Interference inhibition in offending and non-offending pedophiles: a preliminary event-related fMRI study

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Abstract

The ability to inhibit behavior is thought to be an import skill for avoiding criminal conduct, especially when combined with personal predispositions or criminogenic needs such as a pedophilic preference disorder. While previous research emphasized the relationship between impulsivity and child sexual offending, not pedophilia per se, studies on the underlying neurobiological mechanisms in subdomains of impulsivity remained scarce. Here, we focused on interference inhibition and examined event-related functional magnetic resonance imaging (fMRI) data of three groups of men performing a color-word Stroop task: (1) pedophiles with a history of CSO (P+CSO, n = 11), (2) pedophiles without a history of CSO (P-CSO, n = 8) and (3) non-pedophilic, non-offending healthy controls (HC, n = 10). On the behavioral level, P+CSO revealed increased Stroop interference as compared to P-CSO and HC. Moreover, increased Stroop interference in P+CSO was accompanied by enhanced conflict-related activity in left superior parietal cortex and precentral gyrus as compared to P-CSO. Albeit behavioral analyses of error and post-error processing revealed no significant between-group differences, P-CSO showed increased post-error-related activity in left posterior cingulate, precuneus and middle temporal gyrus as compared to P+CSO. Our preliminary data highlight inhibition deficits in offending as compared to non-offending pedophiles or healthy men and suggest that functional alterations in attention reallocation and impulse suppression/control may moderate the risk for committing CSO in men suffering from pedophilia.

Keywords: pedophilia, Stroop, fMRI, sexual preference

Introduction

According to the Diagnostic and Statistical Manual of Mental Disorders (DSM-5; American Psychiatric Association, 2013), pedophilia is defined as having arousing fantasies about or urges for or sexual behaviors towards prepubescent children. Other criteria include that the individual has to be at least 16 years of age and must be at least five years older than the respective child. Importantly, the current version 5 of the DSM makes a distinction between pedophilia and pedophilic disorder. The latter additionally requires that the individual has acted out the sexual desires or experiences significant distress as a result of these urges (American Psychiatric Association, 2013).

This distinction between pedophiles who do and do not offend against children is in line with research showing that only few men who have engaged in child sexual abuse are exclusively attracted to children (Eher et al., 2010; Gerwinn et al., 2018) and that the proportions of pedophiles who do sexually approach children is about 43% (Seto et al., 2006). However, the majority of previous research is based on populations expressing child sex offenses (CSO), thus combining pedophilic and non-pedophilic or even sex offender populations in general (for reviews see Joyal et al., 2014; Snowden et al., 2011). Similarly, a recent coordinate based meta-analysis across neuroimaging research in idiopathic CSO found no common neural substrate for sexual offenses against children when assessed across functional tasks and neuroimaging measures (Scarpazza et al., 2021). It has been argued that the combination of mixed subgroups of CSO with varying degrees of pedophilic or hebephilic preferences may be partially responsible for the heterogeneous result pattern (Blanchard et al., 2006). Therefore, during the last years, researchers started to face challenges in recruitment to assess distinct subgroups of pedophilic *vs.* non-pedophilic offenders *vs.* nonoffenders. When separating pedophilic and non-pedophilic CSO, Suchy et al. (2009) found that while both offender groups exhibited poorer executive function, conceptualised as composite scores on the Stroop task requiring a verbal response (Stroop, 1935), the Behavioural Dyscontrol Scale (Grigsby et al., 1992), and the Ruff Figural Fluency Test (Ruff, 1988), both offending groups expressed different profile scores. While non-pedophilic CSO had poorer semantic knowledge, pedophiles with CSO history expressed slower processing speed, but no deficits in semantic knowledge (Suchy et al., 2009). A follow-up investigation further revealed slower visual perception and poorer visual-motor integration, but no differences in motor speed, indicating a neurocognitive weakness in offending pedophiles (Suchy et al., 2014). Similarly, pedophilic CSO express a more planful response style when compared to CSO without a diagnosis of pedophila, while both offender types have poorer inhibition (Eastvold et al., 2011). Examining the inhibition ability further, Schiffer and Vonlaufen (2011) found hints for poorer response inhibition in pedophilic and non-pedophilic CSO, but stringent statistical thresholds indicated that this is only applicable to non-pedophilic CSO. Using the Stop Signal Task, Massau et al. (2017) compared inhibitory control abilities between pedophiles with and without CSO as well as CSO without pedophilia and non-offending healthy controls. They found a delayed inhibition process in CSO irrespective of a pedophilia diagnosis, indicating that slower response inhibition is associated with child sexual offending rather than pedophilia.

Additionally, former research also indicated divergencies in neuropsychological and neurobiological profiles between pedophiles who engaged or not engaged in hands-on offenses against children (e.g., Kärgel et al., 2017; Schiffer et al., 2017; Weidacker et al., 2018), pointing towards distinct cognitive and neurological profiles between these groups. The transgressions from pedophilic interests to offending against children is assumed to involve several stages or pathways (Cohen et al., 2002; Ward & Siegert, 2002). Cohen et al. (2002) for example, proposed an increasing risk for offending behavior in individuals who overcome basic social values, who express elevated levels of impulsivity, present with a lack of concern for the victims, and are subject to cognitive distortions. Of particular relevance might be the aspect of increased impulsivity levels, since increased impulsivity levels are associated with enhanced risk taking (e.g., Cyders et al., 2015), which potentially makes the transgression from having fantasies of sexual contacts with children towards acting on those fantasies more likely. However, impulsivity is a multi-facetted construct (e.g., Sharma et al., 2013), with inhibitory control being a core element of executive functioning and most commonly used as a means to test impulsivity (Baddeley, 1996; Miyake et al., 2000). Furthermore, inhibitory control itself is not a unitary concept, but is a behavioral result of strong relationships between the underlying processes of prepotent response inhibition, resistance to interference from distractors, and proactive interference (Friedman & Miyake, 2004). Research examining these subtypes of inhibitory abilities and differentiating pedophiles with and without CSO is limited and previous research has mainly focused on the inhibition of prepotent responses, typically assessed by variants of the Go/No-go task (e.g., Kärgel et al., 2017). Using the Go/No-go task, Kärgel et al. (2017) revealed increased activation in areas related to the cognitive control network, as well as enhanced inhibitory control in pedophiles without CSO as compared to pedophiles with CSO, further supporting the idea of distinct neurobiological and cognitive profiles between these pedophilic groups.

Another sub-domain of impulsivity is researched under the term interference processing (Friedman & Miyake, 2004) and has typically been assessed by Simon or Stroop-like tasks. In the standard color-word Stroop task, participants are asked to name the color of a written word while ignoring the meaning of the word. In this task, the non-relevant stimulus dimension (word meaning) interferes with the task-relevant stimulus dimension when they are incongruent (e.g. the word red written in blue ink), which commonly leads to increased response times and higher error rates. If the meaning of the word and its' color are congruent, then facilitation can occur, speeding up the naming of the color (e.g., Carter et al., 1995;

Joyal et al., 2007). A recent activation likelihood estimation (ALE) analysis on 46 Stroop task fMRI studies in healthy young adults identified the most commonly activated neural areas when comparing incongruent to congruent conditions as left dorsolateral prefrontal cortex (dlPFC), bilateral inferior frontal gyrus (IFG), right superior frontal gyrus (SFG), right anterior cingulate cortex (ACC), and the temporal cortex (Huang et al., 2020). When comparing violent offenders to non-offenders on the fMRI Stroop task, less activation in the left ACC, left inferior frontal cortex, bilateral pre/postcentral gyri and left superior temporal cortex was found for offenders during Stroop interference (Schiffer et al., 2014). The authors also reported aberrant error-processing in offending participants, as indicated by reduced neural activation of the left ACC, left inferior/middle frontal cortex, putamen, superior frontal cortex, right thalamus, bilateral postcentral gyrus, and right precentral gyrus (Schiffer et al., 2014).

To date, few investigations into pedophilia and/or CSO have utilized Stroop-like tasks. Joyal et al. (2014) conducted a meta-analysis on the five available behavioral studies to investigate the differences between CSO and sex offenders with adult victims. They found CSO outperforming sex offenders with exclusively adult victims, while performance was worse when compared to non-offending healthy controls. Even though previous research has adapted the standard Stroop task to reveal inherent biases in pedophilic participants related to their sexual interests (Ó Ciardha & Gormley, 2012), no behavioral or neurobiological data are available comparing pedophiles with and without a history of offenses against children on Stroop interference.

The current study addresses this lack of research and examined event-related functional magnetic resonance imaging (fMRI) data of three groups of men performing on a trial-by-trial version of a color-word Stroop task: (1) pedophiles with a history of CSO, (2) pedophiles without a history of CSO and (3) non-pedophilic, non-offending healthy controls.

Based on the literature, we expected offence-related rather than pedophilia-related between-group differences. More specifically, on the performance level, we firstly hypothesized that relative to both other groups, pedophiles with a history of CSO will show increased error interference, which is expected to impact both, response times as well as error-related processing. Secondly, we also expected that activation of brain areas associated with attentional or cognitive control as well as error processing will differ between offending and non-offending groups.

Method

Participants

The present study was assessed within the framework of a German multi-site research collaboration called "Neural Machanisms Underlying Pedophilia and Sexual Offending against Children" (NeMUP), including five collaborative research sites from the field of forensic psychiatry (Gerwinn et al., 2018). Data acquisition was applied in the context of a single site approach and all participants were assessed at the location of Bochum/Essen. Non-pedophilic controls were recruited from the community via flyers and advertisements in public institutions. Pedophilic participants were recruited via explicit online forums and the research groups' website as well as via the *Prevention Project Dunkelfeld* (Beier et al., 2009) and from correctional services in North Rhine-Westphalia, Germany.

In total, 32 males took part in the fMRI experiment, 22 of which met ICD-10 criteria for pedophilia. The sample was split into 10 controls (HC), 12 pedophilic participants with a history of child sexual abuse (P+CSO), and 10 pedophiles without a history of child sexual abuse (P-CSO). None of the participants received psychotropic medication. According to the German penal code, CSO was defined as involvement in at least one hands-on sexual offense against a child aged below 14 years old (i.e. 13 years or younger). In case of P+CSO participants recruited outside the juridical system, this information was based on self-report.

One participant of the P+CSO group was excluded from the analyses due to extensive motion artefacts during fMRI (> 4.5 mm), resulting in 11 participants in the P+CSO sample. Within the P-CSO group, one participant was excluded due to very slow responses in the paradigm (response times > 3 *SD* from the group mean) and a second participant because of scanner malfunction, resulting in eight participants in the P-CSO sample. The pedophilic samples consists of both, pedophiles known (*n* = 4 in P+CSO; Prison sentence: 48 to 84 months, *M* = 63, *SD* = 18) and unknown (*n* = 15) to the juridical system.

Assessments

Psychopathology. To assess Axis I and Axis II disorders, the complete semi-structured clinical interview of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR; Association, 2000) was used.

Sexual interests. The Kinsey scale for developmental stages (Kirk et al., 2000) was used in all participants to determine sexual orientation and age preference. In this regard, participants indicated their individual sexual age preferences (separately for boys and girls) utilizing photographs that differed in the grade of maturity and secondary sexual characteristics. Further, information regarding sexual interests and offense history was obtained via self-report in community dwelling participants. In respect to the imprisoned participants, criminal records were additionally obtained.

Intelligence. A brief version of the Wechsler Adult Intelligence Scale (WAIS-IV; Wechlser, 2008) was administered to estimate full scale intelligence (FSIQ) based on the Similarities, Vocabulary, Block Design and Matrix Reasoning subtests.

Stroop Task

Participants performed an event-related version of the color-word Stroop task, presenting the words red, green, blue, or yellow in either congruent or incongruent color against a black background. The participants were instructed to react to the color of the written word, not the word itself. Stimuli were presented for 1500 ms or until a button was pressed. A jittered fixation cross (1 to 2 sec, in steps of 50 ms) was used to separate the trials. The task was programmed using Presentation software (Neurobehavioral Systems, Inc) and participants interacted using an fMRI-compatible response pad with their dominant hand. The mapping between response pad and digits were as follows: Digitus Secundus Manus-red, Digitus Medius-green, Digitus Annularis-blue, Digitus Minimus Manus-yellow. Before the experimental task, participants practiced the task and the use of the response pad during the presentation of 60 trials. The experimental task consisted of 240 trials with 25% incongruent and 75% congruent trials. Each word and color were presented equally often across congruent and incongruent trials. Trial presentation was quasi-randomised, with the restriction of not showing the same word twice in a row.

Image acquisition and preprocessing

Images were obtained using a 3 Tesla Siemens Skyra scanner equipped with a 32-channel head coil. Structural volumes were acquired using the MPRAGE sequence (192 slices, 1 x 1 x 1 voxel size, TR = 2.5 sec, TE = 4.37 ms, FOV = 256 mm, flip angle = 7°, distance factor of 50%). BOLD images were acquired by applying echo planar imaging (TR = 2.4 sec, TE = 30 ms, FOV = 240 mm, flip angle = 80°, distance factor of 10%) using 38 transverse slices acquired interleaved, resulting in 2.3 x 2.3 x 3 mm voxel sizes. All fMRI analyses were carried out using SPM12 (Welcome Department of Cognitive Neuroscience, London, UK). Functional images were slice timing corrected, realigned, unwarped and normalised to the Montreal Neurological Institute (MNI) template. The normalised images were smoothed with an isotropic Gaussian kernel of 8 mm full width at half maximum.

Statistical Approach

Pearson Correlations were run between descriptive information (age and FSIQ estimates) and Stroop accuracy as well as response times. FSIQ correlated positively with the number of correct congruent trials ($r = .40$, $p < .05$). Age correlated negatively with the number of correct incongruent trials ($r = -.43$, $p < .05$), as well as positively with response times during congruent ($r = .70$, $p < .001$) and incongruent trials ($r = .68$, $p < .001$), as such, all analyses incorporated FSIQ and age to account for confounds within the ANCOVA design.

Behavioral. Performance was analysed using SPSS v25 and post hoc comparisons were deemed significant when they survived Bonferroni correction for multiple testing unless stated otherwise (p_{uc}). Separately for both, congruent (C) and incongruent (IC) condition, experimental trials were subdivided into correct, error, and missing events.

First, the Stroop interference effect on response times was analysed using a group (P+CSO, P-CSO, HC) by condition (IC *vs.* C) repeated-measures ANCOVA. Next, error processing was analysed using two separate group by condition repeated-measures ANCOVAs as above, defining response times related to error trials and number of errors as dependent variables. Third, to assess for post-error slowing in Stroop performance, trials were further subdivided into: errors, congruent trials preceded by congruent trials (*cC*), congruent trials preceded by incongruent trials (*iC*), incongruent trials preceded by congruent trials (*cI*), incongruent trials preceded by incongruent trials (*iI*), congruent trials preceded by an error (*peC*), and misses. *iI* trials where rare and we therefore restricted post-error analyses to C trials and conducted a repeated-measures ANCOVA with trial type (*cC vs. peC*) and group as factors.

Neuroimaging. All first level analyses included the six motion regressors from SPM's realign and unwarp. All second level models included age and FSIQ per participant as additional regressors of no interest.

For the first level analyses regarding Stroop interference and error processing, C, IC, errors, misses and post-error trials were included as regressors in the design matrix. Event-related responses were modelled with a duration of zero and convolved with the canonical hemodynamic response function (HRF). Respectively for interference and error processing, separate contrast images for IC > C and error trials > C were built, and then used for second level analyses to address condition effects.

To determine whether areas that are more active during Stroop interference (IC > C) are additionally associated with behavioral between-group differences regarding Stroop interference (response times: IC > C), a second level one-way ANCOVA was conducted on the interference contrast (IC > C) with group as between-subjects factor and response time differences between IC and C trials as additional regressor. To ensure that areas exclusively related to Stroop interference are analysed, only areas within a mask containing the one-sample *t*-test results on Stroop interference (IC > C, derived from an uncorrected height threshold of $p < .05$) were included. Independent-sample *t*-test were used to assess whether the correlations between neural and behavioral Stroop interference differ between groups.

The first level analyses on post-error slowing was based on the model including errors, *iC*, *cC*, *cI*, *iI*, misses and p*eC*. The contrast of interest, *peC* > *cC*, was subjected to one-sample and independent-sample *t*-tests on the second level.

Significance was assessed following family-wise error correction (p_{FWE}) at cluster level < .05 derived from an uncorrected height threshold of $p < .001$ unless specified otherwise. This is in line with previous research showing improved FWE control using $p < .001$ as cluster-defining threshold when compared to less stringent thresholds (Eklund et al., 2016). The performed independent-sample *t*-tests assumed unequal variances between the groups.

Results

Characteristics of Study Groups

Descriptive information and between-group comparisons on sample characteristics are shown in Table 1. The groups did not significantly differ on age, FSIQ estimates and handedness. The pedophilic groups were not different in the number of participants expressing an exclusive sexual interest in underage children. The P+CSO and P-CSO samples exposed a primary attraction towards prepubescent children, with one P+CSO participant being primarily attracted to adults and one P-CSO participant expressing mainly hebephilic interests. The pedophilic samples did not differ significantly in their preferred sexual age category. The prevalence of Axis I and II disorders was not statistical different between the groups, but both pedophilic groups presented with a somewhat higher prevalence when compared to HC.

Behavioral Results

Response Times: Stroop Interference. The repeated measures ANCOVA on the response times revealed a significant main effect of group ($F(2,24) = 4.14$, $p < .05$, $\eta_p^2 = .26$), age ($F(1,24) = 47.86$, $p < .001$, $\eta_p^2 = .67$), FSIQ ($F(1,24) = 16.54$, $p < .001$, $\eta_p^2 = .41$), and as hypothesized, a significant group by condition interaction ($F(2,24) = 8.30$, $p < .01$, $\eta_p^2 = .41$). The remaining effects were not significant (*p*s > .20). Post-hoc independent *t*-tests indicated enhanced interference (difference score between IC and C) in P+CSO ($M = 199.37$ ms, $SD = 69.09$ ms) compared to both P-CSO ($M = 80.18$ ms, $SD = 81.09$ ms; $t(17) = 3.45$, $p < .01$, $d = 1.60$) and HC ($M = 92.80$ ms, $SD = 46.25$ ms; $t(19) = 4.11$, $p < .001$, $d = 1.80$), see Figure 1.

Error processing: Response Times. Two P-CSO participants as well as one HC did not show any IC error trials and were therefore excluded from this analysis. The repeated measures ANCOVA on response times during error trials revealed a significant effect of age ($F(1,20) = 17.93$, $p < .001$, $\eta_p^2 = .47$) and FSIQ ($F(1,20) = 25.61$, $p < .001$, $\eta_p^2 = .56$), no other effects were significant (*p*s > .38).

Error processing: Number of Errors. The repeated measures ANCOVA on the number of errors revealed the hypothesized significant interaction between group and condition ($F(1,24) = 3.64$, $p < .05$, $\eta_p^2 = .23$), all remaining effects were not significant (*p*s > .07). Independent-sample *t*-tests on the difference score between the number of in/congruent errors revealed marginally higher error rates to IC than C trials in P+CSO when compared to HC ($t(19)=2.53$, $p_{uc} = .021$, $d = 1.11$), but this effect did not survive Bonferroni correction. All other comparisons were not significant (*p*s > .17).

Post-Error Slowing. One participant in the HC group had no correct C trials that were preceded by an error and was therefore not incorporated in this analysis. The repeated measures ANCOVA on post-error slowing in C trials revealed a significant main effect of group ($F(2,23) = 6.46$, $p < .01$, $\eta_p^2 = .36$), age ($F(1,23) = 41.23$, $p < .001$, $\eta_p^2 = .64$), FSIQ ($F(1,23)$ 18.12, $p < .001$, $\eta_p^2 = .44$), and interaction between group and condition ($F(2,23) = 3.68$, $p < .05$, $\eta_p^2 = .24$). Independent *t*-tests on the difference score (*peC* minus *cC* trials) revealed that P+CSO ($M = 90.17$ ms, $SD = 98.75$) showed increased post-error slowing compared to HC ($M = 4.09$ ms, $SD = 50.10$; $t(18) = 2.37$, $p_{uc} = .029$, $d = 1.07$), but this effect did not survive Bonferroni correction. The remaining between group comparisons involving P-CSO ($M = 54.60$ ms, $SD = 73.75$) were not significant (*p*s > .11).

Neuroimaging Results

Stroop Interference. Contrasting the main effect of condition (IC > C) revealed enhanced activation to IC trials in a wide-spread network involving superior, medial, and inferior frontal gyri, parietal lobe as well as insular regions (Table 2 provides detailed information on this). No regions expressed enhanced activation to C trials.

Between-group comparison in this contrast indicated significant differences in interference-related neural activation between pedophilic groups depending on offending status, with P+CSO expressing enhanced activation in the left superior parietal lobe (SPL) and precentral gyrus/supramarginal gyrus (SMG) when compared to P-CSO (see Table 2, Figure 2).

Neural Stroop Interference and behavioral performance.

To explore group differences in the correlations between neural and behavioral indices of Stroop interference, a one-way ANCOVA was conducted and revealed a significantly more positive correlation between Stroop interference response times and interference-related right angular gyrus activation in P+CSO compared to P-CSO (see Figure 3a; $p_{FWE\ Cluster} = .020$, $p_{FWE\ Peak} = .996$, MNI coordinates$_{x,y,z}$ 53 -59 29, $k_E = 58$, $T = 4.43$, $z = 3.68$). The reverse contrast did not reveal significant results. No significant differences were found between HC and any pedophilic groups.

To further delineate the between-group difference in the right angular gyrus activation, the 1st Eigenvariate was extracted from a 3 mm sphere around the peak coordinate of the significant cluster. Using Pearson correlation coefficients, this data were correlated with the Stroop interference response times of P-CSO and P+CSO. In this analysis one aberrant datapoint in P-CSO (Leverage > .49, Cook's distance > 3.72) was detected, which was removed from the following correlation results. P+CSO expressed a significant positive correlation ($r = .851$, $p < .001$) while P-CSO expressed a non-significant, negative correlation ($r = -.331$, $p = .47$) between Stroop interference response times and angular gyrus activation (see Figure 3b). Similarly, comparing the obtained correlation coefficients statistically by means of Fisher's r to z transform revealed a significantly larger correlation in P+CSO than in P-CSO ($z = 2.62$, $p = .009$).

Error processing. Comparing activation pattern between Error and C trials revealed enhanced activation for correct C trials in the right occipital and cerebellar region. Error-related activity (Error > C), was enhanced in the supplementary motor cortex/extending into the ACC, the anterior insula/extending into IFG, bilateral caudate/accumbens, MFG, precuneus/lingual gyrus and thalamic regions. Comparing the groups on error-related processing differences revealed enhanced activation for P+CSO compared to HC in right cerebellum and left angular gyrus (See Table 3, Figure 4).

Post Error Slowing. cC trials produced enhanced activation when compared to peC trials in the supplementary motor cortex (SMC), precentral gyri, SPL, caudate and putamen. The reverse contrast did not reveal significant activation differences. In terms of between-group differences on the post-error slowing contrast, peC > cC, P-CSO showed enhanced activation in the triangular part of the left IFG when compared to HC and enhanced activation in left posterior cingulate, precuneus and middle temporal gyrus when compared to P+CSO (See Table 4 and Figure 5). No significant activation differences were found between HC and P+CSO.

Discussion

This is the first fMRI investigation into color-word Stroop performance that differentiates between pedophiles with and without a history of hands-on offenses against children as well as community controls. Such simple "neural" tasks often serve in neuroscience as a model of certain psychobiological mechanisms or cognitive processes. This is based on the assumption that the same mechanisms also underlie real life processes or decisions, in this case ongoing decision processes that are complicated by incongruent information.

We found behavioral differences between groups, with stringent statistical thresholds applied. P+CSO expressed enhanced Stroop interference, which was revealed by increased response times compared to P-CSO as well as HC. Error response times did not differ between groups and in terms of error proportion, P+CSO expressed more errors to IC targets when compared to HC, but not following correction for multiple comparisons. Similarly, post-error slowing (PES) was enhanced in P+CSO when compared to HC, but this effect also did not survive multiple comparison correction. In sum, the behavioral effects point towards slower processing speed in P+CSO with respect to IC trials, where the automatic word reading has to be inhibited. Importantly, P-CSO did not present with the same processing deficit as P+CSO, but instead were less affected by interference than P+CSO.

Previous research on inhibitory ability in pedophilia using a variant of the color-word Stroop task found that individuals with a history of CSO have inhibition deficits regardless of the presence of pedophilia (Eastvold et al., 2011). However, using more stringent statistical thresholds Schiffer and Vonlaufen (2011) found inhibition deficits, in terms of enhanced Go/No-go errors in P-CSO but not in CSO co-presenting with pedophilia. Similarly, when using the Stop Signal Task to index inhibitory control ability, performance was lower for CSO regardless whether pedophilic interests were manifested or not (Massau et al., 2017). In a sexual-pictorial Go/No-go task, CSO were also found to have higher rates of commission errors than non-offending controls, regardless of the tanner picture content (Turner et al., 2018). With an exception regarding Massau et al. (2017), all of these investigations differ to the current investigation in such that pedophiles without a history of sexual offenses were not assessed. When differentiating between pedophiles with and without CSO in the standard Go/No-go task, Kärgel et al. (2017) found P-CSO to have better response inhibition than P+CSO while both did not differ from HC. The current behavioral findings reveal a similar picture, with P+CSO expressing deficits in interference inhibition, but compared to both, P-CSO and HC. As such, even within participants expressing pedophilic interests, inhibitory deficits appear dependent on whether participants have a history of child sexual offenses, with P+CSO presenting with inhibitory control deficits in the color-word Stroop task. This difference between P- and P+CSO is in line with real-world behavioural differences in the ability to inhibit the urge to act on their sexual impulses, as the case for P-CSO, or failing to do so, as in the case for P+CSO. Hence, this reduced inhibitory ability might be independent of pedophilic interests and instead a feature of sexual offenders against children (Massau et al., 2017; Turner & Rettenberger, 2020). We therefore suggest to not only differentiate between pedophiles with and without an offense history, but to additionally control for pedophilic interests when studying CSO and inhibitory processes. Similarly, the type of CSO might be of relevance when studying inhibitory ability, with Rosburg et al. (2021) showing that contact (pedophilia diagnosis required) and non-contact (e.g. offenses confined to child pornography; no diagnosis of pedophilic disorder was required) child sexual offenders differ in Stroop performance with contact CSO experiencing more interference.

In addition to performance indices of aberrant interference inhibition, task-based fMRI was able to differentiate the pedophilic groups. The behavioral effect of increased Stroop interference in P+CSO was accompanied by hyperactivation in the left SPL and precentral gyrus/SMG when compared to P-CSO. Both areas, SPL and SMG, have previously been shown to react with increased activation in Stroop and Flanker tasks when contrasting IC with C trials (Krönke et al., 2018; Siemann et al., 2018) as well as in number-size congruity tasks, where either the numerical magnitude or the physical size of two numbers have to be suppressed (Kaufmann et al., 2006). Increased activation in these areas might underly attention shifts between stimulus dimensions. For example, Heinen et al. (2017) showed that the SMG receives information from frontal areas indicating the need to shift the current focus of attention to a new target, thereby suppressing the information within the current focus of attention (Heinen et al., 2017). Similarly, the SPL is involved in shifting attention across perceptual domains, as evidenced by near identical activation patterns when shifting attention between colored overlays or spatial locations (Greenberg et al., 2010).

As such the enhanced involvement of SPL and SMG in IC *vs.* C trials likely reflects the increased effort needed to shift attention away from the dominant, but goal-irrelevant tendency, i.e., reading the word, towards the goal-relevant process, naming the color of the written word (Siemann et al., 2018). That these areas express stronger activation in P+CSO than P-CSO therefore indicates potential difficulties in offending pedophiles to reallocate attention away from dominant tendencies, here reading the printed word, towards the task-relevant stimulus attribute.

These results thus indicate, that higher interference susceptibility of the perpetrators (the finding is a purely perpetrator-associated one, not a pedophilia-associated one) may be relevant in the context of child sexual abuse. Unlike e.g. criminal psychopaths, who show, in the sense of the response modulation hypothesis (external information can be "better" blanked out, ignored), a low interference susceptibility (Zeier et al., 2009), P+CSO show a higher interference susceptibility in the Stroop task. Psychopaths probably differ from P+CSO in that the latter often have scruples about committing abusive crimes. This is also not inconsistent with an outwardly appearing predatory modus operandi. It may rather reflect a lack or impeded volitional ability to distance oneself from a strong pedo-sexual desire and to avoid opportunities to commit crimes or to avoid initiating respective situations. In other words, the more pronounced the interference vulnerability is, the more difficult it would be to distance oneself from frequent deviant sexual impulses and the more likely it would be that CSO offenses occur. In this respect, the finding may also have legal implications if replicated in larger samples, since a pathologically increased tendency to interference could be associated with a reduction in culpability, at least according to German criminal law. However, we would like to highlight that behavioural inhibition tasks in general, are not necessarily an indication for typical behaviour. As outlined by Wennerhold, Friese and Vazire (2020) assessing typical behaviour might benefit from repeated assessments of the same construct to create a reliable index of typical performance. With respect to interference resolution, a composite score derived from well-validated, albeit domain-specific, interference tasks (such as the color-word Stroop task, the for pedophilic participants adapted pictorial Stroop task, the Flanker task) and self-report measures relating to self-control could be beneficial in assessing a persons central tendency towards interference resolution across contexts.

Additionally, we also assessed whether the enhanced behavioral interference is reflected in distinctive neural correlation patterns between groups and found a strong positive correlation between enhanced interference and right angular gyrus activation in P+CSO only, following corrections for multiple comparisons. The right angular gyrus responds with enhanced activation to IC *vs.* C information as in the current and previous investigations (Siemann et al., 2018). In this line and according to a meta-analysis by Zhang et al. (2017), the angular gyrus is also active when actions are to be withheld and plays an additional role in memory-guided attention processes (for a review of the proposed functions of the angular gyrus see Seghier, 2013). For example, right angular gyrus activation is particularly prominent in switching compared to repeating trials and previous research suggests that activation in this region relates to updating attentional processes with information about subsequent trial type similarity (Taylor et al., 2011). In the current Stroop paradigm, the majority of trials were congruent and therefore the majority of IC trials were switch trials, i.e. the majority of IC trials was preceded by C trials. While the potential interpretations of the significantly larger correlation between behavioral Stroop interference and angular gyrus activation in P+CSO *vs.* P-CSO are manifold, we suggest that P+CSO, who also experienced larger behavioral interference, show enhanced recruitment of angular gyrus activation due to increased difficulty with processing IC information. However, whether this is due to the salience/rarity of IC trials, or the increased necessity for updating memory due to more switching between trial types should be investigated by future research, for example by reversing trial contingencies as done in Mitchell (2010) or by manipulating the number of subsequent IC trials experimentally.

Error performance did not differ statistically between the groups, contrary to the associated neural activation patterns. During error trials, P+CSO expressed hyperactivation compared to HC in the cerebellum, as well as in the left angular gyrus, contralateral to where we found a stronger positive correlation in P+CSO than in P-CSO with behavioral Stroop interference. While the proposed role of the right-hemispheric angular gyrus relates to interference, the left-hemispheric counterpart is more involved in semantic processing, but is also part of the default mode network (Price, 2012; Seghier, 2013). In terms of the Stop Signal Task, where the prepotent motor response has to be inhibited instead of the dominant process of color reading as in the Stroop task, the left angular gyrus increases activity when preparing and executing a fast motor response (Wang et al., 2018) and decreases activity when anticipating stop signals (Hu et al., 2016). The additionally enhanced activation within the right cerebellum in P+CSO fell mainly into Crus 1 (Diedrichsen et al., 2009). Previous research investigating cerebellar function via a multi-domain task battery (MDTB) found our cerebellar region to be activated by predominantly word comprehension and divided attention as well as general language processing (see King et al., 2019 for the functional MDTB atlas). Taken together, the increased cerebellar activation in P+CSO during color-word Stroop error trials might indicate enhanced word reading during error compared to correct C trials. Enhanced word reading should in turn be mostly leading to erroneous responses to IC trials, where word reading is negatively related to the associated correct response. In line with this, we found marginally higher error rates to IC than C trials in P+CSO compared to HC.

In terms of PES, we found neural differences to be driven by the P-CSO group, with P-CSO expressing enhanced left IFG activity compared to HC and enhanced left-hemispheric posterior cingulate, precuneus, and middle temporal gyrus when compared to P+CSO. Kärgel et al. (2017) investigated PES during a response inhibition task while differentiating between pedophiles with and without an offense history against children and found no differences between HC, P+CSO and P-CSO on behavioral or neural indices. PES is usually enhanced following unconscious, but not necessarily conscious errors (Hester et al., 2005), and its' magnitude differs between tasks, with comparable magnitudes of PES in Go/No-go and Stroop tasks, both being larger than for Flanker tasks (Riesel et al., 2013). However, Riesel et al. (2013) also compared neural indices of error processing by means of two event-related potentials (ERPs) commonly evoked by error processing, and both ERPs differentiated between whether the errors were performed during Go/No-go or Stroop tasks, indicating task-specific variations in error processing and potentially associated PES. In our investigation, P-CSO expressed increased left IFG activity compared to HC. Previously, patients suffering from left-hemispheric IFG damage were found to perform more errors in Go/No-go tasks, especially at high difficulty requiring more inhibitory control (Swick et al., 2008). Compared to P+CSO, P-CSO expressed enhanced activation in areas commonly ascribed to the default mode network and deemed relevant for self-referential processing (Buckner et al., 2008; Busler et al., 2019; Cavanna & Trimble, 2006; Fransson & Marrelec, 2008), such as the posterior cingulate, precuneus and middle temporal gyrus. While it would be tempting to assume that the pedophilic group differs from HC in terms of PES due to failures in conscious awareness of the error occurrence or that P+CSO differs from P-CSO in terms of self-referential processing, studies directly comparing offending and non-offending pedophiles on error awareness or tasks assessing self-referential processing are missing. Of note, the aforementioned study by Kärgel et al. (2017) also found hypoactivity in the left posterior cingulate in P+CSO compared to P-CSO when comparing successful No-go to Go trials. Similarly, a recent meta-analysis by Deming and Koenigs (2020) found enhanced activation in the three areas reported here to correlate with psychopathy scores across a variety of tasks. As such the here reported hypoactivity in P+CSO compared to P-CSO might reflect additionally unassessed (but maybe offender-characteristic) personality features or in case of the left posterior cingulate cortex, a more general, potentially task-independent, neural difference between offending and non-offending pedophiles.

This investigation is not without limitations. First of all, differentiating offending from non-offending pedophiles resulted in small sample sizes per group. Similarly, while both pedophilic groups expressed their main sexual interest to be mostly pedophilic in nature, exclusiveness of this sexual interest was lower, with additional sexual interest in pubescent or adult partners. With regards to the fMRI analyses, as in most published fMRI studies, small to moderate condition-related between group effects were deemed significant at an uncorrected height threshold of $p < .001$, which, however, in combination with a small sample size may be prone to lead to false positive results. In order to mitigate the risk of an inflating type-I error, we additionally implemented a cluster-level correction with $p_{FWEc} < .05$.

The present approach provides first evidence of neurobiological differences between pedophiles with and without a history of CSO during interference processing that, however, need to be replicated, ideally with larger samples. To enhance the credibility of the results, effects of age and intelligence levels were accounted for by for example recruiting a matched HC group and incorporating these variables into the statistical design. We further utilized the standard Stroop paradigm where the minority of trials are IC. Future research should therefore investigate whether the here reported aberrant IC processing in P+CSO is due to salience/rarity of these trials or due to difficulties with switching between trial types.

Taken together, here we investigated the standard color-word Stroop task in pedophiles with and without CSO to assess cognitive processes that are complicated by incongruent information. The neural and behavioral main findings of the present study indicate first evidence of increased interference susceptibility in pedophiles with a history of CSO, which may reflect impeded volitional ability to distance oneself from a strong pedo-sexual desire and to avoid initiating opportunities to commit crimes. In this respect, these preliminary findings may also have legal implications (at least in the German jurisdiction), if replicated in larger samples.

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Figure Legends

Figure 1. Bar graphs of the Stroop Interference response times (RT) in ms, corresponding standard errors (*SE*) and significance level of group differences. P+CSO = pedophiles with a history of offenses against children, P-CSO = pedophiles without a history of child sexual offenses, HC = healthy controls. * indicates significance at $p < .01$ and ** at $p < .001$

Figure 2. Significant clusters differentiating P+CSO and P-CSO during Stroop interference (Incongruent > Congruent, only correct trials). P+CSO = pedophiles with a history of child sexual abuse, P-CSO = pedophiles without a history of child sexual abuse. SMG = supramarginal gyrus, SPL = superior parietal lobe. See Table 2 for the associated statistics. Colour coding represents the significance based on *T*-values.

Figure 3. Neural activation that correlates with response time differences (IC minus C) and is within areas that were active during IC > C (= inclusive mask based on .05 uncorrected) and significantly differentiates (uncorrected .001) between P+CSO and P-CSO. A: Shown is the significantly more positive correlation between response time differences and angular gyrus activation (during IC > C) in P+CSO when compared to P-CSO. Colour coding represents the significance based on *T*-values. B: the respective correlations of P+CSO (white dots; $r = .851$, $p < .001$) and P-CSO (grey diamonds; $r = -.331$, $p = .47$) are plotted by extracting the first eigenvariate from a 3 mm sphere around the peak coordinate of the significant angular gyrus cluster and the response time differences. P+CSO = pedophiles with a history of child sexual abuse, P-CSO = pedophiles without a history of child sexual abuse, IC = incongruent, C = congruent.

Figure 4. Significant clusters differentiating P+CSO and HC during Error processing (Errors > correct Congruent). P+CSO = pedophiles with a history of child sexual abuse, HC = healthy controls, E = errors, C = congruent. See Table 3 for the associated statistics. Colour coding represents the significance based on *T*-values.

Figure 5. Significant clusters differentiating the groups during post-error slowing (correct congruent trials preceded by an error [peC] > correct Congruent preceded by correct Congruent [CC]). P-CSO = pedophiles without a history of child sexual abuse, P+CSO = pedophiles with a history of child sexual abuse, HC = healthy controls, IFG = inferior frontal gyrus, MTG = middle temporal gyrus. See Table 4 for the associated statistics. Colour coding represents the significance based on *T*-values.

Figure 1

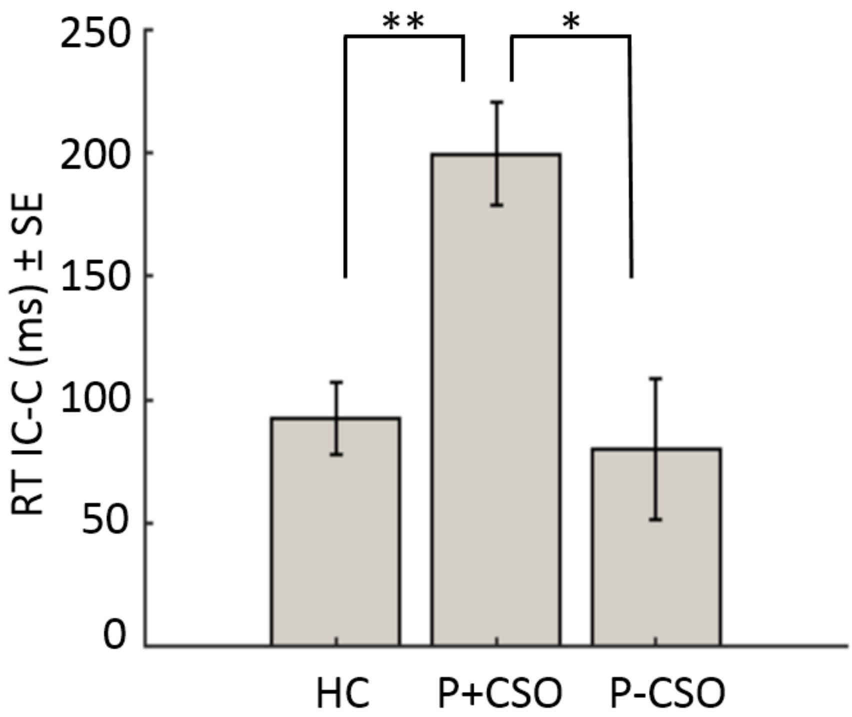

Figure 2

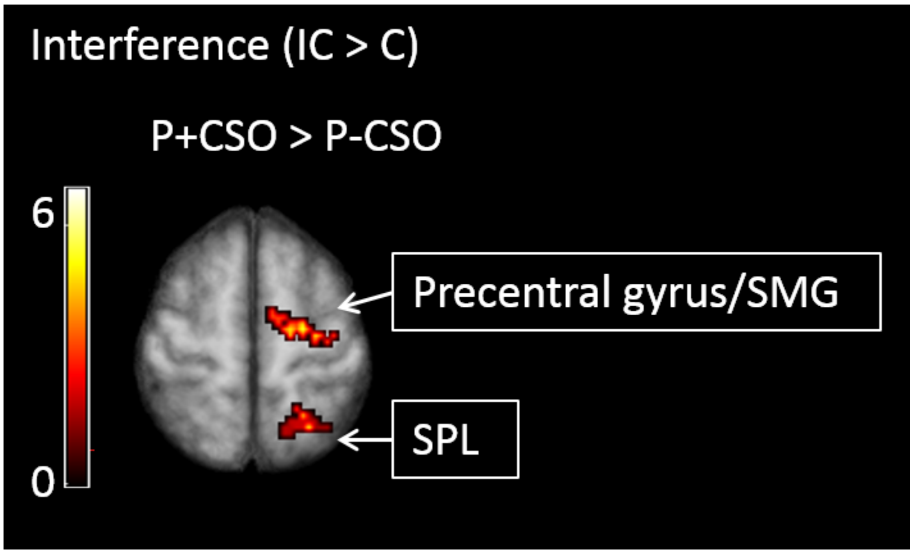

Figure 3

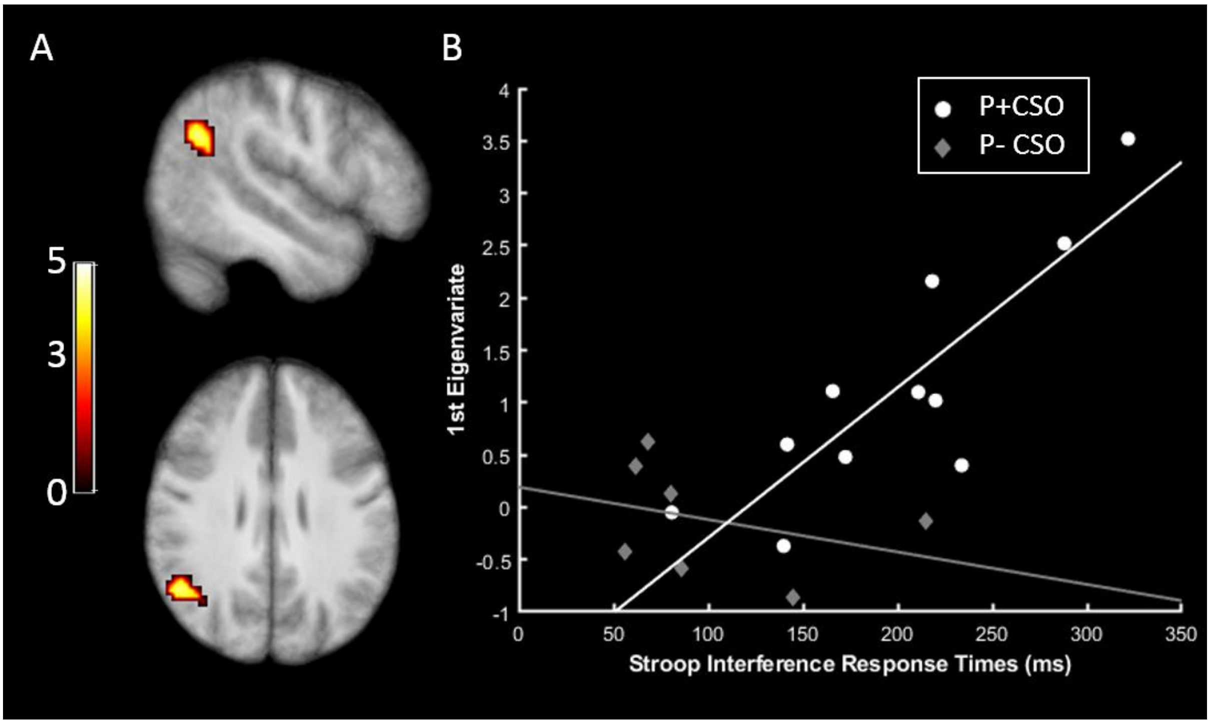
A
B
5
3
0
P+CSO
P- CSO
1st Eigenvariate
Stroop Interference Response Times (ms)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
50
100
150
200
250
300
350

Figure 4

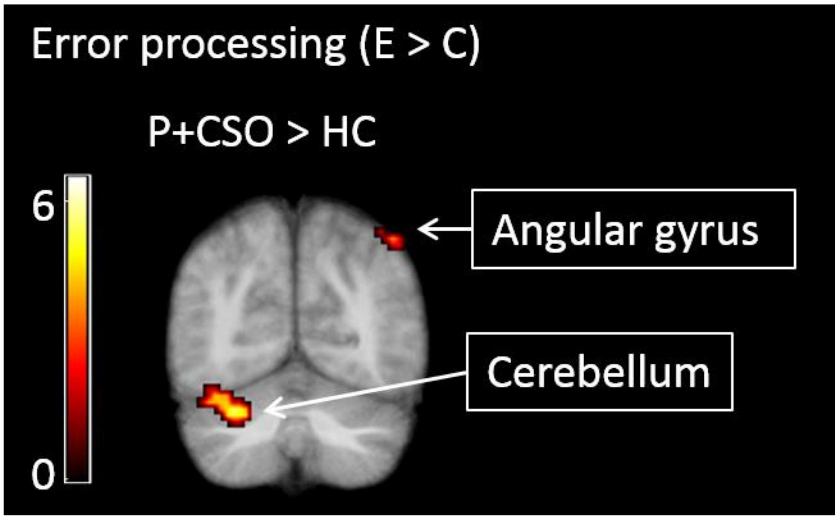

Figure 5

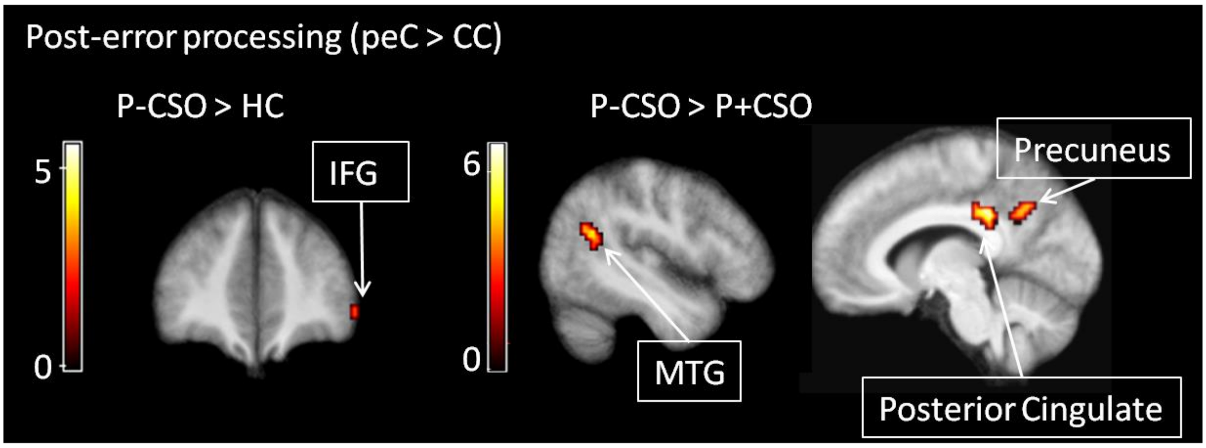
Post-error processing (peC > CC)
P-CSO > HC
P-CSO > P+CSO
5
0
IFG
6
0
MTG
Precuneus
Posterior Cingulate

Table 1. *Sociodemographic and clinical background per study sample*

Measures	**HC (N = 10)**	**P+CSO (N = 11)**	**P-CSO (N = 8)**	**Statistics**
Age (*M* ± *SD*)	37.70 ± 13.12	43.55 ± 11.58	33.25 ± 10.79	($F(2, 28) = 1.77$, $p = .19$)
Handedness (left/right)	1/9	0/11	1/7	$\chi^2(2, N = 29) = 1.36$, $p = .51$
FSIQ (*M* ± *SD*)	108.99± 22.03	101.73 ± 23.58	99.88 ± 17.36	($F(2, 28) = .47$, $p = .63$)
Main sex interest:				
Pedophilic	0%	90.9%	87.5%	[a]FET $p = .68$
Hebephilic	0%	0%	12.5%	
Teleiophilic	100%	9.1%	0%	
Exclusiveness	100%	54.5%	37.5%	[a]($F(1, 18) = .50$, $p = .49$)
Axis II disorder (present)	0%	36.4 %	37.5%	FET *p*s > .08
Axis I disorder (present)	22.2%	72.7%	75%	FET *p*s > .06

Note. Reported statistics are based on individual one-way ANOVAs with group as between-subjects factor and the χ^2 tests or Fisher's exact tests (FET) when appropriate. [a] Here comparisons were made between pedophilic groups only. FSIQ = full scale intelligence quotients, P+CSO = pedophilic participants with a history of child sexual abuse, P-CSO = pedophilic participants without a history of child sexual abuse, HC = healthy controls. *M* = mean; *SD* = standard deviation, Main sex interest = peak sexual preference ratings measured by the Kinsey scales. For one participant in HC, no Axis I and II disorder information was obtained, as such the reported % of disorders for HC is based on 9 participants. Axis 1 disorders within the P+CSO group were panic disorder, major depression, social phobia, alcohol abuse and dependence and cannabis dependence. The Axis 2 disorders included personality disorder not otherwise specified, avoidant personality disorder, antisocial personality disorder and borderline personality disorder. In the P-CSO group, the Axis 1 disorders were social phobia, major depression, cannabis dependence and panic disorder. Axis 2 disorders included dependent personality disorder, narcissistic personality disorder and avoidant personality disorder. For the HC group, Axis 1 disorders contained major depression and specific phobias. None of the HC fulfilled criteria for Axis 2 disorders. Of note, several Axis 1 and 2 disorders were present within the same participants.

Table 2. Brain regions expressing significant interference-related activity ($k_E \geq 5$): Incongruent (IC) compared to Congruent (C)

Contrast	Cluster number	Hemisphere	Location	p_{FWE} Cluster	p_{FWE} peak	MNI coordinates (x, y, z)	*z*	k_E	*T*
One-sample *t*-tests									
IC > C*	1	l.	Medial SFG	< .001	< .001	-3 25 41	5.83	26	8.51
	2	l.	SPL	< .001	< .001	-28 -50 44	5.83	203	8.50
	3	l.	IFG	< .001	< .001	-45 8 23	5.73	229	8.25
	4	r.	SPL	< .001	.001	30 -62 50	5.59	43	7.90
	5	r.	MFG	< .001	.001	58 20 32	5.57	49	7.85
	6	r.	MFG	.001	.003	47 8 50	5.39	5	7.42
	7	r.	Precentral gyrus	.001	.005	36 -3 62	5.33	5	7.28
	8	r.	Anterior insula	< .001	.005	33 17 2	5.31	6	7.25
	9	r.	Precuneus	< .001	.005	5 -70 41	5.30	16	7.22
	10	r.	IFG	< .001	.006	53 20 5	5.27	9	7.15
	11	l.	MFG	< .001	.007	-45 36 17	5.26	6	7.12

	12	l.	MFG	< .001	.010	-45 50 -1	5.19	13	6.98
	13	r.	IFG	< .001	.010	42 25 -10	5.18	6	6.95
C > IC*	-								
Significant independent-sample *t*-tests on IC > C									
P+ CSO > P-CSO	1	l.	SPL	.014	.882	-20 -59 62	4.08	56	5.67
	2	l.	Precentral gyrus/SMG	.001	.890	-14 -17 56	4.07	96	5.65

Note. Shown are the significant brain areas, their lateralization, their location according to SPM's Neuromorphometrics atlas, the corresponding significance following Family-wise Error correction (p_{FWE}) on cluster level, the coordinates of the peak voxel within each cluster according to MNI space, the corresponding *z* statistic, T statistic, cluster extent (k_E) and significance at peak level. * indicates that values were derived from a height threshold of FWE $p < .05$. SFG = superior frontal gyrus, SPL = superior parietal lobe, IFG = inferior frontal gyrus, MFG = medial frontal gyrus, SMG = supramarginal gyrus, P+CSO = pedophiles with a history of child sexual abuse, P-CSO = pedophiles without a history of child sexual abuse, C = congruent, IC = incongruent.

Table 3. Brain regions expressing significant Error-related activity: Error trials (E) compared to Correct congruent trials (C)

Contrast	Cluster number	Hemisphere	Location	p_{FWE} Cluster	p_{FWE} peak	MNI coordinates (x, y, z)	*z*	k_E	*T*
One-sample *t*-tests									
E >C	1	r.	SMC/ACC	< .001	< .001	5 17 50	5.58	2445	8.55
	2	l.	Anterior insula/IFG	< .001	.001	-31 25 -7	5.57	703	7.85
	3	r.	NACC/Caudate	.005	.021	8 8 -4	5.04	84	6.66
	4	l.	NACC/Caudate	.008	.436	-12 8 -1	4.33	79	5.31
	5	bil.	Thalamus proper	< .001	.484	0 -22 8	4.29	199	5.24
	6	l.	MFG	.003	.816	-40 0 65	4.01	91	4.78
	7	l.	Precuneus/lingual gyrus	< .001	.843	-17 -59 5	3.98	129	4.74
C > E	8	r.	Occipital pole	.023	.498	22 -101 17	4.28	63	5.22
	9	r.	Cerebellum (white matter)	.029	.717	25 -53 -40	4.10	60	4.92
Significant independent-sample *t*-tests on E > C									

P+ CSO > HC	1	r.	Cerebellum (Crus I 31-98%, VI 2-69%)	.006	.263	30 -67 -28	4.54	65	6.48
	2	l.	Angular gyrus	.045	.994	-54 -59 47	3.77	43	4.82

Note. Shown are the significant brain areas, their lateralization, their location according to SPM's Neuromorphometrics and the cerebellar atlas by Diedrichsen et al. (2009), the corresponding significance following Family-wise Error correction (p_{FWE}) on cluster level, the coordinates of the peak voxel within each cluster according to MNI space, the corresponding *z* statistic, *T* statistic, cluster extent (k_E) and significance at peak level. SMC = supplementary motor cortex, ACC = anterior cingulate cortex, IFG = inferior frontal gyrus, NACC = nucleus accumbens, MFG = medial frontal gyrus, E = errors, C = congruent, P+CSO = pedophiles with a history of child sexual offenses, HC = healthy controls.

Table 4. Brain regions expressing significant post-error processing-related activity ($k_E \geq 5$): Correct congruent trials preceded by an error (peC) compared to correct congruent trials preceded by a correct congruent trial (CC).

Contrast	Cluster number	Hemisphere	Location	p_{FWE} Cluster	p_{FWE} peak	MNI coordinates (x, y, z)	*z*	k_E	*T*
Main effect of trial type									
peC > CC	-								
CC > peC	1	l.	Putamen	< .001	.001	-17 14 -4	5.68	40	8.24
	2	l.	Precentral gyrus	< .001	.001	-42 -8 50	5.64	28	8.14
	3	r.	SMC	< .001	.001	8 -3 56	5.63	37	8.11
	4	l.	SMC	< .001	.002	-3 -11 62	5.46	21	7.68
	5	r.	Precentral gyrus	< .001	.007	44 -8 44	5.26	6	7.21
	6	r.	Caudate	< .001	.011	11 8 -1	5.17	11	7.03
	7	r.	SPL	.001	.019	16 -50 59	5.07	5	6.80
Significant independent-sample *t*-tests on peC > CC									
P-CSO > HC	1	l.	IFG	.003	.993	-48 53 -1	3.90	61	5.53

P-CSO > P+CSO	1	l.	Posterior cingulate gyrus	.022	.423	-6 -36 32	4.44	49	6.57
	2	l.	Precuneus	.049	.941	-3 -62 35	4.01	41	5.50
	3	l.	Middle Temporal gyrus	.022	.986	-42 -56 20	3.87	49	5.19

Note. Shown are the significant brain areas, their lateralization, their location according to SPM's Neuromorphometrics atlas, the corresponding significance following Family-wise Error correction (p_{FWE}) on cluster level, the coordinates of the peak voxel within each cluster according to MNI space, the corresponding *z* statistic, *T* statistic, cluster extent (k_E) and significance at peak level.* indicates that values were derived from a height threshold of FWE $p < .05$. SMC = supplementary motor cortex, SPL = superior parietal lobe, IFG = inferior frontal gyrus, P+CSO = pedophiles with a history of child sexual abuse, P-CSO = pedophiles without a history of child sexual abuse, HC = healthy controls, peC = correct congruent trials preceded by an error, CC = correct congruent trials preceded by a correct congruent trial.