shifting, the results showed that ADHD performed more poorly on all three tasks (i.e., Color Word, Category Switching, and the Navon Task) with a medium size, and remained significant when controlling for IQ. However, when controlling for inhibition, the effects were no longer significant, except for a tendency toward a significant effect for the Color Word Task ($p=.73$) For fluency, ADHD performed more poorly on letter fluency but not category fluency, in a small range, remaining significant when controlling for either IQ or vocabulary For planning, ADHD performed more poorly in a small range. When controlling for IQ or visual constructive abilities, there was a tendency toward a significant group difference (both $p<.06$) For delay aversion (measured using self-ratings), ADHD reported a higher degree of delay aversion in a medium size, and remaining significant when controlling for either IQ or inhibition
Hudec et al. (2014)	ADHD ($n=20$) HC ($n=15$)	ADHD = 19.65 (1.93) HC = 19.33 (1.05)	KBIT-2	Adults with ADHD were more active and exhibit relatively ubiquitous hyperactivity that is exacerbated when demands on WM increase. Follow-up analyses indicated that between-group differences during control conditions were not solely related to WM demands associated with the control task. WM and ADHD-related hyperactivity, while also indicating that some ADHD-related hyperactivity in adults may occur independently of situational WM demands
In de Braek and Dijkstra (2011)	ADHD ($n=30$) HC ($n=42$)	ADHD = 31.6 (-) HC = 35.9 (-)	Stroop	No differences between two groups in EF
Kamradt et al. (2014)	ADHD ($n=170$) HC ($n=83$)	ADHD = 23.8 (4.7) HC = 20.1 (2.9)	Digit span; DKEFS; Stop Task	Differences between groups in inhibition ($p=.025$) and inhibition/switching ($p=.022$), number-letter sequencing ($p=.022$), motor speed ($p=.009$) measured in seconds, and Stop Task SSRT ($p=.009$) Overall, results indicated that neuropsychological task performance and ratings of EF each uniquely contributed to the variance in ADHD symptom severity and impairment

Table 2 (continued)

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Kim et al. (2014)	ADHD ($n=32$) HC ($n=25$)	ADHD = ?? HC = ??	Digit Span; The Spatial Span (SSP) and spatial WM (SWM) task from CANTAB	The ADHD group had lower scores on the CANTAB SWM The mean scores for the ADHD group on these two tests of WM fell in the low average range. By contrast, scores for the comparison group fell well within the average range
King et al. (2007)	ADHD ($n=22$) HC ($n=22$)	ADHD = 30 (8.1) HC = 30.1 (7.2)	Stroop Task Switching	Cognitive flexibility deficiencies in ADHD and elevated task switching error rates Interference effects and slower performance in both tasks in the ADHD group
Lampe et al. (2007)	ADHD ($n=22$) Borderline PD ($n=21$) ADHD + BPD ($n=20$) HC ($n=20$)	ADHD = 29.95 (8.2) BPD = 24.6 (6.2) ADHD + BPD = 26.50 (7) HC = 28.7 (6.9)	ANT; Stroop; Go/No-Go task (TAP); Stop Signal task; Digit Backward Span	ADHD performed significantly worse on the ANT conflict (interference) and on the stop signal task (inhibition deficits) ADHD individuals did not show significant deficits in Stroop interference or in the capacity to suppress prepotent responses as tested with the error rate of the go/no-go. In all inhibitory tasks, ADHD subjects showed generally longer RTs. However, slow response speed was not specific to inhibitory function, but was also found in non-critical conditions (e.g., congruent trials of the Stroop, general RTs of the stop signal and go/no-go tasks)
Lin and Gua (2020)	ADHD ($n=183$, 142 early, 41 late) HC ($n=148$)	Early onset ADHD = 27.6(6.23) Late onset ADHD = 28.74(6.12) HC = 24.74(5.03)	CANTAB (RT, sustained attention/signal detectability RVP, spatial WM and planning, set-shifting IED)	ADHD, regardless of age-of-onset, had significant deficits in signal detectability (RVP A′), spatial WM (SWM between errors) and set-shifting (IED extradimensional shift errors), after considering the influences of age, sex, and any psychiatric comorbidity, but deficits in planning (SOC five-move task) were only noted in adults with early-onset ADHD Inattentive symptoms of late-onset ADHD might emerge through neuropsychological mechanisms other than alertness, such as impaired executive dysfunctions
Lineweaver et al. (2012)	ADHD ($n=44$) HC ($n=42$)	ADHD = 20.09 (1.80) HC = 19.57 (1.38)	Internal Restless Scale (IRS); PASAT; Digit Span; Spatial Span; N-Back	For DS, participants performed better when repeating digits forward than when repeating digits backward, more pronounced for ADHD, Group × Test Difficulty interaction ADHD less efficient in auditory WM, but they did not differ from controls in their simple auditory attention capacity. For the other three WM tests, participants also generally performed better on the easy than on the more difficult test items However, the magnitude of this effect did not depend on whether participants were in the ADHD group or in the control group. A significant interaction between group and test difficulty indicated that the two groups performed similarly when the task was easy, but ADHD performed more poorly when the task was more difficult. Similarly, the main effect associated with ADHD group did not reach significance in any of the analyses, when no distractions were present, the control participants demonstrated an improvement in their 1-Back score from baseline to retest in contrast to ADHD, whose scores were fairly stable from baseline to retest In the presence of auditory distractions, both declined slightly across the two testing sessions. When retesting occurred in the presence of visual distractions, control participants declined from baseline to retest, whereas students with ADHD improved Young ADHD did not evidence deficits in their visuospatial WM

Table 2 (continued)

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
López et al. (2015)	ADHD (n = 72) HC (n = 147)	ADHD = 29 (-) HC = 28 (-)	UPPS Impulsive Behavior Scale	ADHD patients had higher urgency, lower premeditation and lower perseverance ("the ability to remain focused on a task that may be boring or difficult"). Patients with ADHD-C subtype had higher scores than those with ADHD-PI on urgency and sensation seeking dimensions of impulsivity. ADHD patients had higher self-reported impulsivity behaviours
Luna-Rodríguez et al. (2018)	ADHD (n = 38) HC (n = 39)	ADHD = 36.14 (12.17) HC = 33.61 (9.18)	TAP; WAIS-IV; ad hoc created battery with a task switch protocol without proactive interference	ADHD patients were slower in task switch trials with a simultaneous shift of attention between global/local attentional sets, that is associated with a deficit in flexible deployment of attention to varying sources of stimulus information
Marx et al. (2013)	ADHD (n = 38) HC (n = 40)	ADHD = 25.1 (2.05) HC = 22.8 (0.95)	Stop signal task n-back CPT time discrimination task delay aversion task questionnaire of current motivation	Impaired performance in the ADHD group was observed for stop-signal omission errors, n-back accuracy, reaction time variability in the CPT and time reproduction accuracy, and reward normalized time reproduction accuracy. Furthermore, when rewarded, subjects with ADHD exhibited longer reaction times and fewer false positives in the CPT, which suggests the use of strategies to prevent impulsivity errors Taken together, this suggest cognitive strategies of ''stopping and thinking'' as a possible underlying mechanism for task improvement that seems to be mediated by reward, which highlights the importance of the interaction between motivation and cognition in adult ADHD
Mette et al. (2015)	Medicated ADHD (n = 30) Unmedicated ADHD (n = 29) HC (n = 32)	Medicated ADHD = 34.73 (9.08) Unmedicated ADHD = 34.72 (10.4) HC = 31.28 (7.14)	Time reproduction task; DS forward & backward; block span forward, block span backward; letter-numbering sequence (WMS)	Patients with ADHD exhibited impaired WM performance No general group differences in the raw time reproduction scores were found between the adults with ADHD and the HCs, with the exception of the variability at some time intervals in both MPH- and MPH + patients
Milioni et al. (2017)	ADHD IQ ≥ 110 (n = 20) ADHD IQ < 110 (n = 31) HC (n = 33)	ADHD IQ ≥ 110 = 27.84 (6.54) ADHD IQ < 110 = 28 (6.11) HC = 26.82 (5.49)	WCST; Stroop; TMT; CPT; COWAT; WASI	ADHD groups with standard IQ differed in almost all measures of EF, suggesting executive deficits in inhibitory control, sustained attention, cognitive flexibility, abstraction ability, and impulsivity On the other side, the ADHD group with high IQ underperformed the control group only in an impulsivity score (commission errors) Adults with ADHD and more elevated IQ are more likely to demonstrate better executive performance in some executive tasks
Mor et al. (2015)	Monolinguals ADHD (n = 20); HC (n = 20) Bilinguals ADHD (n = 20); HC (n = 20)	Monolinguals ADHD = 24.35 (2.37) HC = 24.25 (2.45) Bilinguals ADHD = 25.15 (2.16) HC = 24.8 (2.09)	Numeric Stroop task; Simon arrows task; TMT; Task-switching paradigm	Participants with ADHD performed worse, but with a not bilingual advantage in EF The negative impact of ADHD was more pronounced for bilinguals than for monolinguals, but only in interference suppression tasks Bilingual participants with ADHD had the lowest performance

Table 2 (continued)

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Mostert et al. (2015)	ADHD persisters ($n = 155$) HC ($n = 143$)	ADHD = 35.56 (10.40) HC = 36.3 (11.75)	WAIS-III; flanker task; Sustained attention dots task (SA-dots); Sustained attention to response task (SART); TMT; Delay-discounting and time estimation	ADHD showed impaired EF, especially WM and sustained attention, were more sensitive delay aversion, and increased response variability. Not EF differences related to inhibition, set-shifting, or verbal fluency. The largest effect sizes were observed for measures of performance variability, both in terms of fluctuations in errors as in reaction times. The average reaction time on the tasks used to measure RTV did not differ between patients and controls, supporting the notion that RTV is not attributable to differences in processing speed
Mostert et al. (2018)	ADHD ($n = 133$) HC ($n = 132$)	ADHD = 35.56 (10.40) HC = 30.3 (7.7)	Measures tapping into executive functioning (working memory, attention, inhibition, set-shifting, fluency) and delay discounting	The best-fitting six-factor solution produced a superior fit over competing models: $\chi^2(104) = 167.81$, CFI = 0.925, TLI = 0.901, RMSEA = 0.048, 66 free parameters. In the six factors ("reaction time and reaction time variability, "delay discounting," "verbal fluency," "WM", "attention," and "inhibition") ADHD performed significantly worse Both the ADHD and control group separated into three profiles that differed in cognitive performance. Profile 1 was characterized by aberrant attention and inhibition, profile 2 by increased delay discounting, and profile 3 by atypical WM and verbal fluency
Muller et al. (2007)	ADHD ($n = 30$) HC ($n = 27$)	ADHD = 33.8 (8.2) HC = 20 (1.17)	TMT-A & B; Stroop; COWAT; Tower of London; WMS-R; MLS; Neurobat	A difference in performance between groups was found in TMT: Relative to controls [23.8 (7.3)], patients [34 (9.1)] took more time in the visual scanning of numbers [$F(1,55) = 21.5$, $p < .001$, partial Eta = 0.28 (medium) Also, demonstrate lowered performance in EF which may not be present with simple RT tasks, but may emerge under conditions of heightened mental load when attention has to be focussed on simultaneous tasks. However, a low amount of inhibition problems have been assessed. The Stroop task performance, was only partly impaired, patients making more errors but with no prominent indication of altered processing speed. When compared to the results in memory and trail making tasks, inhibition task, differences in Stroop performance between patients and controls were low
Neely et al. (2017)	ADHD ($n = 51$) HC ($n = 51$)	ADHD = 21.1 (1.71) HC = 21 (1.7)	Purdue Pegboard Test Go/No-Go force task	On Go trials of the force task, force output and variability was not different. On No-Go trials in the force task, ADHD produced greater and more variable force Mean force output on No-Go trials was a stronger predictor of the CAARS S: L ADHD Index compared to performance in the standard RT task
Nikolas et al. (2019)	ADHD ($n = 109$) HC ($n = 52$) Other: Depression ($n = 85$)	ADHD = 24.8 (6.2) HC = 23.6 (5.4) Depression = 22.9 (4.5)	DS, Spatial Addition subtest and Symbol Search (WAIS-IV); PASAT-100; Salthouse Listening Span Test; TOVA; Dot Counting Test; D-KEFS; NAB; the Sentence Repetition Test; and the b-Test	Measures of WM, sustained attention, response speed, and variability best discriminated between ADHD vs non-ADHD While single test measures provided performed poorly in identifying ADHD participants, analyses revealed that a combined approach using self and informant symptom ratings, positive family history of ADHD, and a RT variability measure correctly classified 87% of cases

Table 2 (continued)

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Pazvantoglu et al. (2012)	ADHD persisters (*n* = 30) ADHD remitters (*n* = 35) HC (*n* = 30)	ADHD persisters = 37.0 (6.5) ADHD remitters = 39.3 (5.7) HC = 37.7 (5.5)	Turkish version of verbal and non-verbal Cancellation Test (CT) Continuous Performance Test (CPT) Trail Making Test Stroop Test COWAT	ADHD have inefficient attention, interference control and set-shifting functions, which may be revealed on neuropsychological tests that require greater cognitive demand Similar performance on tests of inhibition of prepotent responses. Although both persisters and remitters underperformed relative to HC on the measure of interference control, no significant difference was found between both Regarding other EF tests, performance on the TMT-B was different among patient and HC ([$F_{(2-101)}$ = 56.81], η^2 = 0.119), but there was one difference between groups on the COWAT Interference control scores differentiated ADHD diagnosis at any time (remitters or persisters) from HC. All other tests and sub-tests significantly differentiated the persisters from the others
Pettersson et al. (2018)	ADHD (*n* = 60) HC (*n* = 48)	ADHD = 28.18 (9.09) HC = 32.75 (10.61)	Digit Span Backward and Digit Symbol Coding (WAIS-IV); D-KEFS, TMT B, QBTest Plus	There are differences between ADHD and HC in verbal fluency (GLM: F = 6,118; η^2 = .055) The rest of EF scores and variables does not results in significant differences
Roberts et al. (2011)	ADHD (*n* = 30) HC (*n* = 28)	ADHD = 21.1 (1.7) HC = 22 (1.7)	Cued Go/No-go task; Manual Stopping Task; Visual Stopping Task; DORT; BISS; UPPS; I.7 Impulsiveness Questionnaire	The relations between oculomotor inhibitory control and several facets of impulsivity were most evident in those with ADHD and not controls. This suggests that oculomotor inhibitory control plays a role in the symptoms of impulsivity associated with ADHD
Roberts, Milich and Fillmore (2012)	ADHD (*n* = 38) HC (*n* = 33)	ADHD = 21.3 (1.7) HC = 22.1 (1.7)	Dual task (PRP task) N-back task	Both groups showed declines in performance on both tasks as cognitive load increased Two group differences in PRP task performance were noted. ADHD were slower to respond overall on Task 2 (a general difficulty with task switching) and showed more pronounced slowing as the intertask SOA shortened (this would show reduced response selection capacity). On the n-back task, the ADHD group showed poorer discriminability and appeared to respond slower than HC, although the latter difference was not significant. The group difference in accuracy was similar across memory load conditions. Further, both groups showed a more conservative response style memory load increased, as indicated by load-dependent increases in B and RT. These findings support a specific deficit in response selection capacity in adults with ADHD and may suggest a dissociation between WM and response selection capacity ADHD was less accurate on the n-back task (poorer WM), but the effects of cognitive load on performance suggest no evidence of reduced WM
Roberts et al. (2016)	ADHD (*n* = 88) HC (*n* = 67)	ADHD = 21.7 (1.8) HC = 22.8 (2)	Cued Go/No-go task	Overall, ADHD made more inhibitory failures and responded more slowly. These group differences were only present in the valid-cue condition, with no significant group differences in the invalid-cue conditions

Table 2 (continued)

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Rohlf et al. (2012)	ADHD (n = 37) ADHD + (with comorbid psychopathology) (n = 18); ADHD- (n = 19) HC (n = 32)	ADHD = 21.66 (2.98) ADHD + = 22.79 (3.53) ADHD- = 20.59 (1.89) HC = 22.45 (2.96)	TMT Computerized Card Sorting Test (CKV) Digit Span	The differences between the groups were of medium-to-large effect size (TMT: d = 0.48; DS: d = 0.51; CKV: d = 0.74)
Saboya et al. (2009)	ADHD (n = 23) HC (n = 25)	ADHD = 31.87 (10.55) HC = 33.24 (8.21)	Digit Span; TMT A & B; Stroop; WCST; Tower of Hanoi; Raven Progressive Matrices	No differences between ADHD and control groups in neuropsychological tests results
Salomone et al. (2020)	ADHD (n = 51) HC (n = 28)	ADHD = 32.78 (10.96) HC = 30.6 (10.3)	Test of Everyday Life Attention; Hotel task; The Attention-Related Cognitive Errors Questionnaire (ARCEQ)	A *t* test revealed that the ADHD group showed significantly higher dual task decrement's scores compared with the control group, t(77) = 2.19, p = .04, indicating impaired performance Significantly lower number of attempted tasks was found in the ADHD group compared with the control group, t(77) = − 3.073, p = .004. Adults with ADHD have impaired performance in the Hotel task indicating impaired executive functions and planning compared with a group of adult controls
Sebastian et al. (2012)	ADHD (n = 20) HC (n = 24)	ADHD = 33.3 (8.9) HC = 30.3 (8.1)	BIS-11; SSS-V; UPPS; MWT-B; Simon task; Go/no-go task	ADHD groups perform worse in attentional and motor impulsiveness, non-planning impulsiveness, boredom susceptibility (SSS-V) and urgency, premeditation and sensation seeking (UPPS scale). However, the rest of EF variables are not different compared to HC performance
Semrud-Clickemand and Harder (2010)	ADHD (n = 31) HC (n = 27)	ADHD = 21.2 (1.5) HC = 31.2 (1.0)	D-KEFS; COWA; SATI; SATA	There were no significant group differences on the EF measures
Sethi et al. (2018)	ADHD (n = 30) HC (n = 30)	ADHD = 33.7 (9.51) HC = 32.6 (9.54)	Conners self-report Adult ADHD Rating Scale (CAARS) Novelty Processing Computerized Task TPQ	Unmedicated ADHD participants were significantly more likely than controls to choose novel compared to familiar options on their first presentation [Group Familiarity: F(1,58) = 8.83, p = .030] with post hoc analysis indicating a heightened salience of intrinsically 'novel' stimuli rather than an increased propensity to choose all newly introduced stimuli [% novel items selected: ADHD: 16.8 (± 1.23); control: 12.3 (± 1.09), F(1,58) = 8.83, p = .004; % familiar items selected: ADHD: 15.3 (± 1.03); control: 14.0 (± 1.05); F(1,58) = 0.72, p = .399) Specifically, when ADHD participants were unmedicated, poorer performance was associated with greater persistence in selecting novel stimuli after their initial introduction and a trend towards lower persistence in selecting familiar options. Novelty/reward-related behavioural features explain up to 41% of the variance in clinical ADHD phenotype

Table 2 (continued)

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Stavro et al. (2007)	ADHD ($n=71$) HC ($n=32$)	ADHD = 23.7 (4.28) HC = 24.64 (4.77)	TMT; Stroop; WCST; Stop; ToL; FSIQ	Both groups differ in TMT-B ($p=.01$), TMT-B Residual ($p=.004$), Stroop Word Reading ($p=.012$), Color naming ($p=.014$), Color-Word ($p=.013$) and WCST categories completed ($p=.011$). The rest of index are no significantly different between groups. EF deficits underlie the adaptive impairment associated with ADHD, and symptoms of ADHD in young adults are associated with impairments in adaptive functioning. It was notable that EF did not predict impairment independently of ADHD
Stern et al. (2017)	ADHD ($n=81$) HC ($n=58$)	ADHD = 36.20 (10.18) HC = 29.29 (8.03)	Behavior Rating Inventory of Executive Function–Adult Version; Adult ADHD Quality-of-Life Scale	Significant differences were found between the groups on all BRIEF–A scores, with mostly moderate to strong effect sizes EF profile revealed higher deficit scores on the MI scales than on the BRI scales, indicating a greater deficit in the metacognitive components of EF in adults with ADHD
Studerus et al. (2018)	ADHD ($n=123$) HC ($n=109$) Other: At-Risk mental State (ARMS) for psychosis ($n=168$)	ADHD = 31.6 (9.83) HC = 25 (5.28) ARMS = 25.4 (7.23)	The computer administered Tower oh Hanoi (ToH)	There are no differences in EF
Tatar and Cansiz (2020)	ADHD ($n=40$) HC ($n=40$)	ADHD = 21.72 (4) HC = 21.75 (3.52)	TMT CPT RMET	Executive function deficits in ToM in ADHD group are shown
Thorell et al. (2017)	ADHD older adults (60–75 y) ($n=44$) ADHD younger adults (18–45 y) ($n=56$) HC ($n=56$)	ADHD ol $d=65.09$ (3.52) ADHD young = 26.86 (5.93) HC = 65.52 (4.4)	D-KEFS WAIS-IV MMSE	Older adults with ADHD differed from controls in WM, inhibition and speed of processing. In comparison to younger adults with ADHD, performed at a similar level for WM and planning, but significantly better in inhibition, switching, fluency, speed of processing, and delay aversion When comparing older and younger ADHD, older appear to be less impaired in inhibitory control, switching, fluency, speed of processing, as well as self-rated delay aversion For the neuropsychological test, it is important to note that these comparisons were made using scaled scores, which means that younger ADHD patients were more impaired compared to older adults with ADHD relative to norms
Torralva et al. (2011)	ADHD ($N=16$) BD ($N=15$) HC ($N=15$)	ADHD = 46.6 (14.2) BD = 41.3 (8.1) HC = 43.9 (19.8)	RAVLT; LN (WAIS-III); WCST; Frontal Assessment Examination	Letter Number Sequencing Test differed significantly between the groups with controls scoring significantly better than ADHD ($p=.023$)
Torralva et al. (2013)	High-functioning ADHD ($n=83$) Low-functioning ADHD ($n=34$) HC ($n=21$)	HF-ADHD = 35.5 (15.1) LF-ADHD = 32.4 (15.6) HC = 30.4 (10.1)	Hotel Task; Go/no-go; TAP	HC had more trials in the Hotel task and more correct tasks; ADHD groups did not differ In the TAP, there are differences in correct answers, errors of omission and commission, yielding the control above the rest (there are no differences between ADHD groups) There were also differences in the TMT-B and Letter-number tasks

Table 2 (continued)

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Torres et al. (2017)	ADHD (n = 50) HC (n = 86) Other: ADHD + BD = 23 Bipolar Disorder (n = 70)	ADHD = 37.08 (12.3) HC = 43.31 (13.8) ADHD + BD = 41.52 (9.6) Bipolar Disorder = 46.34 (10.5)	TMT; SCWT; Symbol search, digit symbol, Digit total, arithmetic and Letter & Numbers (WAIS-III); WCST; RCFT	There are significant differences in the total digit index, number of categories and number of perseverative errors in the WCST, TMT-B score, and the phonemic verbal fluency All the clinical groups had poorer performance than the HCs in all the neurocognitive domains, except for executive functions
Vekaria and Peverly (2018)	ADHD (n = 22) HC (n = 50)	ADHD = 23.63 (4.17) HC = 22.18 (3.40)	Participants were instructed to write an organized summary of the lecture without notes The Lottery subtest of the Test of Everyday Attention The listening span test is based on one used by Daneman and Carpenter	Students with ADHD performed worse than their non-handicapped counterparts on written recall and handwriting speed. There were no reliable differences between groups on note-taking, and working memory
Weyandt et al. (2013)	ADHD (n = 24) HC (n = 26)	ADHD = 20.17 (1.20) HC = 20 (1.17)	BRIEF-A Conners' Continuous Performance Test (CPT-II; Conners 2000)	ADHD reported greater overall executive dysfunction on all 12 BRIEF scales. Large group differences were observed, as measured by the General Executive Composite, Metacognition Index, and Behavioral Regulation Index. ADHD also reported significantly more executive dysfunction related to distinct aspects of executive functioning: Inhibit, Shift, Emotional control, Self-Monitor, Initiate, WM, Plan/Organize, Task Management, and Organization of Materials

Table 3 Studies showing results for learning and memory domains

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Aycicegi-Dinn et al. (2011)	ADHD (n = 13) HC (n = 19)	ADHD = 28.31 (6.89) HC = 27.11 (7.77)	ROCFT Wechsler memory scale: (logical memory)	ADHD striking deficits on tests of verbal and nonverbal memory and once information encoded, do not demonstrate significant information loss (i.e., after 30-min delay). ADHD displayed performance deficits on the 1 (p = .003) and 30 min (p = .001) recall trials of the ROCFT and recalled significantly fewer story elements during the immediate, 1 min (p = .009) delay and 30 min (p = .008) delay trials of the Logical Memory Subtest. Group differences on ROCFT and Logical Memory Subtest retention scores did not approach significance
Biederman et al. (2010)	ADHD (n = 116) HC (n = 146)	ADHD = 37.8 (9.8) HC = 30.3 (8.7)	ROCFT CVLT	ADHD was associated with lower scores on all cognitive measures assessed across the adult life cycle when compared to non-ADHD controls in a natural course of adult cognitive development in this population (ADHD did not take any medication)
Deliste and Braun (2011)	ADHD (n = 30) HC (n = 30)	ADHD = 39.03 (10.7) HC = 40 (9.84)	Memory prospective: The Simulation of Occupational Activities	The only cognitive construct on SOA that showed a non-significant trend toward better performance of the ADHD group was a task that required no mental effort whatsoever: the incidental episodic memory task
Dige et al. (2010)	ADHD (n = 69) HC (n = 66)	ADHD = 31.81 (9.36) HC = 37.09 (12.33)	Dichotic Memory test	Better performance in learning and delayed recall for HC for left ear, right ear, and in the total learning for both ears. There was no significant difference in any of the seven dichotic test results for the three subgroups in the ADHD group. Significant difference was found in dichotic learning for right ear, total dichotic learning and percentage recalled, which correctly classify ADHD participants in 79.71% of the time, and it was able to correctly classify 75.76% of HC The result from our ADHD participants indicated not only an impaired performance in all measurements (learning, delayed recall, and percentage of the number of words recalled out of total learned words) but also indicated a strong power calculation
Dobson-Patterson et al. (2016)	ADHD-I (n = 16) ADHD-C (n = 16) HC (n = 30)	ADHD-I = 40.7 (13.2) ADHD-C = 35 (12.9) HC = 39.6 (12.9)	WMS-III (Logical Memory I and II) The Shum Visual Learning Test	Immediate (LM I) and delayed (LM II) memory tests showed the largest difference among the memory tests (p = 0.000) between ADHD and Control Group LM I Slope was lower in ADHD-C (p = .004)
Faraone et al. (2016)	Subthreshold ADHD (n = 41) Late-Onset ADHD (n = 79) Full ADHD (n = 127) HC (n = 30)	Subthreshold ADHD = 35.5 (9.1) Late-Onset ADHD = 36.5 (10.8) Full ADHD = 36.1 (10.8) HC = 29.9 (9)	ROCF CVLT-II	Only late-onset ADHD showed significant deficits, the California Verbal Learning Test, total correct and semantic correct p < .001 and Delay Accuracy of ROCT
Fried et al. (2019)	ADHD (n = 474) HC (n = 163)	ADHD = 31.6 (11.1) HC = 30.8.(9.9)	CANTAB (Verbal Recognition Memory)	No significant differences between ADHD and HC
Fuermaier et al. (2015)	ADHD (n = 55) HC (n = 66)	ADHD = 34.6(10.7) HC = 31.9 (10.2)	Memory Self-Efficacy Questionnaire; Comprehensive Assessment of Prospective Memory; WMS	Effect size calculations indicated large dysfunction in patients with ADHD on all measures of retrospective memory (p = .001) and prospective memory (p = .001)

Table 3 (continued)

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Fuermaier et al. (2017a, b)	ADHD + MPH ($n=31$) ADHD no MPH ($n=36$) HC ($n=36$)	ADHD + MPH = 33.9 (9.6) ADHD no MPH = 34.1 (10.9) HC = 34.1 (10.5)	Logical Memory I and II (WMS) Immediate word recognition, Delayed word recognition and retention source discrimination paradigm Prospective memory	Significant difference of large size in memory functions between groups ($p=.001$), short term memory ($p=.011$), retrospective memory (immediate word recognition ($p=.021$), immediate story recall ($p<.001$), delayed story recall ($p<.001$), and prospective memory (general performance ($p<.001$); planning ($p<.001$). Effects were of medium to large size ADHD not-treated with MPH showed a significantly decreased performance in short-term memory ($p=.047$), immediate word recognition ($p=.021$), immediate story recall ($p<.001$), delayed story recall ($p=.004$), and prospective memory (general task performance ($p<.001$) and planning ($p<.001$). ADHD on MPH displayed a significantly poorer performance in immediate story recall ($p<.001$), delayed story recall ($p=.003$), as well as both general task performance ($p<.001$) and planning ($p=.019$) of the prospective memory task A comparison of patient groups revealed that patients on MPH performed significantly better regarding short-term memory ($p=.023$) and planning as assessed in the prospective memory task ($p=.048$) than patients off MPH. However, negligible to small non-significant effects were found on the remaining measures of memory functions
In de Braek and Dijkstra (2011)	ADHD ($n=30$) HC ($n=42$)	ADHD = 31.6 (-) HC = 35.9 (-)	The Verbal Learning Test	Significant differences in the number of errors on the verbal learning task ($p=.031$): ADHD made more errors No differences were found with respect to verbal learning capacity ($p=.089$)
Muller et al. (2007)	ADHD ($n=30$) HC ($n=27$)	ADHD = 33.8 (8.2) HC = 20 (1.17)	Visual reproduction and logical memory (WMS-R)	Differences emerged in the verbal and in the visual reproduction subtest of the WMS-R ($p<0.001$), where patients showed deficits with large effect sizes with partial η^2 at about .5
Nikolas et al. (2019)	ADHD ($n=109$) HC ($n=52$) Other: Depression ($n=85$)	ADHD = 24.8 (6.2) HC = 23.6 (5.4) Depression = 22.9 (4.5)	CLVT-II Word Memory Test Verbal Fluency	Examination of parameters indicated that worse performance (indexed by higher scores) on CVLT short-delay free recall ($p=.029$) in the ADHD group compared with the non-ADHD group
Pettersson et al. (2018)	ADHD ($n=60$) HC ($n=48$)	ADHD = 28.18 (9.09) HC = 32.75 (10.61)	RAVLT	When comparing group means, showed significant differences on all variables of the RAVLT, but when controlling for both IQ and age, the analyses showed significant differences for only the RAVLT VI
Sethi et al. (2018)	ADHD ($n=30$) HC ($n=30$)	ADHD = 33.7 (9.51) HC = 32.6 (9.54)	Novelty Processing Computerized Task	Unmedicated patients showed a significantly lower learning rate than controls ($p=.02$) and unmedicated controls ($p=.011$). Stimulant medication demonstrated dissociable effects on learning rates across groups [Group x Drug interaction $p=.046$] significantly increasing learning rates in ADHD compared to effects on controls. However, though differences in effects of stimulant medication could be observed between groups, these did not survive within group comparisons

Table 3 (continued)

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Storm and White (2010)	ADHD ($n=40$) HC ($n=40$)	ADHD = 20.9 (-) HC = 20.2(-)	Task category-exemplar pairs	Exemplars receiving retrieval practice were recalled significantly better than their baseline counterparts ($p<.001$). A main effect of retrieval induced forgetting emerged such that recall performance for non-practised items from baseline categories was significantly better than for non-practised items from practised categories ($p<.001$). Retrieval Induced forgetting did not interact with group both ADHD ($p<.05$) and non-ADHD ($p<.05$) participants demonstrated significant levels of forgetting. Both groups demonstrated a substantial benefit from retrieval practice, significantly better for non-ADHD ($p<.01$). Non-ADHD participants demonstrated a significant effect of retrieval-induced forgetting ($p<.01$) whereas ADHD participants demonstrated a non-significant effect of retrieval-induced facilitation ($p=.05$). Whereas both ADHD and non-ADHD participants demonstrated significant levels of retrieval-induced forgetting on the category-cued recall test, only non-ADHD participants demonstrated significant levels of retrieval-induced forgetting on the category-plus-stem-cued recall test
Studerus et al. (2018)	ADHD ($n=123$) HC ($n=109$) Other: At-Risk mental State for psychosis ($n=168$)	ADHD = 31.6 (9.83) HC = 25 (5.28) ARMS = 25.4 (7.23)	CVLT	Pairwise group comparisons revealed that ADHD patients showed a significantly worse performance than HC in all CVLT measures ADHD patients performed significantly worse than ARMS
Torralva et al. (2011)	ADHD (N = 16) BD (N = 15) HC (N = 15)	ADHD = 46.6 (14.2) BD = 41.3 (8.1) HC = 43.9 (19.8)	RAVLT WMS (logical memory) ROCFT	The immediate recall on the logical memory subtest of the WMS-R significantly differed between the groups ($p<0.01$), with BD performing significantly worse than HC ($p=.004$) The performance of the three groups on the delayed recall phase, was not significantly different No significant differences were found across the group on the recognition phase Immediate recall performance on the RAVLT differed between groups ($p=.001$), with HC performing significantly better than both BD ($p=.01$), and ADHD ($p=.045$) On the visual memory task, no significant differences were found for the initial phase ($p=.24$) or the delayed recall phase ($p=.23$). Nonetheless, the groups significantly differed on their ability to recognize the original figure, specifically BD from ADHD ($p=.027$) Differences were found between BD patients and controls on the immediate recall phase of the logical memory task and the RAVLT. Finally, the recognition phase of the RAVLT and the Rey Figure were the only measures that reliably differentiated the two clinical groups
Torralva et al. (2012)	High-functioning ADHD ($n=83$) Low-functioning ADHD ($n=34$) HC ($n=21$)	HF-ADHD = 35.5 (15.1) LF-ADHD = 32.4 (15.6) HC = 30.4 (10.1)	RAVLT WMS (logical memory) ROCFT	Significant difference was observed for the immediate ($p<.001$), and recall ($p<.01$), scores of the WMS-R logical memory test and the immediate score of the RAVLT ($p<.001$). Post hoc comparisons showed a similar pattern for all variables: the Lo-ADHD group patients differed significantly from both Hi-ADHD and control participants, while these two groups showed a similar performance
Torres et al. (2017)	ADHD (N = 50) ADHD + BD (23) BD (N = 70) HC (N = 86)	ADHD = 37.08 (12.3) ADHD + BD = 41.52 (9.6) BD = 46.34 (10.5) HC = 43.31 (13.8)	CVLT WMS-III (Short and delayed recall) RCFT	Regarding visual memory, only the two bipolar groups showed impairment, and patients with pBD showed significantly worse results than those with pADHD ($p<.001$) Concerning the verbal learning/ memory domain, all the clinical groups showed significant impairment, with z scores < -1, albeit without significant differences among them
Weyandt et al. (2013)	ADHD ($n=24$) HC ($n=26$)	ADHD = 20.17 (1.20) HC = 20 (1.17)	CVLT-II	No significant group differences were obtained for any score on the CVLT-II

As can be seen in Table 4, results show significant worse performance in ADHD patients when compared to healthy controls in *reading tasks*, as reported by Biederman et al. (2010), Enghelhardt et al. (2011), Fried et al. (2012) and Laasonen et al. (2010). In relation to *language production*, Engelhardt et al. (2011) reported a larger number of repetitions and unfilled pauses together with a larger production of words in adult ADHD participants ($p < 0.05$) when compared to controls. Moreover, difficulties to deal with metaphors, especially in the literal condition, were reported by Segal et al. (2015), as well as a worse performance in language edition tasks throughout the day in the areas of spelling, punctuation and grammar, as shown by Fried et al. (2012).

When trying to establish differences within the ADHD subgroups, the inattentive subgroup showed to be less fluent than the other ADHD subgroups (Engelhardt et al. 2011). ADHD remitters exhibited a similar profile to combined ADHD subgroup, who altogether showed worse performance than the remaining ADHD subgroups and healthy controls (Engelhardt et al. 2012), by showing more grammatical expression and repair dysfluencies, although remitters were faster starting speech than combined subgroup participants.

Areas not showing significant differences were rate of filled pauses or repairs, organization strategies to plan and execute descriptions, and decisions taken while they worked their way through the networks as shown by Engelhardt et al. (2011); phonological processing or gain in Laasonen et al. (2010); ability to sound out words quickly and the ability to recognise familiar words as sight words in Fried et al. (2016), and naming and comprehension tasks in Torralva et al. (2013).

With regards to *writing performance*, young adults with ADHD exhibited significant worse results than healthy controls in the microstructure, productivity and morphosyntax of a story ($p = 0.044$), where they wrote shorter texts, with a lower number of words and lower diversity of words. They also committed more morphosyntactic errors and, in the information related to the macrostructure, they included significantly less information in their writings about the informative proposal of the story related to the characters and other general descriptive issues such as the scenario or time (Miranda et al. 2013). In the study by Vekaria and Peverly (2018), students with ADHD performed worse in written memory ($p < 0.002$) and writing speed ($p < 0.001$), not showing reliable differences between ADHD and controls neither in the number of notes taken nor in their quality.

In summary, for the language domain, adult patients with ADHD show lower performance in reading tasks (Biederman et al. 2010; Enghelhardt et al. 2011; Fried et al. 2012; Laasonen et al. 2010). In other areas of language, it is difficult to derive general conclusions, as studies measuring similar issues or using similar tasks are scarce, since they focus in very specific tasks or use ad hoc experimental tasks (Enghelhardt et al. 2011, 2012; Fried et al. 2012; Laasonen et al. 2010; Miranda et al. 2013; Segal et al. 2015; Vekaria and Peverly 2018).

Social Cognition

Under the scope of social cognition we have included studies that assess components such as emotion recognition and inferences (Theory of Mind – ToM), although we have also included those measuring emotional dysregulation. Those focused on mood or personality disorders, or targeting other mental health conditions, have been excluded.

Table 5 shows the summary of these studies. In terms of emotion recognition or coding of emotional signs, Bisch et al. (2016) and Conzelmann et al. (2009) report about the independence of the emotion type, valence or modality, as well as about the confusion due to attentional dysfunction during the task (Bisch et al. 2016); and differences between adult ADHD patients versus healthy controls in the reduction of emotional response in terms of the startle attenuation during pleasant pictures (Conzelmann et al. 2009). In the latter, the hyperactive ADHD subgroup did not show any kind of affective modulation, neither in front of pleasant nor unpleasant stimuli, while inattentive subgroup performed similar to healthy controls.

With regards to studies exploring ToM components (Abdel-Hamid et al. 2019; Aycicegi-Dinn et al. 2011; Tatar and Cansiz 2020), contradictory outcomes have been reported. On one hand, some studies use the same measures (i.e., Reading the mind in the eyes test) but do not find differences between ADHD patients and healthy controls ($p = 0.250$) (Aycicegi-Dinn et al. 2011), while others do show differences between ADHD and controls performing this same task ($p = 0.003$) (Tatar and Cansiz, 2020), although they justify their results stating that linear regression analysis showed a significant effect of executive function deficits in ToM in ADHD group. The study by Abdel-Hamid et al. (2019) also assesses these issues but using a completely different task based on a video where different characters interact with each other. This study does not show differences between ADHD and controls for ToM, but shows some deficits in empathy in ADHD when compared to controls ($p = 0.04$).

An additional area of interest in this domain is emotional dysregulation, where two studies by Corbisiero et al. (2017) and Mitchell et al. (2012) report difficulties for individuals with ADHD and state that emotional dysregulation is a predictor for ADHD diagnosis and its severity. Other studies explore the relevance of emotional reflectiveness or impulsivity, and they show high scores in emotional impulsivity in ADHD when compared to controls ($p = 0.019$), as reported

Table 4 Studies showing results for Language domain

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Biederman et al. (2011)	ADHD (n = 116) HC (n = 146)	ADHD = 37.8 (9.8) HC = 30.3 (8.7)	WRAT reading	Independent of age, ADHD was associated with significantly lower scores on WRAT reading (p = .005). After full-scale IQ was controlled for, ADHD not was still significantly WRAT reading scores (p = .71)
Engelhardt et al. (2011)	ADHD-PH((n = 6) ADHD-PI (n = 18) ADHD-C (n = 20) HC (n = 31)	ADHD-PH = 25.33 (2.58) ADHD-PI = 23.11 (4.71) ADHD-C = 23.20 (4.77) HC = 24.77 (4.93)	Reading was assessed with the Wide Range Achievement Test Experiments were programmed with E-Prime	ADHD participants produced significantly more words overall and were more likely to make unfilled pauses and repetitions. The ADHD-PI group was significantly more disfluent than HC. No differences in the organizational strategies that ADHD participants used when planning and executing their descriptions, in the rate of filled pauses or repairs and in the decisions that they made as they worked their way through the networks
Engelhardt, Veld, Nigg and Ferreira (2012)	HC (n = 20) ADHD-PI (n = 22) ADHD-C (n = 22) Remitted (n = 21)	HC = 23.60 (4.99) ADHD-PI = 22.50 (3.91) ADHD-C = 22.91 (3.82) Remitted = 24.14 (4.94)	Sentence production in E-Prime experimental software	Remitted produced significantly more ungrammatical utterances compared to both HC and ADHD. For the participle verbs, there were no omnibus group differences. However, the remitted group was again significantly different from HC, and in this case, they patterned similarly to the ADHD-C group. In the animate-participle condition, both the remitted group and the ADHD-C group were significantly worse than HC. In the inanimate-optional condition, the combined group was significantly worse than HC and the remitters were marginally worse than HC (p = .055). Thus, in terms of repair disfluencies, the remitted group patterned more similarly to the ADHD-C group, and both were worse than controls. The remitted group was significantly faster to begin speaking compared to the ADHD-C group ($t(41) = 2.47$, $p < .05$). Remitted was more similar to the combined in the number of ungrammatical utterances when the sentence contained a participle verb, and both the remitted group and ADHD-C participants were worse than HC. Also, the tendency to produce ungrammatical utterances in this condition seemed to be linked to reading ability and IQ, and the remitted group was similar to the ADHD-C subtype in reading. However, the significant verb type × group interaction was actually driven by differences with the optional verbs. For the number of ungrammatical utterances with optional verbs, the remitted group performed significantly worse than all of the other three groups. With regards to disfluencies, results showed significant group differences only in the number of repairs. Results showed that there were significant group differences in repairs in two of the within subjects conditions (i.e., animate-participle and inanimate-optional). The remitted participants patterned similarly to the ADHD-C group. In the other two (within subject) conditions, the remitted group tended to produce slightly more repairs compared to controls and ADHD participants.. However, there were no reliable group differences in either the inanimate-participle or the animate-optional conditions
Fried et al. (2012)	ADHD (n = 56) HC (n = 63)	ADHD = 28.3 (8.5) HC = 30.8 (10.2)	Test of Word Reading Efficiency; note-taking task of the Process Assessment of the Learner; The Qualitative Reading Inventory-4; Workplace simulation tasks	ADHD participants demonstrated poor performance throughout the day on editing text for spelling, punctuation, and grammar

Table 4 (continued)

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Fried et al. (2016)	ADHD ($n=26$) HC ($n=52$) Other: ASD ($n=26$)	ADHD = 28.2 (5.6) HC = 27.5 (4.1) ASD = 27.5 (6.2)	The Test of Word Reading Efficiency	No significant differences in reading between ADHD and HC
Laasonen et al. (2010)	ADHD ($n=30$) HC ($n=40$) Dyslexia ($n=40$)	ADHD = 31.60 (8.17) HC = 35.45 (10.27) Dyslexia = 37.15 (11.70)	Ad hoc language tests; Stroop; WMS-III; Pig-Latin	Technical reading accuracy was poor in both clinical groups and also poorer in the dyslexia group than in ADHD. Corrected errors of technical reading did not differentiate between the groups. In the ADHD group, none of the areas of phonological processing was impaired No evidence was gained for a shared impairment in processing speed because those with ADHD were not impaired in the speed variables and every speed variable differentiated the poorer dyslexia group from those with ADHD. Participants with ADHD were the least affected, and their difficulties reflected less accurate performance. Furthermore, all the observed differences became nonsignificant when IQ was controlled for, suggesting ADHD is not related to significant impairments in phonological processing or achievement
Miranda et al. (2013)	combined subtype ADHD ($n=27$) HC ($n=27$)	All 18—24	Composed a written narration based on short story number 11, ''Shark''; WAIS III	Young ADHD adults obtained significantly worse results than without on five of the six quantitative parameters of the microstructure of the story, productivity and morphosyntax ($p=.044$). Thus, wrote shorter texts ($p=.019$) with a lower number of words ($p=.040$), and including fewer different words ($p=.033$). They also made more morphosyntactic errors ($p=.044$), which is a striking finding in this age group. Furthermore, included significantly less information in their writing about the informative story proposal related to the characters and other general descriptive aspects such as setting or time In the categories of initiating event, internal response, and ending, the same tendency was observed, although the differences between the two groups did not reach significance
Segal et al. (2015)	ADHD ($n=26$) HC ($n=24$)	ADHD = 26.42 (3.18) HC = 25.33 (3.18)	Picture Naming Task Metaphor processing task Test of phonological short term memory	A Scheffe Post Hoc analysis revealed that the only significant difference between the groups was in the Metaphor-literal condition. In this condition, the inverse efficiency scores were significantly higher (less effective) in the ADHD group than in the control group ($p<0.01$), meaning that the ADHD group was less efficient in conflict resolution compared to controls. No group differences were obtained between the inverse efficiency scores in the Double-metaphor condition, nor in the Double-literal condition High functioning adults with ADHD performed worse than adults without ADHD when they had to resolve conflicts between metaphorical and literal meanings
Torralva et al. (2013)	High-functioning ADHD ($n=83$) Low-functioning ADHD ($n=34$) HC ($n=21$)	HF-ADHD = 35.5 (15.1) LF-ADHD = 32.4 (15.6) HC = 30.4 (10.1)	BNT (abbreviated version) Token Test	No significant differences were found between the groups

Table 4 (continued)

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Vekaria and Peverly (2018)	ADHD ($n=22$) HC ($n=50$)	ADHD = 23.63 (4.17) HC = 22.18 (3.40)	Participants were instructed to write an organized summary of the lecture without notes	Students with ADHD performed worse than their non-handicapped counterparts on written recall ($p<.002$) and handwriting speed ($p<.001$) There were no reliable differences between groups on note-taking There were no significant differences between groups on quality of notes

by Mitchell et al. (2012) or Perroud et al. (2017), in which patients with ADHD get low-medium scores in reflectiveness that correlate inversely with the severity of the disorder and ability for anger management.

In summary, it can be concluded that there are not enough studies to establish a specific profile in terms of social cognition in ADHD. Both ADHD and controls would show similar results in emotion recognition (Bisch et al. 2016; Conzelmann et al. 2009), ToM does not seem to be deteriorated in ADHD (Abdel-Hamid et al. 2019; Aycicegi-Dinn et al. 2011; Tatar and Cansiz 2020) and there are signs of difficulties in emotional dysregulation and emotional impulsivity (Corbisiero et al. 2017; Mitchell et al. 2012; Perroud et al. 2017).

Arithmetic

Among all the articles included in this systematic review, only five either report specifically on arithmetic or include measures of this domain within their neuropsychological protocols (and not just as an IQ control measure). Overall, a lower performance was found in arithmetic tasks for individuals with ADHD, as shown by Biederman et al. (2010), Faraone et al. (2006), Fried et al. (2012) and Laasonen et al. (2010), all of them of significant nature ($p<0.05$). Only one study (Fried et al. 2016) did not find significant differences between ADHD participants and healthy controls. Most common used measures have been WRAT arithmetics and WAIS-III Oral Arithmetic subtest. More specifically, reports of worse performance were provided for late-onset ADHD individuals in the study by Faraone et al. (2006), where even subthreshold individuals showed worse performance than healthy controls in the WRAT test. In Fried et al. (2012), data provided in the Workplace simulation task show that arithmetic task is the one showing the most significant deficits in ADHD individuals when compared to healthy controls in the three different registered daytime periods, as well as the one that worsens the most throughout the day. Subsequently, despite the limited number of studies identified, arithmetic domain seems to show significant worse performance in adult ADHD participants when compared to controls (as can be seen in Table 6).

Discussion

The current review highlights the main features that may distinguish adult ADHD from healthy controls using an approach based on individual cognitive domains. This approach, not without difficulties and certain overlap between domains (especially between attention, memory and executive functions), has attempted to specify the main cognitive characteristics of individuals with adult ADHD, by

Table 5 Studies showing results for social cognition domain

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Abdel-Hamid et al. (2019)	ADHD (N = 30): HC (N = 30)	ADHD = 34.5 (6.81) HC = 35.83 (11.68)	Cambridge Behaviour Scale The Movie for Assessment of Social Cognition	ADHD had a significantly lower average score on the Cambridge Behaviour Scale than the control group ($p = .04$), thus showing impaired empathy There were no significant differences in terms of ToM performance (MASC), although patients performed slightly poorer in particular MASC tasks
Aycicegi-Dinn et al. (2010)	ADHD Combined ($n = 13$) HC ($n = 19$)	ADHD = 28.31 (6.89) HC = 27.11 (7.77)	Reading the mind in the eyes test; Object Alternation Test	No Group differences on alternation learning ($p = .596$) and ToM ($p = .25$)
Bisch et al. (2016)	ADHD (N = 23): HC (N = 31)	ADHD = 27.6 (9.3) HC = 29.3 (8.2)	Ad hoc task on emotional recognition	Lower performance of ADHD patients which was observed for all five categories and all sensory modalities. A general deficit in encoding of emotional cues which occurs independent of emotion type, valence or modality There were also no significant differences regarding the difference between the arithmetic mean and median of RT as indicator of potential attentional lapses. These findings argue for a deficit in emotion recognition in ADHD which cannot be explained by confounds due to decreases in attention during the task
Conzelmann et al. (2009)	ADHD ($N = 197$) ADHD-C($n = 127$) ADHD-I ($n = 50$) ADHD-HI ($n = 20$) HC ($n = 128$)	ADHD-C = 34.97 (9.09) ADHD-I = 32.08 (10.67) ADHD-HI = 34.05 (11.10) HC 34.80 (10.18)	International Affective Picture System	HC exhibited the expected startle response potentiation and attenuation related to unpleasant and pleasant pictures, respectively. In contrast, ADHD-HI did not show affective modulation at all, neither to pleasant nor to unpleasant stimuli, and ADHD-C failed to show startle attenuation during pleasant pictures. The ADHD-I group responded most similarly to control subjects but startle attenuation during pleasant stimuli was not as pronounced All ADHD subgroups showed to some extent a reduced emotional responding to pleasant stimuli. Only the ADHD-HI group also exhibited reduced emotional responding to unpleasant stimuli. The ADHD-C group showed somewhat stronger responses to unpleasant stimuli than HC

Table 5 (continued)

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Corbisiero et al. (2016)	ADHD ($n=116$) ADHD + ED ($n=277$) HC ($n=121$)	All = 32.27 (10.89)	ED (Reimherr et al. 2005; Wender 1995)	The different analyses show that ED proves a reliable and valid scale to measure emotional symptoms in ADHD. The study demonstrates that the core symptoms of ADHD affect ED and, on the other hand, that the diagnosis of ADHD is predicted by ED. Also, the addition of ED to the regression model with the core symptoms is shown to enhance the predictability of an ADHD diagnosis. ED is a major indicator of the severity of ADHD independently of a comorbid disorder, while the presence of other mental disorders is found to intensify symptoms
Mitchell et al. (2012)	ADHD ($n=18$) HC ($n=23$)	AHDHD = 24.83 (4.93) = 22.61 (5.60)	Emotion Dysregulation: Impulsivity/Emotional Lability scale from the CAARS Emotional Impulsivity: UPPS	Higher emotion dysregulation ($p < .001$) and emotional impulsivity ($p = .019$) in ADHD, while controlling for ODD and depressive symptoms Both ADHD symptoms ($\beta = 0.60$, $p < .001$) and emotion dysregulation ($\beta = 0.75$, $p < .001$) predicted emotional impulsivity, and ADHD symptoms predicted emotion dysregulation ($\beta = 0.85$, $p < .001$)
Perroud et al. (2017)	ADHD ($n=101$) BPD ($n=108$) BPD + ADHD ($n=40$) BPD-ADHD ($n=68$) HC ($n=236$)	ADHD = 33.48(10.45) BPD = 32.01 (9.54) BPD + ADHD 30.45 (10.1) BPD-ADHD 32.93 (9.15) HC = 23.27 (2.69)	The Reflective Functioning Questionnaire	With regard to reflective functioning, there were significant group differences in both. ADHD reported RF scores at mid-point between HC and BPD Severity of ADHD was negatively correlated with RF scores on the RFQ-B. Disposition towards anger and poor anger control were significantly associated with low RF scores in the ADHD group There was a combined effect of diagnoses; having both disorders (ADHD + BPD) was associated with the most impaired RF scores compared to BPD without comorbidity and ADHD An association was found between poor mentalizing and the difficulty to control anger in the ADHD group
Tatar and Cansiz (2020)	ADHD ($n=40$) HC ($n=40$)	ADHD = 21.72 (4) HC = 21.75 (3.52)	Reading mind from the eyes test	A significant difference was found between the ADHD and control groups regarding ToM functions ($p = .003$) and a significant effect of EF deficits in ToM in ADHD

Table 6 Studies showing results in Arithmetic domain

Authors and publication year	Participants	Age: Mean (SD)	Measures used	Summary of main results
Biederman et al. (2010)	ADHD (n = 116) HC (n = 146)	ADHD = 37.8 (9.8) HC = 30.3 (8.7)	WRAT arithmetic	After full IQ was controlled, ADHD was still significantly associated with poorer WRAT arithmetic (p = .002)
Faraone et al. (2006)	Subthreshold ADHD (n = 41) Late-Onset ADHD (n = 79) Full ADHD (n = 127) HC (n = 30)	S-ADHD = 35.5 (9.1) L-O ADHD = 36.5 (10.8) Full ADHD = 36.1 (10.8) HC = 29.9 (9)	WAIS-III Oral Arithmetic	Subthreshold (p < .01) and Late-Onset (p < .05) ADHD showed deficits in comparison with HC in oral arithmetic
Fried et al. (2012)	ADHD (n = 56) HC (n = 63)	ADHD = 28.3 (8.5) HC = 30.8 (10.2)	Wide Range Achievement Test; WAIS-III Oral Arithmetic; Workplace simulation tasks	ADHD demonstrated poor performance throughout the day on the math fluency and the task that was most significantly impaired in participants with ADHD than in controls through all three periods of the day was the Math Fluency task
Fried et al. (2016)	ADHD (n = 26) HC (n = 52) Other: ASD (n = 26)	ADHD = 28.2 (5.6) HC = 27.5 (4.1) ASD = 27.5 (6.2)	The Wide Range Achievement Test-III	No significant differences in arithmetic between ADHD and HC
Laasonen et al. (2010)	ADHD (n = 30) HC (n = 40) Dyslexia (n = 40)	ADHD = 31.60 (8.17) HC = 35.45 (10.27) Dyslexia = 37.15 (11.70)	RMAT WAIS-III arithmetic	Both clinical groups were poorer than the control group (p = 0.001)

defining the main findings up to date in six different cognitive domains: (1) attention and processing speed, (2) executive functions, 3) learning and memory, (4) language, (5) social cognition, and (6) arithmetic abilities.

For the Attention domain, some studies found significant deficits across all attentional modalities (alertness, selective and sustained attention) (Mostert et al. 2018) both in regular neuropsychological testing (Fuermaier et al. 2017a, b; Tucha et al. 2017), and using an approach focusing on daily life activities (Groen et al. 2019). A more detailed attentional profile of adults with ADHD would report inattention problems understood as omission errors (Studerus et al. 2018); interference by irrelevant stimuli in selective attention (Pretus et al. 2020); higher impulsivity in the form of commission errors (regardless of IQ) (Millioni et al. 2014); worse and slower performance for divided attention in terms of managing multiple simultaneous sources of information (Salomone et al. 2020); a specific deficit in sustained attention suggesting specific problems to maintain a consistent level of performance (Bisch et al. 2016), as well as high variability of performance in terms of reaction times (Mostert et al. 2015); and, finally, overall slower processing speed (Maruta et al. 2017). Some contradicting studies state the need to focus on the effects of age, intellectual function, as well as emotional symptomatology (Hopwood and Morey 2007; Pettersson et al. 2018), and the need to go beyond single test measures and instead use a combined approach of self and informant symptom ratings, family history and neuropsychological tests.

Findings in the current review in relation to Executive Functions are a reflection of the difficulties existing with the construct of ADHD in adults: an excessive amplitude of definitions, factors and models that lead to a great variability of measures and outcomes with multiple open interpretations. This also mixes with the fact that individuals with ADHD are extremely variable in their responses, and that the role of comorbidities (which have been deliberately left out in this review for clarity purposes, but are common in ADHD) needs further attention and experimental research (Neely et al. 2017; Nikolas et al. 2019). Additionally, due to they being adults and having lived with their disorder for a long time, some patients have developed compensating strategies to solve some deficits, especially those related to consequences of impulsivity (Marx et al. 2013), and this exponentially increases variability not only in one individual's responses, but also between individuals. Thus, most researched factors are those traditionally found in child and adolescent ADHD population, and are also the ones showing more clear and significant deficits in adults with ADHD when compared to HC: working memory and inhibition (and, within the latter, reward delay and interference control). In addition, the frequent use of certain measures in

ADHD research, such as Stroop test and Continuous Performance Tests, may have led to this bias towards this specific type of measures, giving the impression that the only deficits are those shown by these measures (Abdel-Hamid et al. 2019; Holst & Thorell, 2017). On the contrary, constructs that show to be fundamental in a differential ADHD diagnosis, such as cognitive flexibility or alternation, have not generated such a high volume of research. Chances are that these functions are usually assessed earlier in more severe cases in childhood, and are difficult to be established using psychometric tests. Thus, tasks such as verbal fluency, a potential indicator of severity in terms of dysexecutive symptoms, has not yielded consistent differentiating results for adult ADHD (Fuermaier et al. 2015). Nevertheless, executive functions have been shown to be relevant to clarify daily life deficits in reasoning, abstract thinking and logic, which are usually contained in IQ measures.

In relation to Memory, there seems to be a consistent proof that deficits in verbal memory are a defining feature in adults individuals with ADHD (Biederman et al. 2010), while visual memory shows mixed and contradictory results (Torres et al. 2017), and the need of further research in the role of incidental memory in adult ADHD (Delite and Braun 2011).

With regards to Language, adult patients with ADHD show lower performance in reading tasks (Biederman et al. 2010), but it is difficult to establish conclusions for the rest of language features, due to the high variability in used tasks and measures, and a dominance of ad hoc experimental tasks that make comparability between studies more difficult.

Additionally, in terms of Social Cognition, it is difficult to establish a specific profile for adult ADHD, due to the lack of specific studies in the area and the potential mixture with executive function deficits (Tatar and Cansiz 2020). Finally, in Arithmetic abilities, although the numbers of studies found are limited, there seems to be a significantly worse performance in adult ADHD (Biederman et al. 2010).

There are obvious limitations to this systematic review. First, the interest in defining a differential profile for adult ADHD patients in comparison to healthy controls has led to a primary (and almost exclusive) focus in case–control studies. Additionally, to check the possibilities to focus in an ADHD-only, domains based, cognitive profile, the role of comorbidities has been left out of the scope of this review. At the same time, the lack of longitudinal studies in the literature make it difficult to produce a clear profile beyond a static picture obtained by means of several cross-sectional measures. In terms of findings, the main limitation is the shortage of research going beyond attention and executive functions. Some domains would require a more in-depth research, such as social cognition, which is usually fragmented in isolated studies focusing on emotional recognition or attribution. In terms of sample size, many studies have limited sample sizes and focus on very specific tasks that make it difficult to establish inter-study comparisons in the form of a meta-analysis, which, as a consequence, was discarded for the purposes of this research.

Based on the current systematic review, our understanding is that future research in adult ADHD needs to overcome certain limitations to provide further clarity to differential diagnosis and develop an accurate characterization of the cognitive and functional profile of the disorder. Reviewed research has shown a large heterogeneity and disparities in terms of sample sizes (with many studies having limited sample sizes) but mainly in how a diagnosis is established in the inclusion criteria. In many instances, it requires a significant effort to distinguish clearly how the diagnosis of adult ADHD was made, what criteria and procedures were followed, or whether individuals had a confirmed diagnosis, or the label was assigned due to an ad hoc assessment of symptoms. In addition, the active role of medication intake and comorbidities require further consideration and need to be examined and controlled to increase the accuracy of the diagnosis and subsequent treatment. Comorbidities were left out of this review as they were, we believe, a confounding factor when trying to establish a cognitive profile for adult ADHD, but the high prevalence of comorbidities in ADHD may limit the generalizability of the results described here and it is necessary to consider them further and control their impact on ADHD in future research and clinical work.

Moreover, methodological heterogeneity is a consequence of a primary focus on self-reported measures (in many cases, these were the only reported measures for cognition), but also due to the diversity of neuropsychological measures used, which made it difficult to establish clear inter-study comparisons. It would be desirable, we believe, to establish to some extent common comprehensive neuropsychological assessment protocols that capture domains described in this review beyond the usual biased focus on attention and executive functions. Also, emerging variables such as time estimation (only found in Marusich and Gilden 2014) may become potential core symptoms that demand further attention in ADHD in the near future. Furthermore, emotional dysregulation, as shown in a very recent meta-analysis by Beheshti et al. (2020), may constitute a core feature of adult ADHD psychopathology, with emotional lability and negative emotional responses as main characteristics, but with the role of moderator variables still unclear. Separately, there are no clear screening criteria or systems between ADHD and some comorbidities, and the excessive reliance on self-reported measures, we believe, needs to be overcome and addressed if we aim to get a more detailed, accurate differential diagnosis between adult ADHD and other comorbid conditions. Likewise, medication management and specific differences between those who are medication naive versus those who quit medication at the time of the assessment needs further clarification in ongoing studies and further exploration in future research. Additionally, an important step in future research would be to consider multivariate models and determine individual cognitive profiles of patients with ADHD, i.e., which and how many deficits are present in particular patients. Such an analysis can only be performed if patients perform comprehensive batteries of neuropsychological tests, and not just self-reported questionnaires or single tests.

Conclusion

To our understanding, this is the first systematic review that aims to establish a cognitive characterization of adult ADHD based on domains, and it has shown how it is possible to establish a comprehensive cognitive profile that defines adult ADHD as a disorder that includes deficits across all attention modalities (with a prominence on inattention, impulsivity, interference by irrelevant stimuli, divided attention, sustained attention, and processing speed), executive functions (working memory and inhibition, with a special emphasis on reward delay and interference control), memory (mainly verbal), language (reading), social cognition (with mixed results), and arithmetic abilities.

Author contributions All the authors formulated the research question. Each author performed the literature review in 2 databases each, and all checked the grey literature. All authors worked in detection of duplicates and screened 2/3 of the available articles. Conflicting decisions between two authors were resolved by a third author. UD wrote the first draft of the introduction, methods and the attention section in the results. IO and NP reviewed and corrected the introduction and methods. IO wrote the executive functions section, while NP wrote the first draft for sections for learning and memory, language, social cognition and arithmetic, which were corrected and revised by UD. All authors collaborated in writing the discussion. IO and UD performed the final edits.

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