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Jansen, J.M.; Franse, M.E.

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Review

Executive functioning in antisocial behavior: A multi-level systematic meta-analysis

Jochem Milan Jansen [a,b,*], Melanie Elisabeth Franse [c,d]

[a] Institute for Criminal Law & Criminology, Faculty of Law, Leiden University, Leiden, Netherlands
[b] Inforsa, Arkin, Amsterdam, The Netherlands
[c] Netherlands Institute of Forensic Psychiatry and Psychology, Department of Science and Education, Herman Gorterstraat 5, 3511EW Utrecht, Netherlands
[d] Institute of Education and Child Studies, Faculty of Social Sciences, Leiden University, Wassenaarseweg 52, 2333AK Leiden, Netherlands

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ABSTRACT

Neurobiological information – including executive functioning – is increasingly relevant for forensic clinical practice, as well as for the criminal justice system. Previous meta-analyses report that antisocial populations show impaired performance on executive functioning tasks, but these meta-analyses are outdated, have limitations in their methodological approach, and are therefore in need of an update. The current multi-level meta-analysis including 133 studies (2008-2023) confirms impaired performance in executive functioning (d=.42), but studies are heterogeneous. Several moderator analyses showed that neuropsychological test used, type of executive function component, and control group characteristics moderated the overall effect. Specifically, matching psychiatric problems in the non-antisocial control group eliminated any differences in executive functioning between groups. No moderation effects were found for assessment quality, hot or cold executive functions, and various population characteristics. These results could indicate that the assessment of executive functioning in antisocial populations may be less relevant for recidivism risk assessment than thought, although this should first be assessed in prospective longitudinal studies. Executive functioning could potentially be used to identify or screen for individuals with certain treatment needs or be used as a responsivity factor, especially in disorders which are often underdiagnosed in criminal justice settings.

1. Introduction

Neurobiological information is increasingly relevant for forensic clinical practice, as well as for the criminal justice system (Cheng, O'Connell, & Wormith, 2019). Neurobiological information may improve risk assessment (de Ruigh et al., 2021; Haarsma et al., 2020; Norman, Polaschek, & Starkey, 2023), and predict treatment completion in forensic psychiatric populations (Cornet, van der Laan, Nijman, Tollenaar, & de Kogel, 2015; Van der Sluys et al., 2020). One specific neurobiological domain which is increasingly assessed in this context is executive functioning (Haarsma et al., 2020; Norman et al., 2023), most often defined as (higher order) cognitive processes used to perform goal oriented, goal directed or future oriented actions, behaviors or responses (Baggetta & Alexander, 2016). Some authors propose that the nature of criminal responsibility can be reduced to EF (Hirstein, Sifferd, & Fagan, 2018), and impaired executive functioning (EF) has been implicated in interpersonal problems (Sprague, Verona, Kalkhoff, & Kilmer, 2011), physical health (Hall, Elias, & Crossley, 2006), and many psychiatric disorders, including substance abuse (Ersche et al., 2012) and emotion regulation difficulties (Fernandes, Wright, & Essau, 2023). Therefore, EF may be a transdiagnostic and/or risk factor for emotional, behavioral and psychotic disorders (Wade, Zeanah, Fox, & Nelson, 2020), all of which are prevalent within the judicial context.

Despite (custodial) sentences and forensic psychiatric treatment, world-wide recidivism remains at a relatively high and stable 20-60% reconviction rate within 2 years after release (Yukhnenko, Sridhar, & Fazel, 2019). EF could possibly provide (additional) information on recidivism risk and could guide forensic mental health care in order to reduce recidivism (Haarsma et al., 2020; Norman et al., 2023), but this requires a more specific understanding of the relationship between EF and antisocial behavior (ASB). This is necessary in order to assess the (potential) usability and feasibility of EF within a criminal justice setting. Most published research on this relationship uses a group comparison approach, including antisocial populations and non-

* Corresponding author at: Institute for Criminal Law & Criminology, Faculty of Law, Leiden University, Steenschuur 25, 2311ES Leiden, Netherlands.
E-mail address: j.m.jansen@law.leidenuniv.nl (J.M. Jansen).

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offending control groups. Previous meta-analyses report that antisocial populations show impaired performance on EF tasks (Morgan & Lilienfeld, 2000; Ogilvie, Stewart, Chan, & Shum, 2011), but they are outdated, have limitations in their methodological approach and are therefore in need of an update.

1.1. Executive functioning

There is debate about the definition and operationalization of EF (see Baggetta and Alexander (2016) for a review). Studies generally agree that EF is a multidimensional construct, but disagree on the exact number of components and conceptualization of EF. For example, in a review of 106 studies, a total of 39 different components or processes of EF and 48 different theoretical models of EF were identified (Baggetta & Alexander, 2016). The most referenced model is proposed by Miyake et al. (2000) and includes three different components of EF; updating working memory, shifting between task sets, and inhibition of prepotent thoughts or actions. These functions correlate with one another, suggesting so called unity (e.g. they share an underlying ability), but are also separable, which indicates a degree of diversity (Friedman & Miyake, 2017; Miyake et al., 2000). According to this unity/diversity model, EF consists of three different components which share an underlying core ability, known as common EF. This model of shared and unique processes underlying EFs is supported by various neuroimaging studies (Saylik, Williams, Murphy, & Szameitat, 2022; Smolker, Friedman, Hewitt, & Banich, 2018). A similar model was proposed by Diamond (2013), and includes working memory, shifting, and inhibition, but does not include common EF or updating specifically. Instead, (Diamond) suggests that these three components work together in order to perform higher-order EFs such as planning, reasoning, or problem solving. Based on the review on EF conducted by Baggetta and Alexander (2016), we conclude there is most agreement on three separable EF components: working memory (span and updating), shifting between task sets, and inhibition of prepotent thoughts or actions.

Regarding the conceptualization of EF, age is a complicating factor, since confirmatory factor analyses show that different unity/diversity models of EF exist across the life span (Karr et al., 2018). EF seems to differentiate from a more unidimensional construct in children to both unidimensional and distinguishable constructs in adolescents and young adults (Karr et al., 2018). In this process of differentiation, inhibition and working memory seem to develop into distinguishable constructs earlier than shifting (Huizinga et al., 2006; Senn et al., 2004). It is proposed that this differentiation of EF is a direct reflection of cortical areas – which initially function non-specifically – becoming increasingly specialized during development, through activation, interactions, and experiences (Bardikoff & Sabbagh, 2017). From young adulthood to older adulthood, EF seems to dedifferentiate again, with greater unidimensionality of EF in older adults (Karr et al., 2022). Because of these differences in the unity/diversity of EF across the life span, it is important to assess the effects of age in the relationship between EF and ASB.

1.2. Assessment of executive functioning

Besides the conceptualization of EF, Baggetta and Alexander (2016) also reviewed how EFs are assessed, and report a wide variety in assessments. A total of 11 different batteries were reported, which are sets of (sub)tests or scales that measure different aspects of EF. Such batteries can either be performance based, or based on behavioral ratings by participants themselves or others (e.g. teacher, parent, staff). Additionally, 109 different neuropsychological tasks were identified, many of which were only reported once ($n=56$). Most commonly used tasks include the Stroop task, Digit span and the Go/No-Go task, but 27% of these tasks assessed multiple EF processes. For example, the Stroop task was used to measure inhibition, cognitive control, working memory, attention and overall/central executive functioning (Baggetta & Alexander, 2016).

This issue is known as the task impurity problem, which indicates that a certain task or outcome assesses or operates on a number of different executive (and/or non-executive) components. This severely hinders the interpretability of outcomes from such tasks, since it often remains unclear if task impairment is associated with task specific or common EF impairments (or another process all together). Snyder, Miyake, and Hankin (2015) describe that a specific outcome of an EF task often consists of variance explained by (1) task specific EF, (2) common EF, (3) non-EF processes, and (4) measurement error. The task impurity problem can be alleviated by using multiple measures of each EF component and extracting a latent variable constituting the task-specific EF of interest (Friedman et al., 2008). Unfortunately, this is a time consuming approach and therefore not always feasible. An alternative is a thorough task and task-outcome selection, since some tasks provide outcomes which are more closely related to specific EF (Snyder et al., 2015). For example, more traditional EF tasks (including the Stroop task and the Trail Making Test) measure both common and specific EF components and are sometimes considered too coarse to answer questions about specific EF. Some authors have provided guidelines or lists where the quality (including sensitivity to specific EF components) of certain task outcomes is assessed (see Op den Kelder, Van den Akker, Geurts, Lindauer, and Overbeek (2018) or Snyder et al. (2015)). Unfortunately, there is little consensus on when a certain task outcome is deemed to be of high quality, but in theory more specific EF measures should provide a more detailed answer on which processes are implicated in antisocial behavior.

Another complicating factor in the assessment of EF is that EF problems may manifest themselves differently in emotional and/or motivationally salient situations (*Dolan & Lennox, 2013). This idea is in line with studies showing that antisocial behavior is often associated with emotionally salient situations, such as reactive aggression (Bertsch, Florange, & Herpertz, 2020) or committing crime under the influence of peer pressure (Sijtsema & Lindenberg, 2018). Employing EF in these situations has been described as “hot” – as opposed to non-emotional “cold” – EF (Zelazo, 2020). Studies attempt to assess “hot” and “cold” EFs by varying task features (Salehinejad, Ghanavati, Rashid, & Nitsche, 2021). For example, a Go/No-Go task with neutral stimuli is used (i.e. symbols) for the assessment of “cold” EF, whereas emotionally salient images are used as stimuli for the assessment of “hot” EF (Salehinejad et al., 2021). Since ASB is more apparent in emotionally salient situations, it is expected that antisocial populations experience more problems with EF in “hot” situations, resulting in a larger EF impairment in “hot” tasks compared to “cold” tasks.

1.3. Antisocial behavior

ASB is a complex (social) construct, which has proven to be difficult to conceptualize within a single theoretical framework (Rutter, 2003). One proposed operationalization delineates antisocial behavior into three different categories: clinical psychiatric diagnosis, violation of legal and social norms, and aggressive or violent behavior (Ogilvie et al., 2011). Clinical diagnoses most frequently associated with antisocial behavior include oppositional defiant disorder (ODD), conduct disorder (CD), antisocial personality disorder (ASPD), and psychopathy/Callous Unemotional (CU)-traits. Both ODD and CD are sometimes referred to as Disruptive Behavioral Disorders (DBD). Legal operationalizations are related to the violation of social norms and include criminality or delinquency. This is often based on official records, such as the presence of a criminal record or being currently detained. Finally, physically aggressive or violent individuals are also considered antisocial.

1.4. Previous meta-analyses

So far two meta-analyses have assessed the difference in EF between antisocial and non-antisocial control groups (Morgan & Lilienfeld, 2000; Ogilvie et al., 2011). In both meta-analyses, antisocial individuals

generally scored worse on neuropsychological measures of EF than non-antisocial controls, with a medium effect-size (*d*=*.62*; (Morgan & Lilienfeld, 2000); *d*=*.44*; (Ogilvie et al., 2011)), but the included studies showed considerable heterogeneity. Several moderator analyses were reported, e.g. for the neuropsychological tests which were used and participant characteristics. The definition of antisocial behavior appeared to influence the overall effect size, since both meta-analyses reported lowest effect sizes for antisocial personality disorder, (ASPD; *d*=.08*; d*=.19) highest for criminality (*d*=1.09*; d*=.61), and psychopathy was somewhere in the middle (*d*=.29*; d*=.42). A meta-regression analysis with moderators revealed that diagnosis of ADHD in the ASB group negatively affected their EF performance, whereas age and sex did not (Ogilvie et al., 2011). These non-significant moderation effects for age and sex were reported in the meta-analysis by Morgan and Lilienfeld (2000) as well.

Although there is some evidence that specific characteristics may interact in explaining the association between ASB and EF, neither meta-analysis included moderation analyses with interactions between study characteristics. Individual studies support the notion of such interactions, for example, children with a higher levels of conduct problems (CP) and callous-unemotional (CU-)traits may display better EF performance compared to children in a low-CU/high-CP group, and low-CU/low-CP group (Graziano et al., 2022). Additionally, better EF was associated with more externalizing behavior in children with high CU-traits, but lower EF was not associated with externalizing behaviour in children with low CU-traits (de Graaf, Bolhuis, Cecil, White, & van Dongen, 2023). Finally, adolescents with both high-CP and high CU-traits reported higher violence and substance use, with the effects being stronger in youth with higher levels of executive control (i.e. inhibition). These studies in children therefore suggest that impaired EF is primarily a predictor for ASB in children with high CU-traits. Numerous other possible interactions could explain variance between studies and will be explored in this meta-analysis.

Unfortunately, neither of the meta-analyses used a theoretically based model of EF, but instead performed moderator analyses for the specific measure which was used to assess EF. Ogilvie et al. (2011) reported variability, with largest effects sizes for the self-ordered pointing task (*d*=.83; common EF/working memory), porteus maze test (*d*=.71; common EF/planning), delayed match to sample (*d*=.59; common EF/working memory) and the Go/No-Go task (*d*=.56; common EF/inhibition). Although Morgan and Lilienfeld (2000) assessed only a few neuropsychological tests, largest effect sizes were also reported for the maze test (*d*=.80; common EF/planning).

Both meta-analyses did not assess the relationship between EF and ASB in young children (<12 years of age), although much research exists on this topic. For example, a recent meta-analysis of prospective longitudinal studies indicates poor EF predicts future conduct problems (Yang et al., 2022). Although it is complicated to compare ASB in young children (i.e. children with a diagnosis of DBD) to adults (i.e. convicted criminals), it is unclear whether the difference in EF performance in ASB populations compared to controls varies with age. Based on the unity/diversity model - which proposes there are different models of EF throughout the life span - it could be expected that EF is also differently related to ASB throughout life. A recent meta-analysis found that children (aged 3-18) with DBD (described by the authors as an early manifestations of antisocial behavior) scored worse on EF than typically developing controls, with a small effect size for working memory (*d*= -.26), a small to medium effect size for inhibition (*d*= *-.30* to *d*= *-.45*) and a small effect size for shifting (*d*= *-.31*) (Figueiredo, Ramiao, Barroso, & Barbosa, 2023). Another meta-analysis on the relationship between EF and DBD with a lower mean age (3-6 years) found somewhat smaller effect sizes, with small effect sizes for working memory (*d*=*.15*), inhibition (*d*=*.22*), and shifting (*d*=.13) (Schoemaker, Mulder, Dekovic, & Matthys, 2013). Compared to the meta-analyses from Morgan and Lilienfeld (2000) and Ogilvie et al. (2011) - where the youngest included participants were 14 years - smaller effect sizes were found in the meta-analyses that included younger children. The current meta-analysis therefore incorporates (young) child and adult ASB populations in order to assess whether the association between EF and ASB varies with age.

Antisocial populations are characterized by high prevalence of ADHD, substance use disorders, psychosis/schizophrenia and other psychiatric problems (Fazel, Hayes, Bartellas, Clerici, & Trestman, 2016). It is unclear to what extent impairments in EF in antisocial groups are associated with the ASB or with underlying psychiatric symptoms characterized by impaired EF. Some studies indeed indicate that when ADHD children with and without CD are compared, no differences are found in EF (*Noordermeer et al., 2020). Although Ogilvie et al. (2011) showed that antisocial groups with ADHD perform worse than antisocial groups without ADHD, they did not assess whether the non-offending control groups included ADHD participants as well. The authors do suggest that it is possible that EF impairments are not specific to ASB, but that it could be associated with psychological, emotional and behavioral problems in general. Unfortunately, this hypothesis was not assessed in either of the meta-analyses, and it therefore remains unclear to what extent EFs are associated with ASB when analyses are controlled for comorbid psychological, emotional, and behavioral problems.

Although both meta-analyses conclude there is a robust relationship between impairments in EF and ASB, there are several theoretical and methodological limitations to consider. For example, although both meta-analyses assessed differences in specific measures used to assess EF, they lack a theoretically based assessment of EF. It is therefore unclear whether one EF component is more strongly associated with ASB than another. Additionally, traditional neuropsychological test are generally developed to assess large deviations in EF, whereas more recently developed tests are more sensitive to smaller deviations (Snyder et al., 2015). The meta-analysis by Ogilvie et al. (2011) used the 'extreme groups method', including only the largest effect size of each study. A disadvantage of this methodology is that it can cause inflation of the effect sizes in the meta-analysis. Both meta-analyses used a grand mean effect size per study, lumping together effect sizes for the association between antisocial groups and EF. Neither of the previous meta-analyses performed a multi-level meta-analysis which enables the researcher to include all effect sizes from a single study without violating the independence of effect sizes assumption (Fernandez-Castilla et al., 2020).

1.5. Current Study

The current meta-analysis aims to provide an updated assessment of the difference between antisocial populations and controls in EF, and to evaluate whether these differences vary between (1) EF components, (2) neuropsychological test used, (3) hot and cold EF, (4) EF assessment quality, (5) population characteristics of the antisocial and non-offending control groups, and (6) explorative interaction effects between these characteristics. A multi-level analysis will be performed, thereby addressing several limitations of previous meta-analyses.

2. Methods

This meta-analysis was reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) recommendations (Page et al., 2021). A PRISM research protocol was created before the study, but was not registered.

2.1. Search

A systematic search of the literature was performed on April 12th 2023, in four electronic databases: Criminal Justice Abstracts, PsychINFO, PubMed, and Web of Science. Within this search, there were no language or geographical restrictions, but there were restrictions for publication date (2008 and thereafter) and species (human only). After

consultation with an experienced librarian, the following terms and keywords have been used (see Appendix 1 for the specific search terms and filters used in each database): (1) Study population terms: antisocial, antisocial personality disorder, conduct disorder, oppositional defiant disorder, psychopath*, delinquen*, crim*, aggress*, violen*, offen*, assault*, unlawful*, cybercrim*, abus*, rule break*, inmate, prison*, jail*, incarcerat*, detain*, juvenile. (2) Outcome measure terms: executive function*, frontal function*, cognitive control, executive dysfunction*, shifting, inhibition, updating, working memory, planning, emotion* regulation, affect regulation, reappraisal. (3) In order to limit irrelevant results, all studies needed to contain at least one of the following terms: brain, neuro*, or cogni*. This search resulted in 14,831 unique articles.

2.2. In/Exclusion criteria

To be included in the meta-analysis, the studies needed to meet the following criteria: (1) ASB was operationalized as a clinical diagnosis that is related to ASB (Conduct Disorder, Oppositional Defiant Disorder, Antisocial Personality Disorder and/or Psychopathy) or by official records of criminality, delinquency and/or violent behavior. Diagnosis or ASB based on self-report measures or questionnaires was not sufficient. (2) EF was measured by a neuropsychological tasks assessing (updating) working memory, shifting, inhibition or higher-order EF. Implicit measures of EF and EF measured via self-report or questionnaires were not included. (3) In line with previous meta-analyses, the antisocial group was compared to a non-antisocial control group on EF. The non-antisocial control group had to be free from any form of brain damage. (4) The outcome measures were sufficient to calculate effect sizes, for example means and standard deviations, *t*-values, *F*-values, *p*-values, and/or *r*-values.

2.3. Study selection

With the use of ASReview (Van De Schoot et al., 2021), an active learning software for meta-analytic screening, both authors independently assessed the identified studies for inclusion/exclusion, based on title and abstract. Based on text analysis ASReview presents the record that the machine deems most likely to be relevant first. Following a heuristic approach, the researchers stopped when they marked 200 consecutive articles as irrelevant because it is unlikely that any relevant studies remain present in the rest of the dataset. We chose 200 as a safe choice, whereas in literature often 50 or 100 is used (Ros, Bjarnason, & Runeson, 2017). This resulted in an inter-rater reliability of 98% between both authors. When the researchers were inconclusive about the eligibility of a study, they discussed the eligibility together until consensus was reached. This study selection based on title and abstract resulted in 337 possibly eligible studies. Following the inclusion and exclusion criteria, 133 articles of the initial 337 were included in the meta-analysis. The reasons for exclusion of the articles were: (1) no

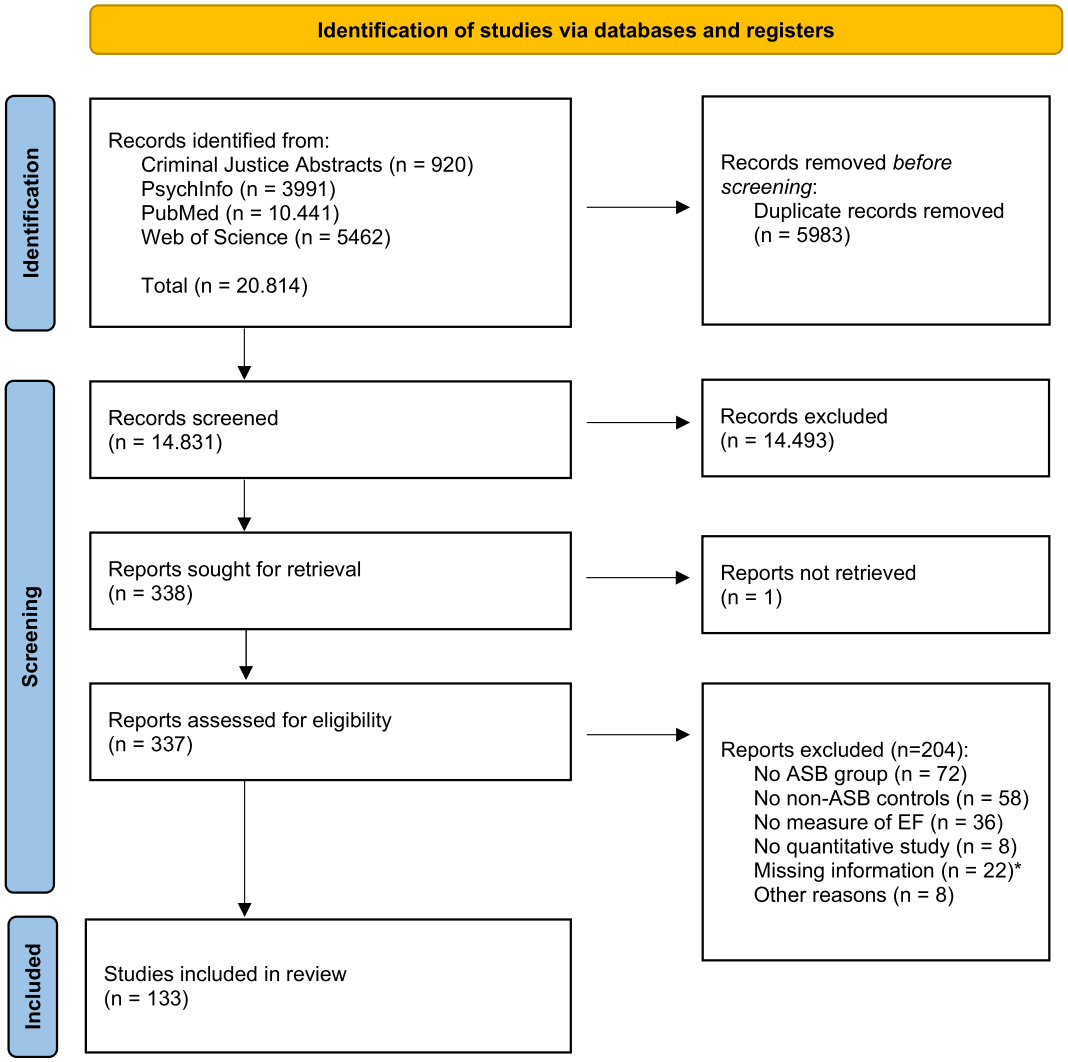

Fig. 1. Flowchart. *The authors of these studies were contacted twice, but without any response.

sufficient operationalization of ASB ($n = 72$), (2) no non-ASB control group ($n = 58$), (3) no sufficient measure of EF ($n=36$), (4) missing required information ($n = 22$), (5) no quantitative study ($n = 8$), (6) and other reasons ($n = 8$), see Figure 1.

2.4. Data collection and coding procedure

The following data was extracted from each study: (1) general study characteristics, (2) eligibility criteria, (3) information about the population and setting, (4) study methods, (5) study outcomes and results, (6) and key conclusions and limitations. The authors of articles that met the inclusion criteria but did not report sufficient information were contacted via email multiple times before exclusion.

Each outcome of each study was assessed for which specific EF component was measured; updating, working memory, shifting between task sets and inhibition of prepotent thoughts or actions. Since updating working memory and maintaining information in working memory (e.g. memory span), are often considered separate components (Baggetta & Alexander, 2016), they were both included separately. Additionally, higher order EFs – including planning, decision making and problem solving – were also included and labelled as Higher order EF. If different versions of neuropsychological tests were used, they were recoded into one specific test, for example, different versions of the Stroop test (word version, emotional version, children version, etc.) were all relabeled as Stoop test. Additionally, all outcomes where emotionally or motivationally salient stimuli were used, were considered "hot" EF, whereas all outcomes acquired under neutral stimuli were considered measuring "cold" EF.

Several participant characteristics were coded, including mean age of the ASB group and percentage of male participants. The ASB group was coded as being violent when specifically noted in the manuscript (e.g. conviction for violent crime, interpersonal violence perpetration, or sexual offending), and as non-violent otherwise. Additionally, dummy variables were created for all psychiatric disorders for both control and ASB groups separately when specifically assessed and described in the manuscripts. This indicates that studies which did not assess psychiatric diagnoses or offender characteristics were all labeled as non-diagnosed or non (sexually) violent.

Each outcome of each study was assessed for quality (low, medium or high) by JMJ. The assessment was based on previous work by Op den Kelder et al., 2018 and Snyder et al. (2015), and extended for outcomes which had not been previously evaluated. All individual study outcomes were assessed on a case-by-case basis, and looked at whether EF assessment was confounded by assessment of speed or other EF elements and the level of cognitive load of the measures. For example, the Trail Making Test consists of part A and part B. Part B provides a measure of shifting, whereas part A provides a measure of (sustained) attention. Nevertheless sustained attention influences performance during part B. Therefore, a more specific and qualitatively better outcome measure would be to subtract the score on part A from part B. In this example, those effect sizes based on part B were scored of medium quality (Op den Kelder et al. (2018)), whereas a subtracted score (B-A) was scored as high quality. Since higher order EFs recruit several executive functions, they are generally scored as low quality. A full list of all outcomes per task and their quality assessment can be found in Appendix 4.

2.4.1. Risk of bias assessment

Risk of bias was assessed using the Newcastle – Ottawa Quality Assessment Scale for case control studies (Wells et al., 2000), adapted slightly for the purpose of this study (see appendix 5). The instrument includes eight criteria, with a star assigned each time criteria are met (maximum nine stars). The first 10 studies were joint rated (IRR = 87%, disagreements resolved via discussion).

2.5. Analysis

2.5.1. Data structure

Most studies reported multiple effect sizes for multiple EFs. Since this violates the independence of effect sizes assumption of meta-analysis, a three-level meta-analysis with EF as a cross-classified random effects was conducted using the metafor package (Viechtbauer, 2010) in R-studio (version 2023.09.1). All extreme effect sizes were windsorized before analyses were performed, Cohen's d was used as the measure of effect size, and p-values of $p<.05$ were considered statistically significant.

We found that the three-level model indeed provided a better fit compared to a two-level model with level 3 heterogeneity constrained to zero ($\chi^2_1 = 257.30;\ p < .001$). We also found that including EF as cross-classified random effects did not improve model fit ($\chi^2_1 = .00;\ p = 1.00$). Therefore, the final data structure used in subsequent analyses was a three level meta-analysis, modelling effect-sizes within studies. A trim and fill analysis was conducted to assess publication bias using a regular meta-analytic model, because the analysis is not available for a three-level meta-analysis (Shi & Lin, 2019).

2.5.2. Moderation analysis

Moderation analyses were conducted in order to assess whether the inclusion of a moderator could explain (some of) the heterogeneity in effect sizes. Separate analyses were conducted with categorical moderators concerning EF (components, hot vs cold, neuropsychological test used, and quality of assessment), and study population (ADHD DBD, schizophrenia/psychosis, psychopathy/CU-traits, SUD, or IED diagnosis in the ASB group, ASB group specified as violent or sexual offender, and diagnosis of the non-offending control group). Finally, age and sex were assessed as continuous moderators in separate analyses, and the effect of age group (adults vs youth subjects) were further investigated and reported in Appendix 6.

Exploratory interaction analyses were conducted in order to assess whether interaction between sample and or study characteristics could explain (some of the) heterogeneity in effect sizes. Such exploratory interaction analyses were conducted for: (1) diagnosis of ASPD and presence of psychopathic traits in adult samples, (2) diagnosis of DBD and presence of CU-traits in youth samples, (3) Psychopathy/CU-traits and hot vs cold EF, (4) ADHD diagnosis and hot vs cold EF, and (5) hot vs cold EF and violent vs not classified as violent ASB individuals. All analyses were only performed for cells containing at least 5 effect sizes.

3. Results

3.1. Study characteristics

A total of n=133 studies were incorporated into the analysis, resulting in n=*1238* effect sizes. A total number of n=*9318* ASB participants were included, and compared to n=11738 non-ASB controls. Participants were predominantly male in both ASB (88.92%) and non-antisocial control groups (85.75%), and mean age was similar in both groups (ASB: M=*23.01* SD=*13.89*; Control M=*22.43* SD=*13.40*). Studies in children all assessed ASB through diagnosis and not through official records. Several psychiatric diagnoses were identified in the ASB group, including: ADHD ($n_{effectsizes}$ =*357*), DBD ($n_{effectsizes}$= *516*), Schizophrenia/psychotic ($n_{effectsizes}$=*30*), ASPD ($n_{effectsizes}$=*79*), CU-traits/Psychopathy ($n_{effectsizes}$=*37*), SUD ($n_{effectsizes}$=*22*), IED ($n_{effectsizes}$=*8*) or not diagnosed ($n_{effectsizes}$=*489*). In non-antisocial control groups, four diagnoses were identified: ADHD ($n_{effectsizes}$=*257*), SUD ($n_{effectsizes}$=*25*), and Schizophrenia/psychotic ($n_{effectsizes}$=*30*), and autism spectrum disorder ($n_{effectsizes}$=*3*). See Appendix 3 for a table with study characteristics.

3.2. Risk of bias

Risk of bias assessment using the Newcastle – Ottawa Quality Assessment Scale for case control studies (Wells et al., 2000), shows that studies were generally of good quality, especially for definition of controls and ASB groups and representativeness of cases. There was higher risk of bias related to the way ascertainment of ASB was determined in both groups (i.e. when an antisocial group was assessed for ASB through official records, but controls were included based on self-report), for the non-response rate (which was often not well described), and for the comparability of ASB and control participants (which often differed in psychiatric diagnosis, age and/or gender), see Figure 2.

3.3. Three-level meta-analysis

The pooled Cohen's *d* based on the three-level meta-analytic model was $d = .42$ (95%CI: .34-.50; $p < .001$). The estimated variance components were $\tau^2_{\text{Level 3}} = .17$ and $\tau^2_{\text{Level 2}} = .20$. This means that $I^2_{\text{Level 3}} = 40.5\%$ of the total variation can be attributed to between-cluster, and $I^2_{\text{Level 2}} = 48.2\%$ to within-cluster heterogeneity. The amount of variation, and the prediction interval of the main analysis (95% PI: -.78 – 1.63), reveal that the difference between antisocial groups and controls varies substantially. In order to assess the origins of this variability, several moderation analyses were conducted for: EF component, neuropsychological task used, hot versus cold EF, assessment quality, study population characteristics, and age and gender. The results of the trim and fill funnel plot did not reveal any filled in studies and therefore suggest little risk of publication bias (see Appendix 2)

3.4. Moderation analyses

3.4.1. Different executive function components

A three-level meta-analysis including EF component as a moderator showed that EF component did not moderate the pooled effect sizes $F_{(4, 1233)}=2.11$ $p=.08$. The effect sizes of all EF components differed from zero (see Figure 3), indicating that antisocial populations show impaired performance on all EFs. Although not statistically significant, the impaired performance seems more evident for updating, see Figure 3.

3.4.2. Different neuropsychological tests

A three-level meta-analysis including neuropsychological test as a moderator showed it moderated the pooled effect sizes ($F_{(34, 1128)}=1.67$ $p=.01$), indicating that antisocial populations show more impaired performance on some neuropsychological tests compared to others, see Figure 4. Bonferroni corrected pairwise comparisons did not reveal any differences (all $p>.15$). Please note that specific tests with less than 5 effect sizes were excluded from the analyses.

3.4.3. Hot vs cold executive functioning

A three level meta-analysis including hot ($n_{effectsizes} = 168$) versus cold ($n_{effectsizes} = 1070$) EF as a moderator showed that hot and cold EF did not moderate the pooled effect sizes $F_{(1, 1236)}=1.25$ $p=.26$. Both hot ($d=.48$ se=.07 $t_{(1236)}=7.30$ $p<.001$) and cold ($d=.41$ se=.04, $t_{(1236)}=9.56$ $p<.001$) EF differed from zero. These results indicate that antisocial populations show impaired performance on EF, regardless of whether emotional or motivational stimuli were used or not.

3.4.4. Assessment quality

A three-level meta-analysis including assessment quality (low $n_{effectsizes} =324$; medium $n_{effectsizes} = 338$; high $n_{effectsizes} = 576$) as a moderator showed quality did not moderate the pooled effect sizes, $F_{(2, 1235)}=.76$ $p=.48$. Whether an effect size was of low ($d=.46$ se=.05, $t_{(1235)}=8.79$ $p<.001$), medium ($d=.40$ *se*=.05, $t_{(1235)}=7.90$ $p<.001$) or high quality ($d=.42$ se=.05, $t_{(1235)}=9.30$ $p<.001$) did not make any difference in the pooled effect size, but all differed from zero. These results indicate that antisocial populations show impaired performance on EF regardless of the quality of the assessment of the task outcome

3.4.5. ASB operationalization / diagnoses

Studies included in this meta-analysis showed considerable variation regarding the characteristics of the included ASB participants, and results of moderation analyses showed a moderating effect for a diagnosis of schizophrenia/psychosis in the ASB group $F_{(1,1236)} = 10.15$ $p=.002$. ASB populations with a diagnosis of schizophrenia/psychosis showed no

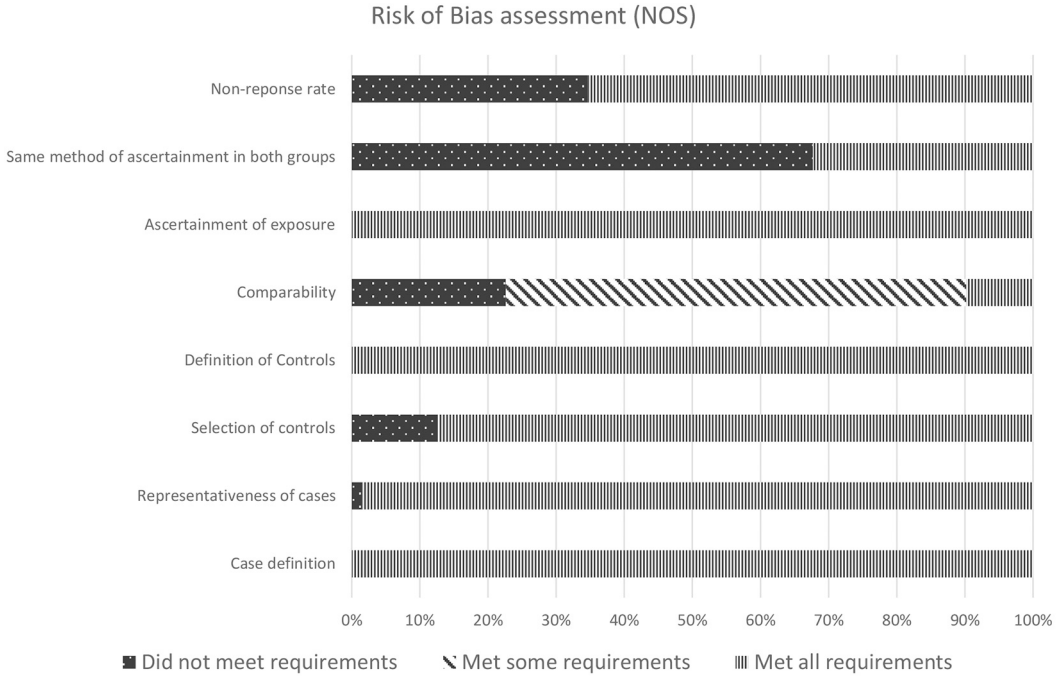

Fig. 2. Risk of Bias assessment. This figure shows the results from the risk of bias assessment using the Newcastle Ottawa Scale. Green indicates the amount of studies which met criteria, yellow indicates when studies partially met criteria, and red indicates when studies did not meet criteria.

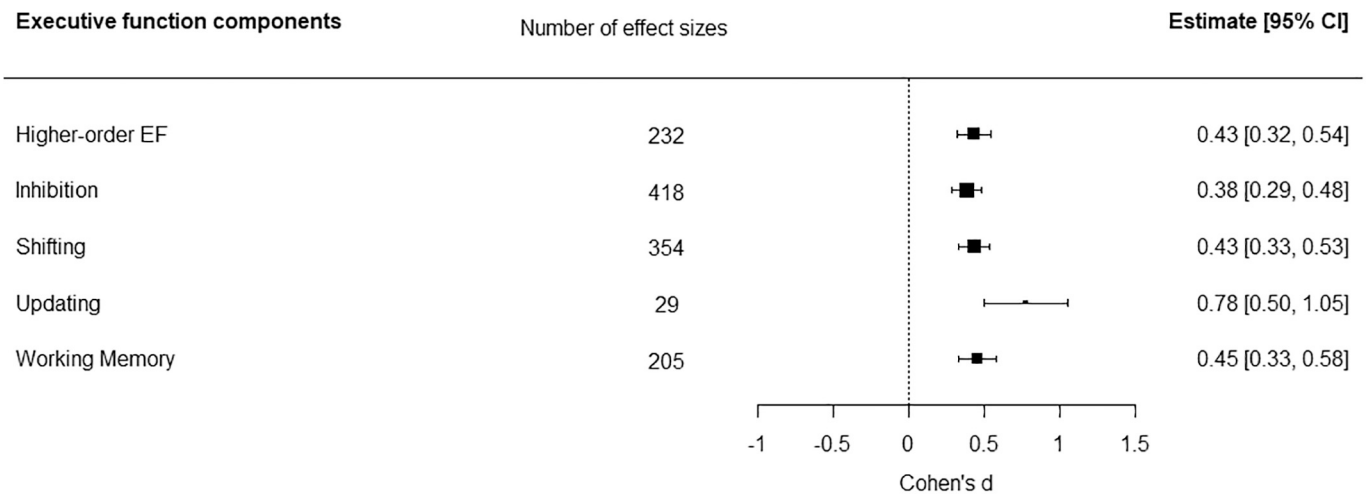

Fig. 3. Meta-analytic results including executive function components as moderating effect. Effect-size estimates are reported using Cohen's *d*.

significant impairment in EF (d= -.03 p=.84), whereas those without a diagnosis of schizophrenia/psychosis did (d=.44 p<.001). This result can likely be explained by the fact that all studies including an antisocial group with diagnosis of schizophrenia/psychosis used a non-antisocial control group which had a schizophrenia/psychosis diagnosis as well (see below).

There were no moderating effects for ADHD diagnosis $F_{(1,1236)}$ = 2.30 p=.13, DBD diagnosis $F_{(1,1236)}$=.54 p=.46, ASPD diagnosis $F_{(1,1236)}$ = 2.61 p=.11, SUD diagnosis $F_{(1,1236)}$=1.75 p=.19, IED diagnosis $F_{(1,1236)}$ = .89 p=.34, the presence of CU traits/psychopathy $F_{(1,1236)}$=.72 p=.40, whether ASB group specified as violent $F_{(1,1236)}$ = .01 p=.92, specified as sexual offender $F_{(1,1236)}$=2.88 p=.09, or whether ASB group was based on official records $F_{(1,1236)}$ = .03 p=.86.

3.4.6. *Non-offending control group with psychiatric diagnoses*

A three-level meta-analysis including diagnoses of the non-offending control group did show a moderating effect $F_{(3,\ 1231)}$ =30.58 p<.001), indicating that studies using control groups with a psychiatric diagnosis differed in the reported effect sizes compared to studies who did not include control groups with a psychiatric diagnosis. Non-offending control groups with an ADHD diagnosis, substance use disorder, or schizophrenia/psychosis did not differ in EF compared to ASB groups – which were often also diagnosed with the same disorder (see Figure 5). A follow-up analyses showed a moderating effect of matching diagnosis in the ASB and non-offending control group $F_{(1,1233)}$=42.70 p<.001, and revealed that ASB and non-offending control groups no longer differed in EF when accounting for underlying psychiatric disorders (d=.06 se=.07; $t_{(1233)}$=.83 p=.41). These results indicate that EF impairments in ASB, may – at least in part – be due to underlying mental health problems and not necessarily directly be related to the ASB.

3.4.7. *Age and sex*

A meta-regression, including age (of the ASB group) as a moderator indicated that age moderated the pooled effect size $F_{(1,\ 1234)}$=4.51 p=.03, where differences in EF between ASB and non-antisocial control groups increased with age. Since EF components may develop differentially, a post-hoc moderation analyses including the interaction between age and EF component was performed, which revealed an interaction effect $F_{(4,\ 1226)}$=4.56 p=.001. This significant interaction originates from a different relationship between age and both shifting and inhibition, where impairments in shifting (and not inhibition) seem to increase with age (see Figure 6). This interaction survived a Bonferroni correction for pairwise comparisons (Δd = .013 p=.01). A moderation analysis for sex, including the percentage of male ASB participants as moderator, did not reveal a statistically significant influence of sex on the pooled effect size $F_{(1,1216)}$=2.35 p=.13.

3.4.8. *Exploratory interaction and post-hoc analyses*

Interaction analysis for diagnosis of ASPD and presence of psychopathic traits in adult samples, did not reveal a statistically significant interaction $F_{(1,\ 514)}$=.37 p=.54, nor did the interaction analyses between Psychopathy/CUtraits and hot vs cold EF $F_{(1,\ 1234)}$=.59 p=.44, ADHD diagnosis and hot vs cold EF in youth $F_{(1,707)}$=.01 p=.90, or hot vs cold EF and violent ASB individuals $F_{(1,1234)}$=.01 p=.73. Several exploratory interaction analyses could not be conducted, because of empty cells in the data. For example, there were no studies in children with CU-traits but without a DBD diagnosis, and ADHD was not assessed in adults samples.

Finally, a post-hoc analysis was conducted to assess possible bias resulting from our coding procedure (see discussion). Results on this analysis of studies (n=11, $n_{effectsizes}$ = 120) which included DBD participants with and without ADHD, showed that ADHD did not increase EF impairment relative to the non-antisocial control group $F_{(1,118)}$=2.77 p=.10.

4. Discussion

The current meta-analysis updates the available evidence for differences between antisocial populations and controls in EF using more advanced meta-analytic procedures, and by evaluating whether these differences vary between (1) EF components, (2) neuropsychological test used, (3) hot and cold EF, (4) EF assessment quality, (5) population characteristics of the antisocial and non-antisocial control groups. Additionally, (6) explorative interaction effects between these characteristics are conducted. Antisocial populations indeed showed impaired performance in EF (medium effect size d=.42), but studies are heterogeneous. Several moderator analyses showed that neuropsychological test used, age and other characteristics of both antisocial and non-offending control groups moderated the overall effect. Specifically, a non-antisocial control group with matching psychiatric problems eliminated any differences in EF between groups. No moderation effects were found for assessment quality, hot or cold EF, or various population characteristics (of the antisocial group), including diagnoses of DBD and ASPD. Whether the antisocial groups were defined through official records or not, or specified as violent or not also did not influence the results.

The reported impairment in EF in antisocial groups is in agreement with previous meta-analyses (Morgan & Lilienfeld, 2000; Ogilvie et al., 2011), although Morgan and Lilienfeld (2000) reported a larger effect size with a more select group of neuropsychological tests. In line with

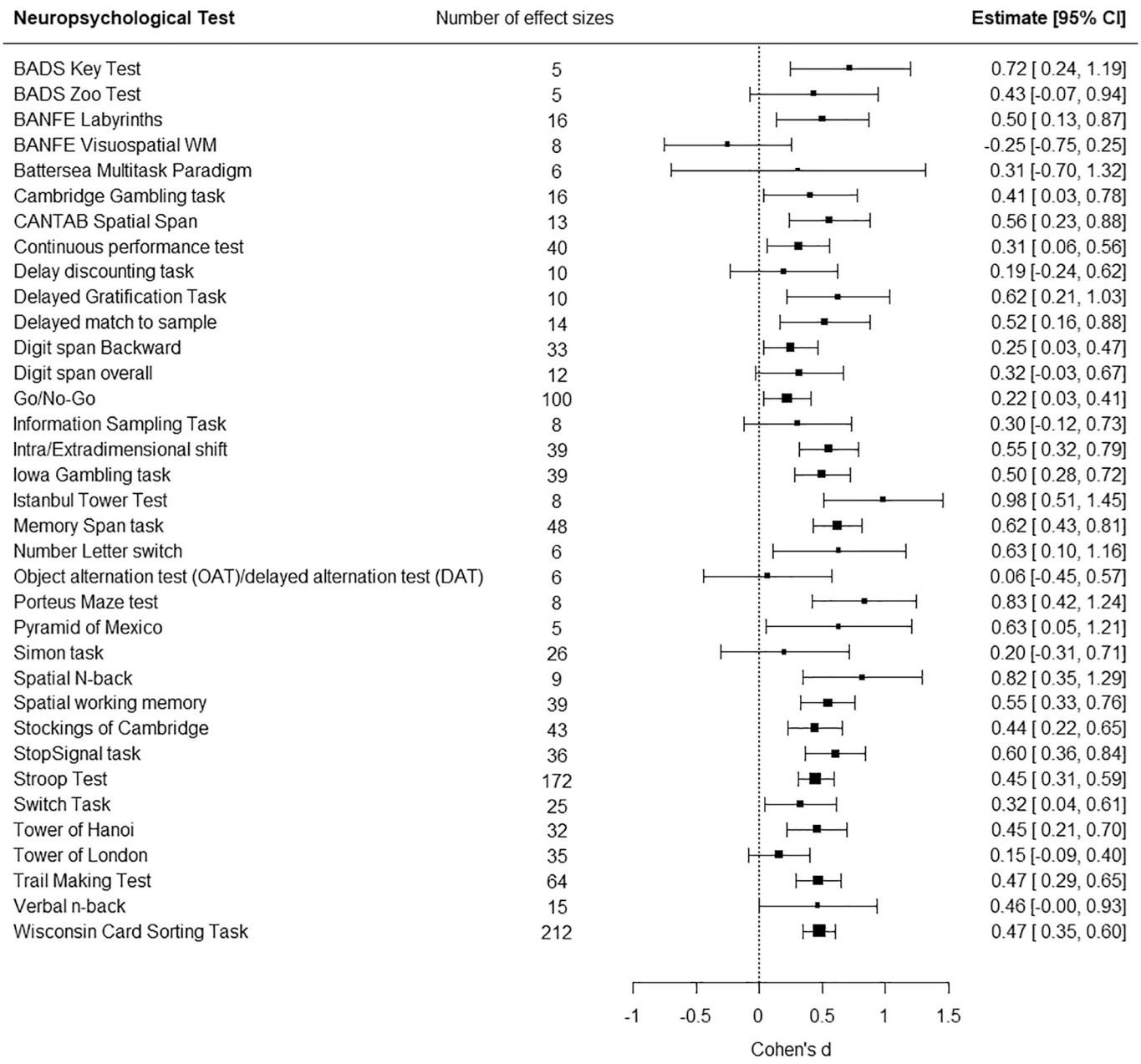

Fig. 4. Meta-analytic results including neuropsychological test as moderating effect. Only neuropsychological tests which were used at least 5 times are included in this analysis. Effect-size estimates are reported using Cohen's *d*.

these previous meta-analyses we report high heterogeneity between studies, which indicates that the grand-mean effect should be interpreted with caution. It suggests that the effect sizes found in our meta-analyses did not derive from a single population of studies, which is most likely in the result of varying methodological approaches of the individual studies. In order to delineate this heterogeneity, several moderator analyses were conducted.

The use of different neuropsychological tests explains some of the heterogeneity, where antisocial groups experience the most problems on the Hayling test (d=.86), Spatial N-back (d=.81) and Porteus maze test (d=.83), whereas smaller differences were found using the Tower of London (d=.15), Object alternation test/delayed alternation test (d=.06) and the Delay discounting task (d=.19). Although these more extreme values were mostly for neuropsychological tests used 10 times or less, they are well aligned with the meta-analyses of Ogilvie et al. (2011), who – for example - report similar effect sizes for the Porteus maze test, and Tower of London task. Some differences were found as well, as we report smaller effect sizes for the Go/No-Go task (d=.56 vs d=.22) and larger effect sizes for the stop signal task (d=.42 vs d=.60). Since we did not find moderating effects of the EF components, variability in neuropsychological tests is likely to reflect differences in task-instructions, stimuli and procedures.

Age was expected to have a moderating effect on the relationship between EF and ASB, because EFs continue to develop into late adolescence and smaller effect sizes were previously found for the relation between EF and ASB in children (Figueiredo et al., 2023; Schoemaker et al., 2013) compared to (young) adults (Morgan & Lilienfeld, 2000; Ogilvie et al., 2011). We indeed showed a moderating effect of age - where EF difficulties seem to increase with age - although this seems mostly driven by shifting, which component is thought to differentiate later in development. These results were corroborated when comparing studies in adults with studies in children (appendix 6). Although these results suggest that shifting is more weakly associated with ASB at a younger age, this effect was also expected for the other

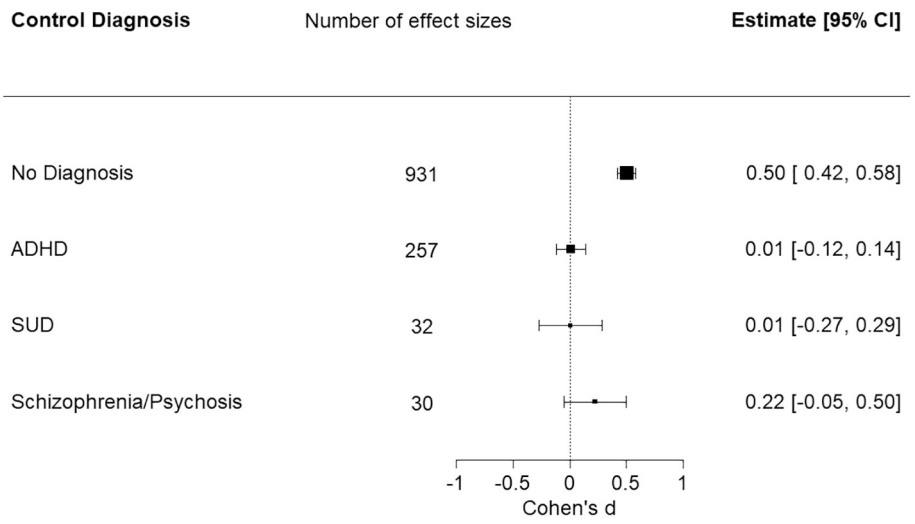

Fig. 5. Meta-analytic results including control diagnosis as moderating effect. Effect-size estimates are reported using Cohen's *d*.

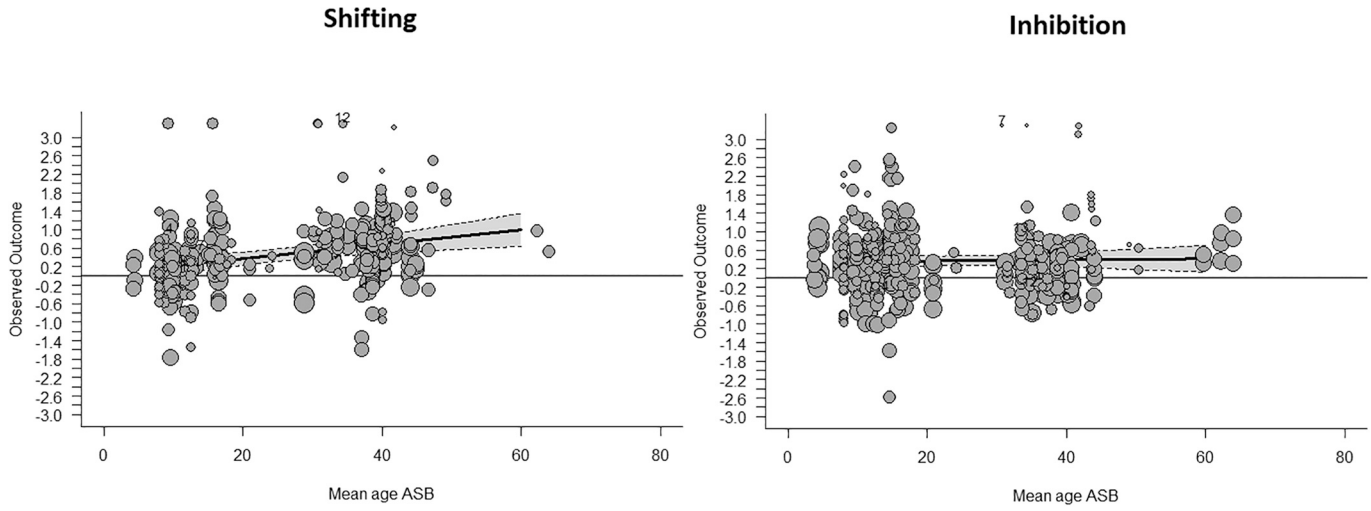

Fig. 6. Meta-analytic results for the interaction between age and both shifting and inhibition. Effect-size estimates are reported using Cohen's *d*.

constructs because lower effect sizes were found in younger participants for inhibition, shifting and working memory (Schoemaker et al., 2013). A possible explanation for not finding this effect in all EF components could be that only the mean age of participants per study was included, without correcting for age range. As a result, subtle differences between young children, adolescents, and older adults may have gone unnoticed. In addition, there is a significant gap in existing studies of EF and ASB with a mean age around young adulthood (18-26 years of age), while ASB is most common at this age and EF constructs are most distinguishable at this moment in the lifespan (Karr et al, 2022). Future studies should investigate age related differences in the association between EF components and ASB in order to more clearly assess these relationships.

Based on previous meta-analyses, it was expected that several characteristics of the ASB group would explain some of the heterogeneity between studies. The results show that heterogeneity was only explained when the ASB group included individuals with schizophrenia or psychosis, since these studies did not show any difference in EF between ASB and controls. These findings may be explained by the fact that all of these studies included a non-antisocial control group with schizophrenia or psychosis as well (see below). It is surprising that none of the other characteristics explained any of the heterogeneity, since previous meta-analysis did report that for example ASB participants with ADHD report more EF impairments. This could be due to the fact that in our coding procedure studies that did not assess the presence of (for example) ADHD were coded as not having ADHD, since studies which screened for and consequently excluded ADHD participants were scarce. A post-hoc analysis on studies which included DBD participants with and without ADHD, showed that ADHD did not increase EF impairment relative to the non-antisocial control group. So although our coding procedure might have resulted in misclassified studies - which would cause an underestimation of the effect of ADHD diagnosis -, our post-hoc analysis suggests this bias is relatively small.

Although characteristics of the included ASB groups did not appear to explain heterogeneity between studies, but characteristics of control participants did. Our results indicate that the presence of a diagnosis in the non-offending control group (ADHD, substance use disorder, or psychosis/schizophrenia) completely abolished the difference in EF between the groups. A comparison between antisocial groups with non-antisocial control groups is based on the assumption that both groups are similar except for the ASB. Any differences in EF are therefore thought to be linked to the ASB. In practice, research shows that antisocial groups generally differ in many characteristics from controls, including socio-economic status, intelligence, or psychiatric problems. Our results show that a diagnosis (ADHD, substance use or schizophrenia/psychosis) in the non-antisocial control group abolished any difference with the

antisocial group. This suggests that impairments in EF could (at least in part) be related to underlying psychiatric problems - which are highly prevalent and underdiagnosed in antisocial populations (Buitelaar & Ferdinand, 2016; Fazel et al., 2016) - rather than being related to the ASB itself. This could indicate that the assessment of EF in ASB populations is less relevant for recidivism risk assessment, although this should first be assessed in longitudinal studies assessing the prospective and predictive value of EF for recidivism. The available evidence from such studies is currently inconclusive (Fine, Steinberg, Frick, & Cauffman, 2016; Ormachea et al., 2017), and reviews or meta-analyses have not yet been conducted. The results do indicate that EF could potentially be used to identify or screen for individuals with certain treatment needs or be used as a responsivity factor, especially in disorders which are often underdiagnosed in criminal justice settings.

It was expected that the extent of the impairments in EF would vary between the different components of EF, but our results suggest this is not the case since EF component did not moderate the overall effect size. Antisocial populations do appear to experience more difficulties with updating working memory. We expected that assessment quality would also moderate the overall effect size, because high quality assessments are more aimed at measuring specific EF components, minimalizing the influence of common EF. We did not find any moderating effects of assessment quality. One explanation for this result could be that antisocial groups show a general impairment in all EF components. An alternative explanation would be that impairment in underlying common EF results in (equally) reduced performance on the specific EF components. In order to assess whether some specific EF components are implicated more than others, studies should use multiple measures of each EF component and extract a latent variable constituting the task-specific EF of interest (Friedman et al., 2008).

4.1. Implications & directions for future research

Our results support previous studies reporting impairments in EF in antisocial groups, but also show that these differences could originate from underlying psychiatric problems rather than be directly related to ASB. Although we did not assess whether EF performance was predictive for recidivism or future ASB, our findings could suggest that EFs are not relevant for ASB and therefore for risk assessment because they relate to underlying psychiatric problems. On the other hand, it remains true that antisocial populations are characterized by higher prevalence of psychiatric problems and impaired EF, and that this could be related to or predictive of (future) antisocial behavior. Studies prospectively assessing the value of EF as predictor for future ASB are relatively scarce and show mixed results (Aharoni et al., 2013; Brassard & Joyal, 2022; Nikulina & Widom, 2019; Zijlmans et al., 2021).To our knowledge, reviews or meta-analyses on the predictive value of EF in ASB are currently unavailable. Since neurobiological information - including EF - is increasingly relevant for forensic clinical practice and risk assessment (de Ruigh et al., 2021; Haarsma et al., 2020; Norman et al., 2023), such reviews or meta-analyses are needed to delineate the association between EF, psychiatric problems and (future) ASB.

Antisocial groups are not more impaired on specific EF components, suggesting either a general impairment in antisocial groups in all EF components or that underlying common EF drives the difference between antisocial and non-antisocial control groups. We did not find any studies that used a latent variable approach, using multiple measures of each EF component to extract task-specific EF of interest (Friedman et al., 2008). These types of studies could provide a more definitive answer to the question whether impairments in specific EF components are implicated in ASB.

For future research on the relationship between EF and ASB, it is important more effort is made to match the controls more closely to the antisocial group in terms of socioeconomic status, education level and traumatic brain injury since these factors are highly associated with EF (Checa & Rueda, 2011; Jansen, 2020; Lawson, Hook, & Farah, 2018). Many of the included studies did not take these differences between the ASB group and controls into account, which may lead to inflation of effect sizes.

4.2. Strengths & limitations

Our results were obtained using a multi-level analytic approach, enabling us to incorporate multiple effect sizes per study in our analysis. This is superior compared to using an "extreme groups method', which may can cause an inflation of the resulting effect sizes of the meta-analysis. Nevertheless, we found similar results as previous meta-analyses, suggesting that the inflation of effect sizes was minimal.

In our analyses we assessed specific EF components and non-offending control group characteristics, both of which had not previously been analyzed or reported upon. Especially for the non-antisocial control group characteristics, we identified that underlying psychiatric problems may play a major role in explaining differences in EF performance between antisocial and non-antisocial control groups. Only 11% of the studies used an appropriate non-antisocial control group with a matching psychiatric diagnosis. Future studies should be aware of – and correct for – underlying psychiatric problems which could explain the often found difference in EF performance between antisocial and non-antisocial control groups.

Although several moderator and interaction analyses were conducted, many included studies did not report on any or all of the moderators. During data extraction all studies which did not report on - for example - violence were coded as "not specified as violent". Consequently, in the analyses we compared effect sizes from violent samples to samples which were not specified as violent. If individuals were not specified as violent, this does not necessarily mean that they are in fact non-violent, and it is likely that the comparison group includes violent individuals to some extent. The results of our moderation analyses might therefore under-estimate the true effect size for these moderators.

Studies using (only) self-report measures of ASB were excluded from the analyses. Some self-report measures are well validated, and in fact may identify a (now under-represented subgroup of) individuals which do exhibit ASB, but have not been caught. We have opted to exclude self-report measures because we wanted to adhere to the in/exclusion criteria used by the original two meta-analyses which excluded such self-report measures. Nevertheless, this should be noted as both a limitation of our study and as a possible avenue for further research. Finally - as both strength and limitation - all included effect sizes were scored on assessment quality by JMJ, because there is no full list of neuropsychological tests or agreed upon criteria for EF assessment quality. Previous studies were helpful, but did not include all measures reported in our selected studies (Op den Kelder et al., 2018; Snyder et al., 2015). Confounding influences of speed or other EF elements and the level of cognitive load of the measures were taken into account, but not all descriptions of the task procedures were clear on the (possible) level of interference. These quality labels should therefore be further validated and/or future studies should provide a golden standard for EF assessment.

4.3. Conclusion

The current meta-analysis updates the available evidence for differences between antisocial populations and controls in EF using more advances meta-analytic procedures, and evaluates whether these differences vary between (1) EF components, (2) neuropsychological test used, (3) hot and cold EF, (4) EF assessment quality, and (5) population characteristics of the antisocial and non-offending control groups. Antisocial populations indeed show impaired performance in EF(medium effect size d=.42), but these differences could be explained by underlying psychiatric problems rather than by the exhibited ASB. No differences were found between hot and cold EF, but some neuropsychological test revealed greater differences between groups than others.

These results could indicate that the assessment of EF in ASB populations is less relevant for recidivism risk assessment, although this should first be assessed in prospective longitudinal studies. EF could potentially be used to identify or screen for individuals with certain treatment needs or be used as a responsivity factor, especially in disorders which are often underdiagnosed in criminal justice settings.

Declaration of competing interest

None.

Data availability

Data has been made available at: https://ssh.datastations.nl/dataset.xhtml?persistentId=doi:10.17026/SS/DDNIZV

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Appendix A. Appendix 1

A.1. Search Criminal Justice Abstracts

(brain OR neuro* OR cogni*) AND (“executive function*” OR “frontal function*” OR “cognitive control” OR “executive dysfunction*” OR “shifting” OR “inhibition” OR “updating” OR “working memory” OR “planning” OR “verbal fluency” OR “delay gratification” OR “instant gratification” OR “impulsivity” OR “spatial working memory” OR “emotion regulation” OR “emotional regulation” OR “Affect regulation” OR “Reappraisal”) AND (“conduct disorder” OR “oppositional defiant disorder” OR “antisocial*“ OR “antisocial personality disorder” OR “psychopath” OR “psychopathy” OR “psychopaths” OR “delinquen*” OR “crim*” OR “aggress* “ OR “violen*” OR “offen*” OR “assault*” OR “unlawful*” OR “cyberbully*” OR “bully*” OR Cybercrime*” OR “rule break*” OR “inmate*” OR “prison*” OR “jail” OR “incarcerat*” OR “detain*” OR “juvenile”).

A.2. Search PsychInfo

(brain OR neuro* OR cogni*) AND (“executive function*” OR (DE “Executive Function”) OR “frontal function” OR “cognitive control” OR (DE “Cognitive Control”) OR “executive dysfunction*” OR (DE “Cognitive Impairment”) OR “shifting” OR “inhibition” OR (DE “Inhibition (Personality)”) OR “updating” OR “working memory” OR “planning” OR (DE “Planned Behavior”) OR “verbal fluency” OR (DE “Verbal Fluency”) OR “delay gratification” OR (DE “Delay of Gratification”) OR “instant gratification” OR “impulsivity” OR (DE “Impulsiveness”) OR “spatial working memory” OR “emotion regulation” OR “emotional regulation” OR (DE “Emotional Regulation”) OR “Affect regulation” OR “Reappraisal”) AND (“conduct disorder” OR (DE “Conduct Disorder”) OR “oppositional defiant disorder” OR (DE “Oppositional Defiant Disorder”) OR “antisocial*“ OR (DE “Antisocial Behavior”) OR “antisocial personality disorder” OR (DE “Antisocial Personality Disorder”) OR “psychopath” OR “psychopathy” OR “psychopaths” OR (DE “Psychopathy”) OR “delinquen*” OR (DE “Juvenile Delinquency”) OR “crim*” OR (DE “Crime”) OR (DE “Criminal Behavior”) OR (DE “Criminal Conviction”) OR (DE “Criminal Offenders”) OR (DE “Criminal Record”) OR “aggress* OR (DE “Aggressive Behavior”) “ OR “violen*” OR (DE “Violence”) OR “offen*” OR “assault*” OR “unlawful*” OR “cyberbully*” OR (DE “Cyberbullying”) OR “bully*” OR (DE “Bullying”) OR “25ybercrime*” OR (DE “Cybercrime”) OR “rule break*” OR “inmate*” OR (DE “Prisoners”) OR “prison*” OR “jail” OR (DE “Prisons”) OR “incarcerat*” OR (DE “Incarceration”) OR “detain*” OR “juvenile”) NOT (Cancer OR Tumor OR metasta* OR rat* OR mouse OR mice OR rodent* OR fish OR zebra OR monkey*).

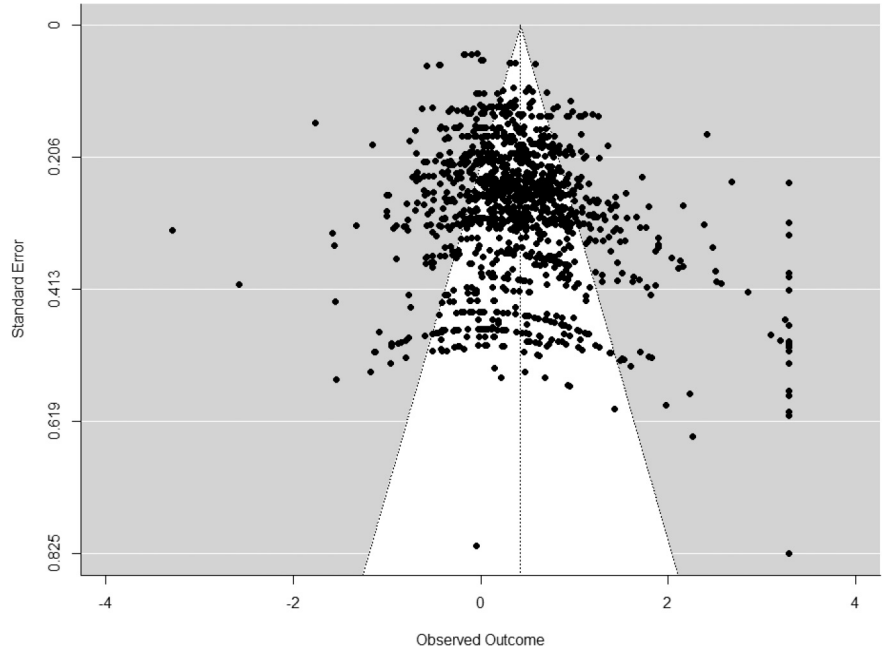
A.3. Search PubMed

(Psychiatry and Psychology Category[MeSH] OR neuro* OR cogni* OR brain) AND ((executive function[MeSH Terms] OR "executive function*" OR "frontal function*" OR "cognitive control" OR shifting OR inhibition OR "Inhibition, Psychological"[Mesh] OR updating OR "working memory" OR planning OR "emotion regulation" OR "emotional regulation" OR "Emotional Regulation"[Mesh] OR "Affect regulation" OR "Reappraisal")) AND (("conduct disorder" OR "oppositional defiant disorder" OR antisocial* OR "antisocial personality disorder" OR "Antisocial Personality Disorder"[Mesh] OR psychopath OR psychopaths OR psychopathy OR delinquen* OR crim* OR aggress* OR violen* OR offen* OR assault* OR unlawful* OR cybercrime* OR rule break* OR inmate* OR prison* OR jail OR incarcerat* OR detain* OR juvenile)) NOT ((meta-analysis[Filter] OR review[Filter] OR systematicreview[Filter])

A.4. Search Web of Science

(ALL=(brain OR neuro* OR cogni*)) AND (ALL= (“executive function*” OR “frontal function*” OR “cognitive control” OR “executive dysfunction*” OR “shifting” OR “inhibition” OR “updating” OR “working memory” OR “planning” OR “verbal fluency” OR “delay gratification” OR “instant gratification” OR “impulsivity” OR “spatial working memory” OR “emotion regulation” OR “emotional regulation” OR “Affect regulation” OR “Reappraisal”)) AND (All=(“conduct disorder” OR “oppositional defiant disorder” OR “antisocial*” OR “antisocial personality disorder” OR “psychopath” OR “psychopathy” OR “psychopaths” OR “delinquen*” OR “crim*” OR “aggress* “ OR “violen*” OR “offen*” OR “assault*” OR “unlawful*” OR “26ybercrime*” OR “rule break*” OR “inmate*” OR “prison*” OR “jail” OR “incarcerat*” OR “detain*” OR “juvenile”)) NOT (ALL=(Cancer OR Tumor OR metasta* OR rat* OR mouse OR mice OR rodent* OR fish OR zebra OR monkey*)) Refined by: PUBLICATION YEARS: (2023 OR 2022 OR 2021 OR 2011 OR 2020 OR 2010 OR 2019 OR 2009 OR 2018 OR 2008 OR 2017 OR 2016 OR 2015 OR 2014 OR 2013 OR 2012)

Appendix B. Appendix 2



Appendix 3

Study	Assessment Method	ASB classification	Participant Groups	n	Mean Age (SD)	Males (%)	EF task	EF domain	Hot/ Cold EF
Antonini et al., 2015	Diagnosis	ODD	ADHD + ODD ADHD controls Healthy controls	33 67 30	9.44 (1.75) 8.88 (1.48) 9.00 (1.80)	72.72% 75.76% 66.67%	Memory Span Task Wisconsin Card Sorting Task Delay Discounting Task Iowa Gambling Task	Working memory maintenance Shifting Choice impulsivity Affective decision making	Cold Cold Hot Hot
Frias-Armenta et al., 2011	Official records	Offender	Offenders Healthy controls	48 27	14.00 (1.35) -	80.0% -	Wisconsin Card Sorting Task Stroop Test	Shifting Inhibition	Cold Cold
Baliousis et al., 2019	Official records + diagnosis	Offender, ASPD, Psychopathy	Offenders + ASPD Offenders + psychopathy Healthy controls	52 27 20	30.3 (8.9) 34.3 (10.9) 33.9 (10.7)	100% 100% 100%	Spatial Working Memory Task Stockings of Cambridge Intra/ Extradimensional Shift Task Go/No-Go	Working memory maintenance Planning Shifting Inhibition	Cold Cold Cold Hot
Barkataki et al., 2008	Official records + diagnosis	Offender, ASPD	Offenders + ASPD Offenders + schizophrenia Controls + schizophrenia Healthy controls	14 12 12 14	33.5 (10.45) 34.83 (4.97) 34.92 (7.60) 32.14 (7.75)	100% 100% 100% 100%	Go/No-Go	Inhibition	Cold
Barlati et al., 2023	Official records	Offender	Violent offenders + schizophrenia Healthy controls	50 50	37.92 (11.14) 37.70 (11.08)	86% 86%	Trail Making Test Stroop Test Memory Span task Tower of London	Shifting Inhibition Working memory Maintenance Planning	Cold Cold Cold Cold
Barnett et al., 2009	Diagnosis	ODD, CD	ODD + ADHD CD + ADHD Controls + ADHD Healthy controls	22 20 23 25	9.02 (2.11) 8.24 (1.64)	86.36% 80.0% 73.91% 72.0%	Memory Span Task Spatial Working Memory Task Delayed Match to	Working memory maintenance Working	Cold Cold Cold

(continued on next page)

Appendix 3 (*continued*)

Study	Assessment Method	ASB classification	Participant Groups	n	Mean Age (SD)	Males (%)	EF task	EF domain	Hot/ Cold EF
					8.23 (1.94) 8.81 (1.48)		Sample Spatial Recognition Task Tower of London	memory maintenance Working memory maintenance Working memory maintenance Planning	Cold Cold
Becerra-García, 2015	Official records	Offender	Domestic offenders Sex offenders Violent offenders Non-violent offenders Healthy controls	10 20 9 8 31	42.00 (8.48) 37.55 (9.27) 30.22 (7.17) 40.88 (10.48) 38.45 (12.58)	100% 100% 100% 100% 100%	Trail Making Test	Shifting	Cold
Becerra-García & Egan, 2014	Official records	Offender	Sex offenders (incestuous) Sex offenders Healthy controls	21 11 28	47.33 (7.92) 49.09 (13.38) 45.61 (8.77)	100% 100% 100%	Trail Making Test Digit Span Backward	Shifting Working memory manipulation	Cold Cold
Blum et al., 2017	Diagnosis	ASPD	ASPD Healthy controls	26 266	24.3 (3.8) 22.8 (3.7)	57.7% 68.4%	Intra-Extradimensional Shift Task Stop Signal Task Stockings of Cambridge Cambridge Gambling Task	Shifting Inhibition Planning Affective decision making	Cold Cold Cold Hot
Borrani et al., 2015	Official records	Offender	Offenders Healthy controls (age-paired) Healthy controls (age- and education-paired)	27 27 27	17.66 (1.55) 17.11 (1.55) 17.59 (1.69)	100% 100% 100%	Stroop Test	Inhibition	Cold
Brænden et al., 2023	Diagnosis	ODD	ODD Controls + ADHD	23 43	9.9 (1.5) 9.6 (1.8)	58.0% 63.0%	NEPSY-2 Design Fluency NEPSY-2 Inhibition NEPSY-2 Inhibition NEPSY-2 Word List Interference	Shifting Inhibition Shifting Working memory maintenance	Cold Cold Cold Cold
Bulgari et al., 2017	Official records	Offender	Offenders + schizophrenia Controls + schizophrenia	50 37	46.7 (10.0) 49.2 (9.9)	92.0% 86.5%	Wisconsin Card Sorting Task Iowa Gambling Task Memory Span Task Tower of London	Shifting Affective decision making Working memory maintenance Planning	Cold Hot Cold Cold
Cantrell, 2008	Diagnosis	CD	CD CD + ADHD Healthy controls	29 20 59	17.07 (1.03) 16.75 (0.68) -	100% 100% 100%	Trail Making Test Stroop Test Wisconsin Card Sorting Task D-KEFS Tower Test	Shifting Inhibition Shifting Planning	Cold Cold Cold Cold
Carter Leno et al., 2018	Diagnosis	ODD/CD	ODD/CD Controls + ADHD Controls + ASS Healthy controls	26 21 41 43	12.79 (1.61) 12.98 (1.47) 12.31 (1.62) 13.77 (1.08)	83.72% 95.24% 65.38% 58.54%	Go/No-Go Task Switch Task	Inhibition Shifting	Cold Cold
Chamberlain et al., 2016	Diagnosis	ASPD	ASPD Healthy controls	17 229	23.8 (3.9) 23.6 (3.1)	58.8% 61.6%	Intra/ Extradimensional Shift Task Stop Signal Task Cambridge Gambling Task Spatial Working	Shifting Inhibition Affective decision making Working memory	Cold Cold Hot Cold Cold

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Appendix 3 (*continued*)

Study	Assessment Method	ASB classification	Participant Groups	n	Mean Age (SD)	Males (%)	EF task	EF domain	Hot/ Cold EF
							Memory Task Stockings of Cambridge	maintenance Planning	
Coenen et al., 2022	Official records	Offender	Offenders Healthy controls	34 36	16.67 (1.21) 17.25 (1.00)	100% 100%	StopSignal task Stroop Test Digit span Backward Spatial working memory Trail Making Test Local-Global Iowa Gambling task	Inhibition Inhibition Working Memory Working Memory Working Memory Shifting Shifting Higher-order EF	Cold Cold Cold Cold Cold Cold Hot
Cohen et al., 2010	Official records	Offender	Sex offenders Healthy controls	51 84	38.63 (12.2) 33.81 (9.7)	- -	Wisconsin Card Sorting Task Trail Making Test Stroop Test Porteus Maze Test	Shifting Shifting Inhibition Planning	Cold Cold Cold Cold
Combalbert et al., 2016	Official records	Offender	Offenders Healthy controls	138 138	59.72 (8.02) 68.40 (8.03)	100% 100%	FAB Conflicting Information Task	Inhibition	Cold
Crippa et al., 2015	Diagnosis	ODD	ODD + ADHD Controls + ADHD Healthy controls	12 11 68	10.00 (1.65) 9.00 (1.67) 10.40 (2.04)	91.66% 90.90% 64.71%	Honk Test Battersea Multitask paradigm	Inhibition Planning	Cold Cold
Cubillo et al., 2023	Diagnosis	CD	CD Healthy controls	753 693	14.14 (2.48) 14.39 (2.29)	33.60% 38.39%	Go/No-go Task Go/No-go Task	Inhibition Inhibition	Cold Hot
Curtis et al., 2021	Diagnosis	Offender	Violent offenders + SUD Non-violent offenders + SUD Controls + SUD	69 58 63	37.01 (8.35) 38.03 (9.35) 43.54 (11.72)	85% 77% 60%	Memory Span task Stroop Test Trail Making Test	Working Memory Inhibition Shifting	Cold Cold Cold
De Brito et al., 2013	Diagnosis	ASPD, Psychopathy	ASPD + Psychopathy ASPD Healthy controls	17 28 21	40.0 (9.0) 35.8 (8.4) 35.0 (8.2)	100% 100% 100%	Digit Span (overall) Object Alternation Test Response Reversal Task Cambridge Gambling Task	Working memory manipulation Shifting Shifting Affective decision making	Cold Cold Hot Hot
Delfin et al., 2020	Official records	Offender	Offenders Healthy controls	27 20	36.63 (9.85) 33.10 (11.82)	100% 100%	Go/No-go Task	Inhibition	Cold
Déry et al., 2009	Diagnosis	CD	CD Healthy controls	105 138	9.57 (2.04) 10.08 (1.72)	74.29% 73.19%	Stroop Test Trail Making Test Wisconsin Card Sorting Task	Inhibition Shifting Shifting	Cold Cold Cold
Dolan & Lennox, 2013	Diagnosis	CD	CD CD + ADHD Healthy controls	72 35 22	16.41 (0.68) 15.97 (0.96) 15.63 (1.50)	100% 100% 100%	Stockings of Cambridge Intra/ Extradimensional Shift Go/No-go Task Card Playing Task Delayed Gratification Task	Planning Shifting Inhibition Inhibition Choice impulsivity	Cold Cold Cold Hot Hot
Dolan, 2012	Diagnosis, official records	ASPD, offender	Offenders + ASPD (LP) Offenders + ASPD (MP) Offenders + ASPD (HP) Healthy controls	35 28 33 49	37.18 (10.48) 35.04 (10.12) 38.79 (11.42) 33.69 (10.24)	100% 100% 100% 100%	Stockings of Cambridge Go/No-go Task Intra/ Extradimensional Shift	Planning Inhibition Shifting	Cold Cold Cold

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Appendix 3 (*continued*)

Study	Assessment Method	ASB classification	Participant Groups	n	Mean Age (SD)	Males (%)	EF task	EF domain	Hot/ Cold EF
Easton et al., 2008	Official records	Offender	Violent offenders + SUD Controls + SUD Healthy controls	9 9 7	40 (9.9) 40 (9.9) 40 (9.9)	100% 100% 100%	Wisconsin Card Sorting Task Digit Span Backward Stroop Test Continuous Performance Task Trail Making Test Iowa Gambling Task	Shifting Working memory manipulation Inhibition Inhibition Shifting Affective decision making	Cold Cold Cold Cold Hot
Enticott et al., 2008	Official records	Offender	Offenders + schizophrenia Healthy controls	18 18	36.11 (10.78) 36.00 (11.42)	72.22% 66.67%	Stroop Test Negative Priming Task	Inhibition Inhibition	Cold Cold
Euler et al., 2014	Diagnosis	CD	CD Healthy controls	20 20	14.25 (1.52) 14.15 (0.88)	100% 100%	Stroop Test	Inhibition	Cold
Ezpeleta & Granero, 2015	Diagnosis	ODD	ODD ODD + ADHD Controls + ADHD Healthy controls	51 10 23 538	3.87 (0.30) 3.69 (0.31) 3.74 (0.33) 3.76 (0.33)	56.9% 40.0% 73.9% 48.5%	Continuous Performance Task	Inhibition	Cold
Fairchild et al., 2009	Diagnosis	CD	CD (adolescent-onset) CD (early-onset) Healthy controls	34 38 84	15.54 (0.90) 15.75 (0.75) 15.77 (0.82)	100% 100% 100%	Wisconsin Card Sorting Task	Shifting	Cold
Feilhauer et al., 2012	Official records	Offender	Offenders Healthy controls	53 64	16.11 (0.64) 15.92 (0.63)	100% 100%	Go/No-go Task	Inhibition	Cold
Fonseca-Parra & Rey-Anacona, 2013	Diagnosis	ODD	ODD Healthy controls	13 18	8.69 (2.06) 9.28 (1.87)	100% 100%	Wisconsin Card Sorting Task Pyramid of Mexico	Shifting Planning	Cold Cold
Franke et al., 2019	Official records	Offender	Sex offenders Healthy controls	15 15	50.5 (11.4) 48.1 (11.0)	100% 100%	Go/No-go Task Tower of London	Inhibition Planning	Cold Cold
Ginsberg et al., 2010	Official records	Offender	Offenders + ADHD Controls + ADHD Healthy controls	30 20 18	34.4 33.4 35.2	100% 100% 100%	Digit Span (overall) Continuous Performance Task	Working memory maintenance Inhibition	Cold Cold
Glenn et al., 2017	Diagnosis	ODD, CD	ODD/CD ODD/CD + ADHD Controls + ADHD	33 133 99	11.39 (2.03) 10.44 (1.93) 10.60 (1.78)	87.9% 89.5% 85.9%	Stop Signal Task Stockings of Cambridge	Inhibition Planning	Cold Cold
Gobbi et al., 2020	Official records	Offender	Offenders Healthy controls	126 121	44.9 (10.0) 44.5 (11.2)	81.75% 74.38%	Wisconsin Card Sorting Task Iowa Gambling Task Memory Span Task Tower of London	Shifting Affective decision making Working memory maintenance Planning	Cold Hot Cold Cold
Gonzalez-Gadea et al., 2014	Official records	Offender	Offenders Healthy controls	30 16	16.67 (0.54) 16.00 (0.63)	100% 100%	Go/No-go Task Hayling Test Digit Span Backward Memory Span Task FAB Conflicting Information Task	Inhibition Inhibition Working memory manipulation Working memory maintenance Inhibition	Cold Cold Cold Cold Cold
Grant et al., 2012	Official records	Offender	Offenders Healthy controls	14 95	21.0 (3.1) 20.0 (2.8)	64.3% 68.4%	Cambridge Gambling Task Spatial Working Memory Task	Affective decision making Working memory	Hot Cold Cold Cold

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Appendix 3 (*continued*)

Study	Assessment Method	ASB classification	Participant Groups	n	Mean Age (SD)	Males (%)	EF task	EF domain	Hot/ Cold EF
							Intra/ Extradimensional Shift	maintenance Shifting	
							Stop Signal Task	Inhibition	
Guan et al., 2015	Official records	Offender	Offenders	20	16.58 (0.77)	100%	Go/No-go Task	Inhibition	Cold
			Healthy controls	20	16.23 (0.71)	100%			
Gunn et al., 2018	Diagnosis	ASPD	ASPD + SUD	139	-	-	Delay Discouting Task	Choice impulsivity	Hot
			Controls + SUD	309	-	-			
			Healthy controls	185	-	-			
Habermeyer et al., 2013	Official records	Offender	Pedophilic sex offenders	11	49.0 (12.5)	100%	Go/No-go Task	Inhibition	Cold
			Healthy controls	7	47.0 (8.6)	100%			
Hanlon et al., 2013	Official records	Offender	Offenders + schizophrenia	7	31.00 (5.45)	100%	Trail Making Test	Shifting	Cold
							Wisconsin Card Sorting Task	Shifting	Cold
			Controls + schizophrenia	7	27.60 (3.23)	100%	Digit Span Backward	Working memory manipulation	Cold
Herrero et al., 2018	Official records	Offender	Sex offenders	26	37.8 (8.87)	100%	Letter Memory Task	Updating	Cold
			Child Sex offenders	17		100%	Number Letter	Shifting	Cold
			Non-sex offenders	35	44.0 (11.5)	100%	Switch	Inhibition	Cold
			Healthy controls	32	34.84 (8.17)	100%	Simon Task		
					29.0 (2.37)				
Herrero et al., 2010	Official records	Offender	Offenders	24	33.6 (7.5)	100%	Letter Memory Task	Updating	Cold
			Healthy controls	32	29.0 (2.4)	100%	Number Letter Switch	Shifting Inhibition	Cold Cold
							Simon Task		
Hobson et al., 2011	Diagnosis	ODD, CD	ODD/CD	28	12.64 (1.98)	67.86%	Go/No-go Task	Inhibition	Cold
			Healthy controls	34	13.13 (1.99)	73.53%	Stop Signal Task	Inhibition	Cold
							Continuous Performance Test	Inhibition Shifting	Cold Cold
							Wisconsin Card Sorting Task	Affective decision making	Hot
							Iowa Gambling Task		
Hoppenbrouwers et al., 2013	Official records, diagnosis	Offender, psychopathy	Offenders + psychopathy	13	34.2 (9.2)	100%	Letter Number Sequencing Task	Working memory manipulation	Cold
			Healthy controls	15	34.0 (9.9)	100%			
Hummer et al., 2015	Diagnosis	CD, ODD	CD/ODD	14	15.3 (1.3)	57.0%	Stroop Test	Inhibition	Cold
			CD/ODD + ADHD	19	15.4 (1.5)	84.0%	Digit Span (overall)	Working memory maintenance	Cold
			Healthy controls	33	15.3 (1.4)	73.0%			
Hummer et al., 2011	Diagnosis	CD, ODD	CD/ODD	23	14.8 (1.3)	56.52%	Stroop Test	Inhibition	Cold
			CD/ODD + ADHD	25	14.7 (1.2)	76.0%	Digit Span (overall)	Working memory maintenance	Cold
			Healthy controls	25	15.1 (1.4)	52.0%	Continuous Performance Task	Inhibition	Cold
Hwang et al., 2016	Diagnosis	CD/ODD	CD/ODD (low CU)	17	14.78 (2.39)	70.0%	Stroop Test	Inhibition	Cold
			CD/ODD (high CU)	18	14.56 (1.84)	56.0%	Stroop Test	Inhibition	Hot
			Healthy controls	28	12.88 (2.03)	54.0%			
Iria et al., 2012	Official records, diagnosis	Offender, psychopathy	Offenders + psychopathy	25	40.76 (10.03)	100%	Go/No-go Task	Inhibition	Hot
			Offenders	37		100%			
			Controls + psychopathy	12	38.70 (8.98)	100%			
			Healthy controls	39	37.75 (8.87)	100%			
					37.87 (11.63)				
Iselin & DeCoster, 2009	Official records	Offender	Offenders (adolescent)	44	15.70 (1.67)	100%	Continuous Performance Task	Inhibition	Cold
			Offenders (young	41	20.86	100%			

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Appendix 3 (*continued*)

Study	Assessment Method	ASB classification	Participant Groups	n	Mean Age (SD)	Males (%)	EF task	EF domain	Hot/ Cold EF
			adult)	33	(1.47)	100%			
			Controls (adolescent)	35	14.52 (1.53)	100%			
			Controls (young adult)		19.34 (2.93)				
Iselin & DeCoster, 2012	Official records	Offender	Offenders (adolescent)	41	15.70 (1.67)	100%	Stroop Test	Inhibition	Cold
			Offenders (young adult)	40	20.86 (1.47)	100%			
			Controls (adolescent)	32	14.48 (1.54)	100%			
			Controls (young adult)	31	19.34 (0.80)	100%			
Jiang et al., 2016	Diagnosis	ODD	ODD	7	11.76	95.83%	Stroop Test	Inhibition	Cold
			ODD + ADHD	17	12.64	95.83%	Wisconsin Card Sorting Task	Shifting	Cold
			Controls + ADHD	24	12.17	91.67%	Memory Span Task	Working memory	Cold
			Healthy controls	36	12.92	75.0%	Digit Span Backward	maintenance	Cold
							Stockings of Cambridge	Working memory manipulation	Cold
							Spatial Working Memory Task	Planning	
								Working memory maintenance	
Joyal et al., 2020	Official records	Offender	Sex offenders (child victim)	39	15.0 (1.5)	100%	Wisconsin Card Sorting Task	Shifting	Cold
			Sec offenders (peer victim)	15	16.0 (1.7)	100%	Iowa Gambling Task	Affective decision making	Hot
			Non-sex offenders	41	16.1 (1.1)	100%	Stop Signal Task	Inhibition	Cold
			Healthy controls	39	15.4 (1.7)	100%			
Kallitsoglou, 2018	Diagnosis	CD	CD	26	7.6 (0.41)	78.0%	Tower of London	Planning	Cold
			CD + reading disorder	27	7.6 (0.34)	77.0%	Digit Span Backward	Working memory	Cold
			Controls + reading disorder	35	7.5 (0.33)	54.0%	Continuous Performance Task	manipulation	Cold
			Healthy controls	31	7.7 (0.37)	74.0%		Inhibition	
Kashiwagi et al., 2015	Official records	Offender	Offenders + schizophrenia	30	44.1 (11.5)	100%	Digit Span (overall)	Working memory	Cold
			Controls + schizophrenia	24	40.3 (10.7)	100%	Tower of London	maintenance	Cold
								Planning	
Kim et al., 2023	Diagnosis	ODD	ODD + ADHD	36	7.8 (1.9)	91.7%	Stroop Test	Inhibition	Cold
			Controls + ADHD	307	7.7 (1.8)	83.7%	Trail Making Test	Shifting	Cold
			Healthy controls	128	8.2 (2.5)	50.8%			
Kleine Deters et al., 2020	Diagnosis	CD, ODD	ODD	44	12.3 (2.6)	72.7%	Delayed Match to Sample	Working memory maintenance	Cold
			CD	48	13.5 (3.0)	87.5%			
			Healthy controls	86	13.3 (2.7)	57.0%			
Krakowski et al., 2015	Official records	Offender	Offenders	16	41.7 (19.6)	93.7%	Go/No-go Task	Inhibition	Hot
			Healthy controls	22	41.4 (9.5)	77.3%	Switch Task	Shifting	Cold
Krischer et al., 2008	Official records	Offender	Offenders	33	18.12 (1.05)	0.0%	Self-ordered Pointing Task	Working memory maintenance	Cold
			Healthy controls	20	17.05 (0.69)	0.0%	Affective Self-ordered Pointing Task	Working memory maintenance	Hot
Lin & Gau, 2017	Diagnosis	CD, ODD	CD + ADHD	76	13.21 (1.70)	93.42%	Digit Span Backward	Working memory	Cold
			ODD + ADHD	133	12.01 (1.57)	79.70%	Spatial Working Memory	manipulation	Cold
			Controls + ADHD	273	12.18 (1.66)	78.39%	CANTAB Spatial Span	Working memory maintenance	Cold
			Healthy controls	347		58.06%			

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Appendix 3 (*continued*)

Study	Assessment Method	ASB classification	Participant Groups	n	Mean Age (SD)	Males (%)	EF task	EF domain	Hot/ Cold EF
					12.90 (2.05)			Working memory maintenance	
Lishak et al., 2021	Official records	Offender	Domestic violent offenders	54	37.07 (9.27)	100%	Go/No-go Task Digit span	Inhibition Working memory	Cold Cold
			Domestic violent offenders (+ additional criminality)	56	36.43 (8.5)	100%			
			Healthy controls	82	37.77 (9.55)	100%			
Liu et al., 2023	Diagnosis	CD, ODD	CD/ODD + ADHD	1026	10.6	83.92%	Trail Making Test	Shifting	Cold
			Controls + ADHD	1026	(2.62)	86.74%	Stroop Test	Inhibition	Cold
			Healthy controls	406	10.36 (2.55)	61.58%			
					9.9 (1.65)				
Luman et al., 2009	Diagnosis	ODD	ODD + ADHD	18	9.83	69.0%	Stop Signal Task	Inhibition	Cold
			Controls + ADHD	20	(1.5)	69.0%			
			Healthy controls	50	8.83 (1.42)	56.0%			
					9.5 (1.25)				
Majorek et al., 2009	Official records	Offender	Offenders + schizophrenia	33	31.5	97.97%	Wisconsin Card Sorting Task	Shifting Planning	Cold Cold
			Controls + schizophrenia	38	35.9	47.37%	BADS Zoo Test		
			Healthy controls	29	(11.6)	34.48%			
					37.0 (13.7)				
Manfei Xu et al., 2017	Diagnosis	ODD	ODD	14	9.85	100%	Stockings of Cambridge	Planning	Cold
			ODD + ADHD	29	(1.91)	100%	Spatial Working Memory	Working memory maintenance	Cold
			Controls + ADHD	39	10.11	100%	CANTAB Spatial Span		Cold
			Healthy controls	52	(1.74)	100%	Wisconsin Card Sorting Task	Working memory maintenance	Cold
					9.16 (1.82)		Digit Span Backward	Shifting	
					10.02 (2.10)			Working memory manipulation	
Marceau et al., 2008	Official records	Offender	Offenders	584	28.78	100%	Trail Making Test	Shifting	Cold
			Psychiatric controls	494	(6.32)	100%	Wisconsin Card Sorting Task	Shifting	Cold
			Healthy controls	132	28.94 (7.09)	100%			
					27.92 (7.03)				
Massau et al., 2017	Official records	Offender	Child sexual offender + pedophilia	45	38.04 (8.62)	100%	Stop Signal Task Information Sampling Task	Inhibition Inhibition	Cold Cold
			Child sexual offender – pedophilia	19		100%	Intra/ Extradimensional Shift	Shifting Planning	Cold Cold
			Controls + pedophilia	45	40.26 (12.71)	100%	Stockings of Cambridge Memory Span Task	Working memory maintenance	Cold
			Healthy controls	49	36.51 (9.46)	100%			
					36.43 (6.70)				
Medrano Nava et al., 2022	Diagnosis	CD, ODD	ODD + ADHD	10	7-9	100%	BANFE Labyriths	Planning	Cold
			ODD + ADHD + ADD	10	7-9	100%	BANFE Card Classification	Shifting	Cold
			ODD + ADHD + LD	8	7-9	100%	BANFE Card game	Affective decision making	Hot
			ODD + CD + ADHD + LD	9	7-9	100%	BANFE Hanoi	Planning	Cold
			Controls + ADHD	10	7-9	100%	BANFE Visuospatial WM	Working memory maintenance	Cold
			Controls + ADHD + ADD	8	7-9	100%	BANFE Stroop B	Inhibition	Cold
Meier et al., 2012	Official records	Offender	Offenders	13	31.5	100%	Go/No-go Task	Inhibition	Cold
			Controls + ADHD	13	(10.02)	100%	Go/No-go Task	Inhibition	Hot
			Healthy controls	13	31.3 (9.73)	100%			
					28.5 (5.49)				

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Appendix 3 (*continued*)

Study	Assessment Method	ASB classification	Participant Groups	n	Mean Age (SD)	Males (%)	EF task	EF domain	Hot/ Cold EF
Mellentin et al., 2013	Diagnosis	ASPD	ASPD + SUD Controls + SUD Healthy controls	16 30 17	36.81 (8.60) 34.18 (8.01) 36.65 (10.62)	93.75% 66.67% 76.47%	Iowa Gambling Task	Affective decision making	Hot
Moeller et al., 2014	Diagnosis	IED	IED Controls + SUD Healthy controls	11 17 22	33.5 (7.1) 32.6 (6.4) 43.2 (6.5)	100% 100% 100%	Stroop Test	Inhibition	Cold
Molleman et al., 2021	Official records	Offender	Offenders Offenders (psychiatric) Healthy controls	57 119 66	31.2 38.9 36.1	100% 100% 100%	Stroop Test Continuous Performance Test	Inhibition Inhibition	Hot Cold
Molleman et al., 2022	Official Records	Offender	Offenders Offenders (psychiatric) Healthy controls	57 119 65	31.2 (8.5) 38.9 (9.2) 36.1 (11.8)	100% 100% 100%	Reversal learning task StopSignal task	Shifting Inhibition	Hot Cold
Munkvold et al., 2014	Diagnosis	ODD	ODD ODD + ADHD Controls + ADHD Healthy controls	10 15 50 160	9.3 (0.8) 9.7 (1.0) 9.6 (0.8) 9.4 (1.0)	70.0% 100% 78.0% 55.63%	Continuous Performance Test	Inhibition	Cold
Muscatello et al., 2014	Official records	Offender	Offenders Healthy controls	147 150	17.07 (1.1) 17.29 (0.9)	100% 100%	Stroop Test Wisconsin Card Sorting Test	Inhibition Shifting	Cold Cold
*Närhi, Lehto-Salo, Ahonen, & Marttunen, 2010	Diagnosis	CD/ODD	CD/ODD Healthy controls	77 48	15.35 (1.08) 14.79 (0.81)	48.1% 35.4%	Trail Making Test Wisconsin Card Sorting Test Tower of Hanoi Digit Span Backward	Shifting Shifting Planning Working memory manipulation	Cold Cold Cold Cold
Neves & Pinho, 2018	Official records	Offender	Offenders Healthy controls	59 59	34.4 (7.9) 33.7 (8.9)	51.0% 49.0%	Stroop Test Porteus Maze Test	Inhibition Planning	Cold Cold
Nishinaka et al., 2016	Official records	Offender	Offenders Healthy controls	71 54	42.79 (11.92) 42.06 (11.43)	84.51% 88.89%	Two Back Task Iowa Gambling Task Groton Maze Learning Task	Updating Affective decision making Planning	Cold Hot Cold
Noordermeer et al., 2020	Diagnosis	ODD	ODD + ADHD Controls + ADHD Healthy controls	82 82 82	16.3 (3.1) 16.3 (3.0) 16.1 (3.3)	67.0% 67.0% 67.0%	Stop Signal Task Digit Span Backward Delay Discounting Task	Inhibition Working memory maintenance Choice impulsivity	Cold Cold Hot
Nordvall, Jonsson, & Neely, 2017	Official records	Offender	Offenders Healthy controls	31 40	17.0 (1.7) 17.5 (1.3)	51.61% 50.0%	Stroop Test Switch Task Verbal n-back Task Memory Span Task	Inhibition Shifting Updating Working memory maintenance	Cold Cold Cold Cold
Nordvall, Neely, & Jonsson, 2017	Official records	Offender	Offenders Healthy controls	37 39	17.7 (1.4) 17.3 (1.1)	62.16% 51.28%	Stroop Test Switch Task Verbal n-back Task Memory Span Task	Inhibition Shifting Updating Working memory maintenance	Cold Cold Cold Cold
Ostrosky et al., 2012	Official records	Offender	Offenders Healthy controls	82 76	44 (9.0) 42 (8.5)	100% 100%	Porteus Maze Test BANFE Visuospatial WM Task Stroop Test BANFE Subtraction Task BANFE Gambling Task Wisconsin Card Sorting Task BANFE Maze Tower of Hanoi	Planning Working memory maintenance Inhibition Working memory maintenance Affective decision making Shifting	Cold Cold Cold Cold Hot Cold Cold Cold

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Appendix 3 (*continued*)

Study	Assessment Method	ASB classification	Participant Groups	n	Mean Age (SD)	Males (%)	EF task	EF domain	Hot/ Cold EF
								Planning	
								Planning	
Pajer et al., 2008	Diagnosis	CD	CD	52	16.5	0.0%	Stroop Test	Inhibition	Cold
			Healthy controls	41	(0.95)	0.0%	Digit Span (overall)	Working	Cold
					16.1		Wisconsin Card	memory	Cold
					(0.78)		Sorting Task	maintenance	
								Shifting	
Palix et al., 2022	Official records	Offender	Violent offenders	22	39.27	100%	Go/No-Go	Inhibition	Cold
			Healthy controls	24	(12.12)	100%			
					32.46				
					(12.47)				
Pasion et al., 2018	Official records	Offender	Offenders	56	32	100%	Stroop Test	Inhibition	Cold
			Healthy controls	48	(11.6)	100%	Spatial N-back Task	Updating	Cold
					39				
					(9.97)				
Patiz & Bayraktar, 2023	Official records	Offender	Offenders	30	15.97	76.7%	Wisconsin Card	Shifting	Cold
			Victims	30	(1.35)	63.3%	Sorting Task	Planning	Cold
			Healthy controls	25	-	44.0%	Tower Test		
					15.00				
					(1.36)				
Pera-Guardiola et al., 2016	Official records, diagnosis	Offender, ASPD	Offenders + ASPD (HP)	31	33.45	100%	Wisconsin Card	Shifting	Cold
				13	(4.84)	100%	Sorting Task		
			Offenders + ASPD (LP)	24	39.93	100%			
					(10.01)				
			Healthy controls		41.04				
					(9.17)				
Perino et al., 2019	Official records	Offender	Offenders	24	16.2	50.0%	Go/No-go Task	Inhibition	Cold
			Healthy controls	24	(1.2)	50.0%			
					15.8				
					(0.36)				
Poon, 2020	Official records	Offender	Offenders	122	15.28	50.82%	Cambridge Gambling Task	Affective decision making	Hot
			Healthy controls	129	15.18	45.74%			
Prehn et al., 2013	Official records, diagnosis	Offender, ASPD	Offenders + ASPD	15	27.87	100%	Verbal N-back Task	Updating	Cold
			Healthy controls	17	(9.86)	100%	Verbal N-back Task	Updating	Hot
					28.88				
					(9.49)				
Price et al., 2013	Official records	Offender	Sex offenders	27	43.31	100%	Hayling Test	Inhibition	Cold
			Non-sex offenders	21	(9.82)	100%	Stroop Test	Inhibition	Hot
			Healthy controls	38	35.24	100%			
					(10.06)				
					20.47				
					(2.48)				
Price et al., 2014	Official records	Offender	Sex offenders	24	15.96	100%	Hayling Test	Inhibition	Cold
			Non-sex offenders	21	(1.27)	100%	Stroop Test	Inhibition	Hot
			Healthy controls	21	16.75	100%			
					(0.91)				
					17.05				
					(0.76)				
Qian et al., 2010	Diagnosis	ODD	ODD + ADHD	53	9.25	79.25%	Stroop Test	Inhibition	Cold
			Controls + ADHD	89	(1.79)	62.92%	Trail Making Test	Shifting	Cold
			Healthy controls	116	9.07	83.62%	Digit Span Backward	Working	Cold
					(1.92)		Tower of Hanoi	memory	Cold
					9.19			manipulation	
					(1.62)			Planning	
Raszkiewicz, 2010	Diagnosis	CD	CD	34	15.51	82.35%	Continuous	Inhibition	Cold
			Healthy controls	35	(0.82)	45.71%	Performance Test		
					15.76				
					(1.02)				
Rhodes et al., 2012	Diagnosis	ODD	ODD	21	9.91	100%	Memory Span Task	Working	Cold
			ODD + ADHD	27	(1.94)	100%	CANTAB Spatial	memory	Cold
			Controls + ADHD	21	9.77	100%	Span Task	maintenance	Cold
			Healthy controls	26	(1.82)	100%	Verbal Executive	Working	Cold
					9.47		Function Task	memory	Cold
					(2.01)		Spatial Executive	maintenance	Cold
					9.69		Function Task	Working	Cold
					(1.46)		Spatial Working	memory	
							Memory Task	manipulation	
							Delayed Match to	Working	
							Sample Task	memory	
							Spatial N-back Task	manipulation	
								Working	
								memory	
								maintenance	
								Working	

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Appendix 3 (*continued*)

Study	Assessment Method	ASB classification	Participant Groups	n	Mean Age (SD)	Males (%)	EF task	EF domain	Hot/ Cold EF
								memory maintenance Updating	
Romero-Martínez, Lila, & Moya-Albiol, 2021	Official records	Offender	Domestic offenders Healthy controls	89 39	40.10 (11.05) 41.89 (11.10)	100% 100%	Wisconsin Card Sorting Task Switch Task	Shifting Shifting	Cold Cold
Romero-Martínez, Lila, Vitoria-Estruch, & Moya-Albiol, 2021	Official records	Offender	Domestic offenders Healthy controls	47 41	38.61 (11.40) 41.72 (11.01)	100% 100%	Trail Making Test Wisconsin Card Sorting Task	Shifting Shifting	Cold Cold
Romero-Martínez, Lila, & Moya-Albiol, 2021	Official records	Offender	Domestic offenders Healthy controls	51 39	41.72 (11.01) 40.10 (10.90)	100% 100%	CANTAB Spatial Span Cambrigde Gambling Task	Working memory maintenance Affective decision making	Cold Hot
Romero-Martínez, Lila, Vitoria-Estruch, & Moya-Albiol, 2021	Official records	Offender	Intimate partner violence perpetrators + SUD Intimate partner violence perpetrators - SUD Healthy controls	104 120 82	40.08 (9.49) 40.07 (9.17) 40.30 (10.59)	100% 100% 100%	Digit Span Task Wisconsin Card Sorting Task Key Test	Working memory Shifting Planning	Cold Cold Cold
Rosburg et al., 2018	Official records	Offender	Child sex offenders Healthy controls	40 21	36.5 (10.3) 30.8 (10.2)	100% 100%	Go/No-go Task	Inhibition	Cold
Rubia et al., 2009	Diagnosis	CD, ODD	CD/ODD Controls + ADHD Healthy controls	13 20 20	12.9 (2.2) 13.2 (1.4) 14.0 (1.9)	100% 100% 100%	Simon Task	Inhibition	Cold
Rubia et al., 2008	Diagnosis	CD, ODD	CD/ODD Controls + ADHD Healthy controls	13 20 20	13.0 (1.0) 13.2 (1.5) 14.0 (2.0)	100% 100% 100%	Stop Signal Task	Inhibition	Cold
Rubia et al., 2010	Diagnosis	CD, ODD	CD/ODD Controls + ADHD Healthy controls	14 14 20	12.6 (2.3) 13.3 (1.1) 13.5 (1.9)	100% 100% 100%	Switch Task	Shifting	Cold
Saarinen et al., 2015	Diagnosis	CD, ODD	CD/ODD Healthy controls	26 26	10.1 (1.2)		Spatial N-back Task	Updating	Cold
Barbosa and Monteiro, 2008	Official records	Offender	Offenders Healthy controls	30 30	39.3 (9.89) 32.7 (11.8)	100% 100%	Wisconsin Card Sorting Task BADS Action Program BADS Zoo Test BADS Key Test BADS Modified Sex Elements Task	Shifting Planning Planning Planning Planning	Cold Cold Cold Cold Cold
Schiffer & Vonlaufen, 2011	Official records	Offender	Non-sex offenders Child sex offenders Child sex offenders + pedophilia Healthy controls	16 15 15 17	37.4 (9.1) 44.2 (7.9) 38.7 (8.9) 37.7 (10.2)	100% 100% 100% 100%	Wisconsin Card Sorting Task Go/No-go Task Trail Making Test Memory Span Task Tower of London	Shifting Inhibition Shifting Working memory maintenance Planning	Cold Cold Cold Cold Cold
Schiffer et al., 2014	Official records	Offender	Offenders + SUD Healthy controls	21 23	35.2 (8.2) 34.1 (8.9)	100% 100%	Stroop Test	Inhibition	Cold
Schoemaker et al., 2012	Diagnosis	CD, ODD	CD/ODD CD/ODD + ADHD	33 52	4.32 (0.69) 4.51	81.8% 82.7%	Go/No-go Task Delayed Gratification Task	Inhibition Choice impulsivity	Cold Hot

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Appendix 3 (*continued*)

Study	Assessment Method	ASB classification	Participant Groups	n	Mean Age (SD)	Males (%)	EF task	EF domain	Hot/ Cold EF
			Controls + ADHD	61	(0.57)	80.3%	Shape School Task	Inhibition	Hot
			Healthy controls	56	4.60 (0.62) 4.64 (0.60)	69.6%	Object Alternation Test	Shifting	Cold
Schoorl et al., 2016	Diagnosis	CD, ODD	CD/ODD	65	10.3 (1.28)	100%	Ultimatum Game (child version)	Affective decision making	Hot
			Healthy controls	38	10.1 (1.27)	100%			
Schoorl et al., 2018	Diagnosis	CD, ODD	CD/ODD	65	10.3 (1.28)	100%	Digit Span Backward	Working memory manipulation	Cold
			Healthy controls	32	9.9 (1.24)	100%	Shifting Attention Set Task		Cold
							Digit Span Backward	Shifting	Hot
							Shifting Attention Set Task	Working memory manipulation	Hot
								Shifting	
Schwenck et al., 2017	Diagnosis	CD, ODD	CD/ODD	19	13.81 (1.56)	100%	Iowa Gambling Task	Affective Decision Making	Hot
			Healthy controls	24	14.76 (2.12)	100%			
Seruca & Silva, 2016	Official records	Offender	Offenders	42	33.67 (8.66)	100%	Trail Making Test	Shifting	Cold
			Healthy controls	28	35.57 (8.95)	100%	Digit Span Backward	Working memory maintenance	Cold
							Stroop Test	Inhibition	Cold
							Porteus Maze Test	Planning	Cold
Shuai et al., 2011	Diagnosis	CD, ODD	CD/ODD + ADHD	38	10.34 (2.53)	100%	Stroop Test	Inhibition	Cold
			Controls + ADHD + LD	38		100%	Trail Making Test	Shifting	Cold
				76	10.38 (2.56)	100%	Tower of Hanoi	Planning	Cold
			Controls + ADHD	76	10.24 (2.40)	100%			
			Healthy controls		10.21 (2.30)				
Stratton et al., 2018	Official records	Offender	Offenders + schizophrenia	25	37.12 (12.91)	96.0%	Trail Making Test	Shifting	Cold
				25		92.0%	Wisconsin Card Sorting Test	Shifting	Cold
			Controls + schizophrenia	25	33.89 (5.74)	84.0%			
			Healthy controls		30.92 (6.55)				
Swann et al., 2009	Diagnosis, official records	ASPD, offender	Offenders + ASPD	34	38.7 (10.3)	100%	Delay Discounting Task	Choice impulsivity	Hot
			Healthy controls	30	31.5 (9.5)	100%	Continuous Performance Task	Inhibition	Cold
Syngelaki et al., 2009	Official records	Offender	Offenders	102	16.33	100%	Risky Choice Task	Affective decision making	Hot
			Healthy controls	83	15.77	100%			
Szczypiński et al., 2022	Diagnosis, official records	Offender	Sex offenders (to child)	13	43.69 (7.61)	100%	Go/No-go Task	Inhibition	Cold
			Healthy controls	18	35.06 (7.69)	100%			Hot
Tung & Chhabra, 2011	Official records	Offender	Offenders	40	15.7	100%	Stroop Test	Inhibition	Cold
			Healthy controls	40	15.0	100%			
Turner et al., 2020	Official records	Offender	Sex offenders (to child)	70	41.66 (13.85)	100%	Iowa Gambling Task	Affective decision making	Hot
				49		100%	Wisconsin Card Sorting Task	Shifting	Cold
			Sex offenders (to adult)	54	37.73 (11.44)	100%	Tower of London	Planning	Cold
				73		100%	Trail Making Test	Shifting	Cold
			Non-sex offenders		32.72 (9.81)		Stroop Test	Inhibition	
			Healthy controls		38.10 (12.97)				
Turner et al., 2018	Official records	Offender	Sex offenders (to child)	63	42.14 (13.19)	100%	Go/No-go Task	Inhibition	Hot
				63		100%	Iowa Gambling Task	Affective decision making	Hot
			Healthy controls		27.0 (4.75)		Game of Dice Task	Affective decision making	Hot
Urazán-Torres et al., 2013	Diagnosis	CD	CD	39	9.54 (1.99)	77.0%	Wisconsin Card Sorting Task	Shifting	Cold
			Healthy controls	39	9.26 (2.11)	49.0%	Pyramid of Mexico	Planning	Cold
Uytun et al., 2017	Diagnosis	CD	CD + ADHD	10	-	100%	Wisconsin Card Sorting Task	Shifting	Cold
			Controls + ADHD	10	-	100%		Inhibition	Cold
			Healthy controls	10	-	100%	Stroop Test		

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Appendix 3 (*continued*)

Study	Assessment Method	ASB classification	Participant Groups	n	Mean Age (SD)	Males (%)	EF task	EF domain	Hot/ Cold EF
Van der Meere et al., 2008	Diagnosis	CD	CD + IQ 70-75 Controls + IQ 70-75	21 19	12.08 (1.08) 11.00 (1.08)	100% 100%	Continuous Performance Test	Inhibition	Cold
Vilà-Balló et al., 2014	Official records	Offender	Offenders Healthy controls	17 17	18.3 (0.3) 18.6 (0.3)	100% 100%	Stop Signal Task	Inhibition	Cold
Vila-Ballo et al., 2015	Official records	Offender	Offenders Healthy controls	14 14	18.43 (1.16) 18.43 (1.02)	100% 100%	Wisconsin Card Sorting Task	Shifting	Cold
Vitoria-Estruch et al., 2018	Official records	Offender	Offender (IPV) + SUD Offender (IPV) Healthy controls	28 35 37	40.21 (11.90) 39.34 (9.83) 41.75 (11.0)	100% 100% 100%	Switch Task Memory Span Task Digit Span Backward Wisconsin Card Sorting Task BADS Zoo Test BADS Key Test One Touch Stockings of Cambridge Number Letter Switch	Shifting Working memory maintenance Working memory manipulation Shifting Planning Planning Shifting	Cold Cold Cold Cold Cold Cold Cold Cold
Vloet et al., 2011	Diagnosis	CD, ODD	CD/ODD + ADHD Healthy controls	17 17	12.5 (1.6) 11.8 (2.3)	100% 100%	Go/No-go Task Go/No-go Task	Inhibition Inhibition	Cold Hot
Weidacker et al., 2022	Official records	Offender	Sex offenders + pedophilia Controls + pedophilia Healthy controls	11 8 10	43.55 (11.58) 33.25 (10.79) 37.70 (13.12)	100% 100% 100%	Stroop Test	Inhibition	Cold
Zhu et al., 2014	Diagnosis	ODD	ODD Healthy controls	11 10	11.5 11.7	100% 100%	Stop Signal Task	Inhibition	Cold
Zhu et al., 2021	Diagnosis	CD, ODD	CD/ODD CD/ODD + ADHD Controls + ADHD Healthy controls	26 22 30 20	11.1 11.7 12.7 12.8	68.2% 57.7% 76.7% 75.00%	Stroop Test Stroop Test	Inhibition Inhibition	Cold Hot
Zou et al., 2013	Official records	Offender	Offenders (violent) Offenders (non-violent) Healthy controls	107 107 107	16.5 (0.6) 16.5 (0.6) 16.5 (0.6)	100% 100% 100%	Intra-Extradimensional Shift Stockings of Cambridge Spatial Working Memory Task	Shifting Planning Working memory maintenance	Cold Cold Cold

Appendix 4

Executive Function	Neuropsychological test	Outcome Measure	Quality	Freq
Higher-order EF	BADS action program	Overall performance	Low	1
Higher-order EF	BADS Key Test	Overall performance	Low	2
Higher-order EF	BADS Key Test	Strategy	Low	1
Higher-order EF	BADS modified six elements	Overall performance	Low	1
Higher-order EF	BADS Zoo Test	Overall performance	Low	5
Higher-order EF	BANFE Gambling task	% disadvantage decks	High	1
Higher-order EF	BANFE Gambling task	Overall performance	High	1
Higher-order EF	BANFE Labyrinths	Completion time	Low	8
Higher-order EF	BANFE Labyrinths	Planning time	Low	8
Higher-order EF	BANFE Maze	Completion time	Low	1
Higher-order EF	BANFE Maze	Planning error	Low	1
Higher-order EF	Battersea Multitask Paradigm	BMP coherence	Low	2
Higher-order EF	Battersea Multitask Paradigm	BMP performance	Low	2
Higher-order EF	Battersea Multitask Paradigm	BMP planning	Low	2
Higher-order EF	Cambridge Gambling task	Decision-making	High	3
Higher-order EF	Cambridge Gambling task	Decision-making	Medium	1
Higher-order EF	Cambridge Gambling task	Delay aversion	Medium	1
Higher-order EF	Cambridge Gambling task	Deliberation time	Low	3
Higher-order EF	Cambridge Gambling task	Deliberation time	Medium	1

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Appendix 4 (*continued*)

Executive Function	Neuropsychological test	Outcome Measure	Quality	Freq
Higher-order EF	Cambridge Gambling task	Number of bankruptcies	Low	1
Higher-order EF	Cambridge Gambling task	Proportion bet	Medium	1
Higher-order EF	Cambridge Gambling task	Risk adjustment	High	3
Higher-order EF	Cambridge Gambling task	Risk adjustment	Medium	1
Higher-order EF	Cambridge Gambling task	Risk taking	Medium	1
Higher-order EF	Child version of the Ultimatum Game (UG)	Emotional decision making	Medium	1
Higher-order EF	D-KEFS Tower Test	Total achievement scaled score	Low	2
Higher-order EF	Game of Dice Task	Net score	High	1
Higher-order EF	Groton Maze Learning Task	Completion time	Low	1
Higher-order EF	Iowa Gambling task	Advantageous Deck Picks	High	1
Higher-order EF	Iowa Gambling task	Net score	High	18
Higher-order EF	Iowa Gambling task	Number of risky picks	High	4
Higher-order EF	Iowa Gambling task	Ratio good/bad deck	High	4
Higher-order EF	Iowa Gambling task	Risk cards percentage	High	8
Higher-order EF	Iowa Gambling task	Total punctuation	High	8
Higher-order EF	One Touch Stocking of Cambridge	Mean choices to correct	Low	2
Higher-order EF	One Touch Stocking of Cambridge	Problems solved on first choice	Low	2
Higher-order EF	Porteus Maze test	Number of mazes completed	Low	4
Higher-order EF	Porteus Maze test	Qualitative error score	Low	2
Higher-order EF	Porteus Maze test	Total number of errors	Low	2
Higher-order EF	Pyramid of Mexico	Design with the fewest possible moves	Low	1
Higher-order EF	Pyramid of Mexico	Number of moves	Low	1
Higher-order EF	Pyramid of Mexico	Total no of solved problems	Low	3
Higher-order EF	Risky Choice Task	Mean number of points	High	1
Higher-order EF	Stockings of Cambridge	Average moves	Low	14
Higher-order EF	Stockings of Cambridge	Initial thinking time	Low	4
Higher-order EF	Stockings of Cambridge	Problems solved in minimum moves	Low	21
Higher-order EF	Stockings of Cambridge	Subsequent thinking time	Low	4
Higher-order EF	Tower of Hanoi	Completion time	Low	15
Higher-order EF	Tower of Hanoi	Error steps	Low	3
Higher-order EF	Tower of Hanoi	Movements	Low	8
Higher-order EF	Tower of Hanoi	Points obtained	Low	1
Higher-order EF	Tower of Hanoi	Steps needed to complete	Low	5
Higher-order EF	Tower of London	Completion time	Low	7
Higher-order EF	Tower of London	Failed attempts	Low	9
Higher-order EF	Tower of London	Problems solved in minimum moves	Low	8
Higher-order EF	Tower of London	Total in excess of the minimum	Low	4
Higher-order EF	Tower of London	Total no of solved problems	Low	6
Higher-order EF	Tower of London	Tower of London	Low	1
Inhibition	Card Playing Task	Payoff	Low	2
Inhibition	Continuous performance test	Commission errors	High	37
Inhibition	Delay discounting task	Delay discounting k-values	High	6
Inhibition	Delay discounting task	SKIP longest delay	High	1
Inhibition	Delay discounting task	SKIP Shortest delay	High	1
Inhibition	Delay discounting task	TCIP Maximum consecutive delayed responses	High	1
Inhibition	Delay discounting task	TCIP Percent immediate responses	High	1
Inhibition	Delayed Gratification Task	Complied with rules	High	4
Inhibition	Delayed Gratification Task	Impulsive Choices	High	2
Inhibition	Delayed Gratification Task	Long-term Choices	High	2
Inhibition	Delayed Gratification Task	Payoff	High	2
Inhibition	FAB Conflicting information task	Total erroneous responses	Low	3
Inhibition	Go/No-Go	dPrime	High	5
Inhibition	Go/No-Go	Percentage correct no-go responses	High	33
Inhibition	Go/No-Go	Percentage errors of commission	High	43
Inhibition	Go/No-Go	Reaction time errors of commission	High	12
Inhibition	Go/No-Go	Reaction time errors of commission	Low	1
Inhibition	Go/No-Go	Total percentage correct	Low	2
Inhibition	Go/No-Go	Total reaction time	Low	3
Inhibition	Hayling test	Category B errors	Medium	2
Inhibition	Hayling test	Impairment	High	2
Inhibition	Hayling test	Overall performance	Medium	5
Inhibition	Honk Test	Change errors	Medium	2
Inhibition	Honk Test	Stop errors	High	2
Inhibition	Information Sampling Task	Total correct	High	8
Inhibition	Intra/Extradimensional shift	Stages completed	Medium	1
Inhibition	Negative priming	Negative priming ratio	High	1
Inhibition	NEPSY-2 Inhibition	Inhibition	Medium	1
Inhibition	Shape School task	Total percentage correct	Medium	4
Inhibition	Simon task	Errors (Incongruent)	Medium	8
Inhibition	Simon task	Interference score	High	12
Inhibition	Simon task	RT card III	Medium	6
Inhibition	StopSignal task	% errors	Low	3
Inhibition	StopSignal task	% errors	Medium	1
Inhibition	StopSignal task	Errors (Incongruent)	Medium	1
Inhibition	StopSignal task	Proportion successful stops	Medium	3
Inhibition	StopSignal task	SSRT	High	22

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Appendix 4 (*continued*)

Executive Function	Neuropsychological test	Outcome Measure	Quality	Freq
Inhibition	StopSignal task	Stop latency	Low	1
Inhibition	StopSignal task	Stop latency	Medium	5
Inhibition	Stroop Test	Errors	Medium	8
Inhibition	Stroop Test	Errors (incongruent)	Medium	44
Inhibition	Stroop Test	Interference score	High	52
Inhibition	Stroop Test	RT (incongruent)	Medium	48
Inhibition	Stroop Test	Time	Medium	8
Inhibition	Stroop Test	Total	Medium	8
Shifting	Intra/Extradimensional shift	EDS errors	High	10
Shifting	Intra/Extradimensional shift	Pre-ED errors	Medium	9
Shifting	Intra/Extradimensional shift	Reversal errors	Medium	1
Shifting	Intra/Extradimensional shift	Stages completed	Medium	10
Shifting	Intra/Extradimensional shift	Total errors	Low	2
Shifting	Intra/Extradimensional shift	Total errors adjusted	Medium	6
Shifting	Local-Global	Interference score	High	1
Shifting	NEPSY-2 Design Fluency	Cognitive flexibility	Medium	1
Shifting	NEPSY-2 Inhibition	Switching	Medium	1
Shifting	Number Letter switch	Overall performance	High	2
Shifting	Number Letter switch	Switch cost	High	4
Shifting	Object alternation test (OAT)/delayed alternation test (DAT)	% correct responses	High	4
Shifting	Object alternation test (OAT)/delayed alternation test (DAT)	Number of errors	Low	2
Shifting	Response Reversal task	Number of errors	High	2
Shifting	Reversal learning task	Error switch	Medium	2
Shifting	Reversal learning task	Number of stages completed	Low	2
Shifting	Shifting attention set task	SWitch cost	High	2
Shifting	Switch Task	% correct responses	Low	3
Shifting	Switch Task	Correct rejections	Medium	1
Shifting	Switch Task	Error switch	Medium	2
Shifting	Switch Task	RT shift	High	1
Shifting	Switch Task	RT shift	Medium	3
Shifting	Switch Task	Switch cost	High	16
Shifting	Switch Task	Switch cost	Low	1
Shifting	Trail Making Test	TMT B	Medium	3
Shifting	Trail Making Test	TMT B-A	High	11
Shifting	Trail Making Test	TMT-B	Medium	40
Shifting	Trail Making Test	TMT-B - A	High	8
Shifting	Wisconsin Card Sorting Task	% correct responses	Low	4
Shifting	Wisconsin Card Sorting Task	Categories completed	Low	35
Shifting	Wisconsin Card Sorting Task	Completion time	Low	9
Shifting	Wisconsin Card Sorting Task	Conceptual responses	Low	5
Shifting	Wisconsin Card Sorting Task	Criteria perseverations	High	1
Shifting	Wisconsin Card Sorting Task	Failure to maintain set	High	7
Shifting	Wisconsin Card Sorting Task	global score	High	1
Shifting	Wisconsin Card Sorting Task	Hits	High	8
Shifting	Wisconsin Card Sorting Task	Overal result	High	1
Shifting	Wisconsin Card Sorting Task	Overall performance	High	1
Shifting	Wisconsin Card Sorting Task	Perseverartive errors	High	44
Shifting	Wisconsin Card Sorting Task	Perseverations	High	8
Shifting	Wisconsin Card Sorting Task	Perseverative responses	Medium	21
Shifting	Wisconsin Card Sorting Task	Switch cost	High	2
Shifting	Wisconsin Card Sorting Task	Total correct	Low	4
Shifting	Wisconsin Card Sorting Task	Total errors	Low	35
Shifting	Wisconsin Card Sorting Task	Total trials	Low	2
Shifting	Wisconsin Card Sorting Task	Trials to complete 1st category	Low	2
Updating	Letter Memory Task	Correct recalls	High	4
Updating	Spatial N-back	Accuracy	High	7
Updating	Spatial N-back	dPrime	High	1
Updating	Spatial N-back	RT 2-back	Medium	1
Updating	Two Back Task, TWOB	Accuracy	High	1
Updating	Verbal n-back	Accuracy	High	6
Updating	Verbal n-back	RT 2-back	Medium	4
Updating	Verbal n-back	Total accuracy	Medium	2
Updating	Verbal n-back	Updating cost	High	3
Working Memory	Affective self-ordered pointing task	Errors	High	2
Working Memory	BANFE subtraction task	Completion time	Medium	2
Working Memory	BANFE subtraction task	Overall performance	Medium	2
Working Memory	BANFE visual working memory task	Completion time	Medium	1
Working Memory	BANFE visual working memory task	Overall performance	Medium	1
Working Memory	BANFE visual working memory task	Perseverartive errors	Medium	1
Working Memory	BANFE Visuospatial WM	Level	Medium	8
Working Memory	BANFE visuospatial working memory task	Level	Medium	1
Working Memory	BANFE visuospatial working memory task	Order error	Medium	1
Working Memory	BANFE visuospatial working memory task	Perseverartive errors	Medium	1
Working Memory	CANTAB Spatial Span	SSP Length	High	12
Working Memory	CANTAB Spatial Span	SSP Length	Medium	1
Working Memory	Continuous performance test	Commission errors	High	1

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Appendix 4 (*continued*)

Executive Function	Neuropsychological test	Outcome Measure	Quality	Freq
Working Memory	Delayed match to sample	Accuracy	High	14
Working Memory	Digit span Backward	Digit span backwards	High	3
Working Memory	Digit span Backward	Digit span backwards	Medium	30
Working Memory	Digit span overall	Digit span overall	Low	10
Working Memory	Letter Number Sequencing (LNS)	LNS score	High	1
Working Memory	Memory Span task	Accuracy	High	9
Working Memory	Memory Span task	Accuracy	Medium	2
Working Memory	Memory Span task	Digit span	High	5
Working Memory	Memory Span task	Digit span (WISC) + Corsi Block test	Medium	2
Working Memory	Memory Span task	SSP Length	High	17
Working Memory	Memory Span task	SSP Length	Medium	1
Working Memory	Memory Span task	Strategy	High	4
Working Memory	Memory Span task	SWM between errors 4-8 boxes	Medium	8
Working Memory	NEPSY-2 Word List Interference	Interference score	Medium	1
Working Memory	Self-ordered pointing task	Errors	High	1
Working Memory	Spatial Executive function task	Accuracy	High	4
Working Memory	spatial recognition task	Accuracy	Medium	2
Working Memory	Spatial working memory	Errors	High	1
Working Memory	Spatial working memory	SSP Length	High	1
Working Memory	Spatial working memory	Strategy	High	16
Working Memory	Spatial working memory	SWM between errors 4-8 boxes	Medium	4
Working Memory	Spatial working memory	Total errors	Low	1
Working Memory	Spatial working memory	Total errors 4-8 boxes	High	16
Working Memory	Verbal Executive function task	Accuracy	High	4

Appendix C. Appendix 5:

C.1. Newcastle – Ottawa quality assessment scale case control studies

Note: A study can be awarded a maximum of one star for each numbered item within the Selection and Exposure categories. A maximum of two stars can be given for Comparability.

Selection

1) Is the case definition adequate?

a) yes, from judicial registration data or diagnosis ✸

b) no description

2) Representativeness of the cases

a) consecutive or obviously representative series of cases ✸

b) potential for selection biases or not stated

3) Selection of Controls

a) community controls (or controls with matched diagnosis)✸

b) convenience sample

c) no description

4) Definition of Controls

a) no history of criminal behaviour or antisocial behaviour diagnosis ✸

b) no description of source

Comparability

1) Comparability of cases and controls on the basis of the design or analysis

a) study controls for diagnosis ✸ (for example; ADHD is characterised by significant impairments in executive functioning)

b) study controls for both age and gender ✸ (both known and reliable predictors of criminal behaviour / ASB diagnosis: Mean difference in age $\leq$ 5.0, percentage gender difference $<$5%).

Exposure

1) Ascertainment of exposure

a) secure record (eg judicial registration data, or diagnosis) ✸

b) Self report

c) No description

2) Same method of ascertainment for cases and controls

a) yes ✸

b) no

3) Non-Response rate

a) same rate for both groups ✸

b) non respondents described

c) rate different and no designation

Appendix D. Appendix 6

Meta-analytic results assessing differences between adult and youth samples.

D.1. Different executive functions

The three-level meta-analysis including the interaction between and main effects of age group (adults vs children) and executive function as moderators showed a significant interaction effect F(4,1234)=4.51 p=.001. Although none of the Bonferroni corrected pairwise comparisons revealed a significant interaction (see main manuscript section 3.4.1.), separate analysis per age group showed that executive function did not moderate the pooled effect sizes in children F(4, 709)=1.33 p=.26, but did in adults F(4,525)=6.19 p<.001. Bonferroni corrected pairwise comparisons indicated shifting (Δd=.24 p<.01) and updating (Δd=.77 p<.01) were more impaired than inhibition, and that updating was more impaired than higher-order EF (Δd=.68 p<.05).

D.2. Different neuropsychological tests

A three-level meta-analysis including neuropsychological test, age group (adult vs youth) and their interaction as moderators showed no significant interaction effect (F(22, 1108)=1.00 p=.46, or main effect of age group (F(1, 1130)=.49 p =.49). Neuropsychological test did moderate the pooled effect sizes (F(34, 1130)=2.07 p<.001), but these results are discussed in the main manuscript (section 3.4.2).

D.3. Hot vs cold executive functioning

A three-level meta-analysis including hot vs cold EF, age group (adult vs youth) and their interaction as moderators showed no significant interaction effect (F(1, 1240)=1.17 p=.46), or main effects of age group (F(1, 1241)=1.16 p =.28) or hot vs cold EF (F(1, 1241)=.49 p =.49).

D.4. Assessment quality

A three-level meta-analysis including assessment quality (high, medium, low), age group (adult vs. youth) and their interaction as moderators showed no significant interaction effect F(2, 1238)=.14 p=.87, nor main effects of assessment quality (F2, 1240)=.83 p=.44) and age group (F (1,1240)=1.14 p=.29).

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