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Response Inhibition in Pedophilia: An fMRI Pilot Study

Benedikt Habermeyer[a, d] Fabrizio Esposito[f] Nadja Händel[d] Patrick Lemoine[d] Hans Christian Kuhl[d] Markus Klarhöfer[e] Ralph Mager[d] Andreas Mokros[b] Volker Dittmann[d] Erich Seifritz[c] Marc Graf[d]

Departments of [a]General and Social Psychiatry and [b]Forensic Psychiatry and [c]Clinic for Affective Disorders and General Psychiatry, Psychiatric University Hospital, Zurich, [d]Forensic Psychiatric Hospital, Psychiatric University Hospital, and [e]Department of Medical Radiology, MR-Physics, University of Basel, Basel, Switzerland; [f]Department of Medicine and Surgery, University of Salerno, Baronissi, Italy

Key Words
Pedophilia · Response inhibition · fMRI · Default mode network

Abstract
Background: The failure to inhibit pleasurable but inappropriate urges is associated with frontal lobe pathology and has been suggested as a possible cause of pedophilic behavior. However, imaging and neuropsychological findings about frontal pathology in pedophilia are heterogeneous. In our study we therefore address inhibition behaviorally and by means of functional imaging, aiming to assess how inhibition in pedophilia is related to a differential recruitment of frontal brain areas. ***Method:*** Eleven pedophilic subjects and 7 non-pedophilic controls underwent fMRI while performing a go/no-go task composed of neutral letters. ***Results:*** Pedophilic subjects showed a slower reaction time and less accurate visual target discrimination. fMRI voxel-level ANOVA revealed as a main effect of the go/no-go task an activation of prefrontal and parietal brain regions in the no-go condition, while the left anterior cingulate, precuneus and gyrus angularis became more activated in the go condition. In addition, a group × task interaction was found in the left precuneus and gyrus angularis. This interaction was based on an attenuated deactivation of these brain regions in the pedophilic group during performance of the no-go condition. The positive correlation between blood oxygen level-dependent imaging signal and reaction time in these brain areas indicates that attenuated deactivation is related to the behavioral findings. ***Conclusion:*** Slower reaction time and less accurate visual target discrimination in pedophilia was accompanied by attenuated deactivation of brain areas belonging to the default mode network. Our findings thus support the notion that behavioral differences might also derive from self-related processes and not necessarily from frontal lobe pathology.

Introduction

According to the DSM-IV-TR (Diagnostic and Statistical Manual of Mental Disorders, 4th Edition, Text Revision) [1], pedophilia is defined by two main criteria: firstly, persistent sexual fantasies, urges or behaviors involving sexual activity with prepubescent children (criterion A), and secondly, that individuals suffering from the disorder have either acted on such urges or that these urges or fantasies have caused marked distress or interpersonal difficulties (criterion B).

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E-Mail karger@karger.com
www.karger.com/nps

Benedikt Habermeyer, MD
Department of General and Social Psychiatry, Psychiatric University Hospital
Lenggstrasse 31
CH–8032 Zurich (Switzerland)
E-Mail benedikt.habermeyer@puk.zh.ch

Earlier work by several research groups (as summarized by Cohen et al. [2]) suggested that if a person is pedophilic, heterogeneous factors like, e.g. aberrant cortical development, sexual hyperarousal, personality pathology or cognitive distortion contribute to the impaired behavioral inhibition and finally lead to child sexual abuse. Based on their own findings, Cohen et al. [2] proposed a tentative multifactorial biological model of pedophilia. Some studies on late-onset pedophilia supported the assumption that pedophilic behavior might be related to a lack of inhibition due to temporal [3] or orbitofrontal pathology [4]. Further evidence for this notion came from recent fMRI studies showing frontal [5] or temporal [2] impairment or alterations in the white matter connections between these brain regions [6].

Neuropsychological studies provided further evidence for brain abnormalities in pedophilia. While findings like a lower IQ [7], educational difficulties [8] or a higher rate of left-handedness [9] indicated a rather generalized brain dysfunction, other studies suggested focal weaknesses in frontal-executive [10] and/or temporal-verbal [11] skills.

On the other hand, Kruger and Schiffer [12] showed that some of these findings might at least partly be explained by other factors like age or education. Even more to the point, one has to keep in mind that especially older studies on child abuse did not differentiate between nonpedophilic and pedophilic child molesters. The importance of this distinction has recently been stressed by various leading authors in the field [13, 14] and is supported by studies that demonstrated better executive functions in pedophilic than in nonpedophilic child molesters [10, 15, 16]. The notion that pedophilia is related to frontal dysfunction has moreover been challenged by studies in which pedophilic subjects displayed a slower processing speed but no increased error rate. These results would be in accordance with a more deliberate response style and greater self-monitoring [15, 16], and they would better correspond to findings from clinical work showing that pedophilic subjects often abuse children repeatedly over a period of many years without arousing anybody's suspicion and that they often entangle their victims gradually into abuse. This behavioral pattern would rather indicate a deliberate than an impulsive modus operandi. Thus, Eastvold et al. [15] and Suchy et al. [16] prompted the critical question to which extent some of the behavioral findings (e.g. slower processing speed) were rather related to an alteration in cognitive style than to a neurological disturbance like e.g. frontal lobe pathology.

fMRI studies linking behavioral performance in neuropsychological tasks sensitive to frontal lobe dysfunction to brain activation patterns are currently missing in research about pedophilia. Even though sexually abusive behavior against children cannot be equated with a pedophilic sexual preference, such studies might contribute to a better understanding of the reasons for the heterogeneous results in this area of research. We therefore applied a continuous performance task using a go/no-go paradigm that was adopted for use with the fMRI scanner. The go/no-go task examines the ability to withhold a preparatory behavioral response (response inhibition); that is, subjects must respond to a prevailing target stimulus but have to withhold responses to a similar distracter. From earlier fMRI research we know that the prefrontal, premotor, insular and parietal cortex areas are critically involved in response inhibition [17].

The critical dependent variables of such tasks are commission errors (failed suppression of an inappropriate response), omission errors (missing appropriate response) and reaction time. Whilst commission errors and short reaction times are believed to indicate impulsivity, omission errors and long reaction times indicate inattention [18]. The visual discrimination between target and distracter can be quantified with d′, a behavioral measure that considers correct target hits as well as false alarms [19].

Based on the arguments mentioned above, we hypothesize that mean response latencies in a go/no-go task will be longer among pedophilic subjects. We further expect behavioral differences to be related to a differential brain activation pattern and that this pattern might help answer the critical question to what extent behavioral findings in pedophilia are related to frontal or other brain networks.

Subjects and Methods

Subjects

Behavioral and fMRI data were acquired from 18 male right-handed subjects. Pedophilic subjects (n = 11) were recruited from an outpatient cognitive behavioral group therapy at the Forensic Psychiatric Hospital, Basel, Switzerland. All pedophilic subjects fulfilled the DSM-IV-TR criteria for pedophilia. Five of the pedophilic subjects had committed sexual offenses against children that had involved direct physical contact, whereas 6 subjects had been sentenced for the use of Internet child pornography.

The pedophilic subjects initially did not admit to their sexual orientation (i.e. they were so-called 'deniers'). Before encountering legal problems, they did not seek advice or treatment in that matter. The preference of each participant for prepubescent erotic

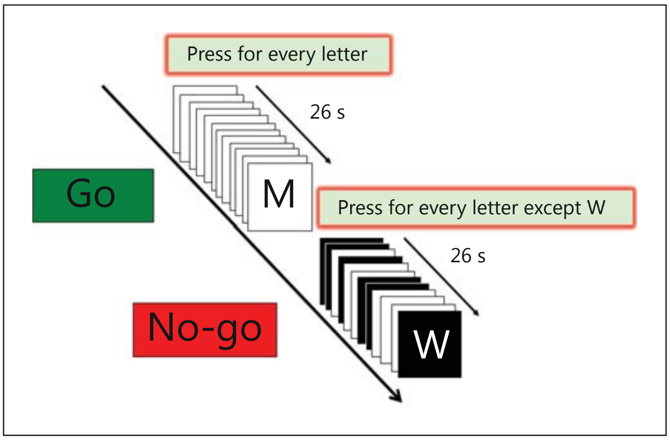

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Fig. 1. Experimental no-go task and go task in a blocked design. In each of the 12 epochs (each lasting 26 s) the letters were presented for 500 ms with a 1,500-ms interstimulus interval. In the go task, subjects were instructed to press for every letter. In the no-go task the instruction was to press for every letter except 'W'. In that condition, the letter 'W' was randomly presented (50%).

stimuli and his sexual orientation were assessed using the Multiphasic Sex Inventory [20], and the subjects underwent a thorough clinical examination by a senior forensic psychiatrist. The outcome of the assessment was additionally verified by comparing it with clinical records and court files. For all subjects, neither the interview nor the records indicated other comorbid paraphilias.

Seven control subjects were recruited using an advert on the University Hospital bulletin board. Careful clinical evaluation of all subjects (pedophilic and controls) revealed no other psychiatric, neurological or medical disorders. None of the study subjects was on medication. Their overall intelligence was assessed using the revised German version of the Wechsler Adult Intelligence Scale [21]. The ethics committee of the University of Basel, Switzerland, approved the study.

Stimulation and Paradigm

The study design was adapted from Singh et al. [22]. In the fMRI scanner, subjects were instructed to pay attention to 2 alternating conditions (go and no-go) in a blocked design (fig. 1). In each condition, the subjects viewed a series of 12 letters ('W' or 'M'). Each single letter was presented for 500 ms with an interstimulus interval of 1,500 ms.

At the beginning of each block, a 2-second instruction regarding the present task condition was presented. In the go block, the instruction was 'press for every letter'. In contrast to the original design by Singh et al. [22], we presented the letter 'M' only in this condition, in order to increase the overall target/distracter ratio to 75% against 25% of presentations. The instruction for the no-go condition was 'press for every letter except W'. In the no-go condition, both letters were presented in a pseudorandom order with a ratio of 50%. Each block lasted 26 s and the entire paradigm consisted of 6 cycles of go and no-go conditions. Before and after the behavioral task, there was a 30-second rest period with a white fixation cross.

Visual stimuli were generated and displayed on a personal computer using the Neurobehavioral Systems software package (Presentation®). Stimuli were presented via fMRI-compatible digital video goggles (NodicNeuroLab, Bergen, Norway) and the subjects were instructed to respond according to the presented instruction and letter, using the forefinger of their right hand and an fMRI-compatible keypad. Response and reaction times (RT) were recorded. The mean RT for correct responses was calculated separately for both conditions (go and no-go) and groups.

To provide a measure of discrimination of target stimuli in relation to nontarget stimuli, we calculated the so-called 'sensitivity index' (d′), a numeric value frequently used in signal detection theory [19]. d′ is calculated by subtraction of the Z-transformed false alarm rate from the Z-transformed hit rate: $d' = Z(\text{hit rate}) - Z(\text{false alarm rate})$. A higher d′ indicates that the presented target stimulus is distinguished more readily from the distracters.

fMRI Acquisition and Analysis

Images were acquired on a 3-tesla MRI scanner (Verio; Siemens Healthcare, Erlangen, Germany) equipped with a standard radio frequency head coil. First, a T1-weighted high-resolution data set that covered the whole brain was acquired by a 3D MPRAGE (magnetization-prepared rapid acquisition gradient echo) sequence with an isotropic spatial resolution of 1.0 mm^3. T2*-weighted functional images were acquired using echo planar imaging with a repetition time of 2,500 ms and an isotropic spatial resolution of $3 \times 3 \times 3$ mm (field of view: 228 mm^2; matrix: 76; interslice time: 69 ms). Altogether, 152 volumes with 36 image slices of a thickness of 3 mm were obtained.

Image Preprocessing and Statistical Analysis

Image time series were processed using the BrainVoyager QX 2.3.0 software package (Brain Innovation, Maastricht, The Netherlands). Preprocessing included head motion correction, slice scan time correction, temporal high-pass filtering and removal of linear trends. Using the results of image registration with anatomical scans, the functional image time series were then warped into Talairach space and resampled into 3-mm isotropic voxel time series. Normalized images were smoothed using a 6.00-mm isotropic gaussian kernel.

For the purposes of analysis, a general linear model was built on separate subject predictors with a percent signal change transformation. In the matrix, the predictors of interest were go and no-go. A two-factorial ANOVA was performed: (task effect: go vs. no-go) × (group effect: pedophilia vs. control). The resulting estimates were statistically evaluated and compared using voxel-level F tests. The main effects of the factors task and group as well as their interaction were evaluated at the statistical thresholds of $p = 0.005$ (uncorrected). In order to correct the F maps for the multiple voxel-level comparisons, we employed a cluster-level threshold correction procedure based on Monte Carlo simulations [23] and accepted a cluster-level corrected significance of 5%. In order to show the direction of the effects, we additionally calculated the linear contrast no-go > go (fig. 2).

To disentangle the interaction of the factors task and group, we also extracted the β of the regions of interest (ROI) that showed a significant interaction between task and group in voxel-level ANOVA. With the data of these ROIs, we built an ROI-general linear model and calculated the contrast no-go > go separately for the respective ROI and group. Finally, we performed a correlation

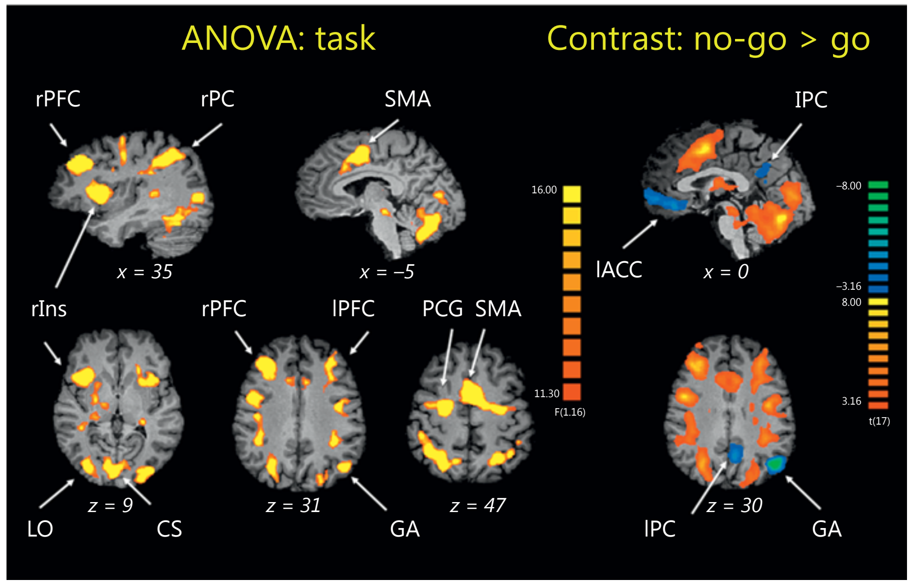
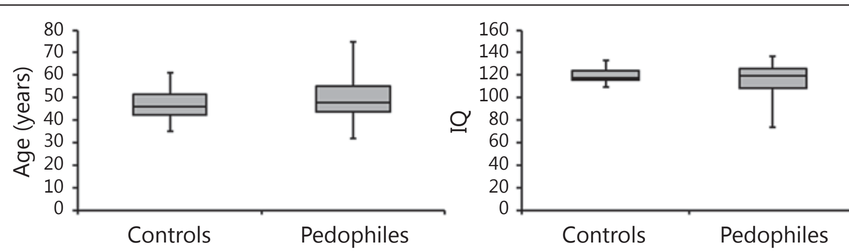


Fig. 2. Left side: map showing voxel-level ANOVA of factor task. Right side: voxel-level contrast no-go > go. Both maps are thresholded on a corrected p level of 0.05. rPFC = Right prefrontal cortex; lPFC = left prefrontal cortex; rPC = right parietal cortex; SMA = supplementary motor area; rIns = right insula; PCG = precentral gyrus; LO = left occipital cortex, CS = cuneus; lPC = left precuneus; GA = gyrus angularis; lACC = left anterior cingulate cortex.

Table 1. Demographic and clinical variables of control and pedophilic subjects

	Controls	Pedophiles	t test (two-tailed)
Mean age ± SD, years	47±8.6	49±12.5	$t(16) = 0.34$, $p = 0.74$
Mean IQ ± SD	118±6	115.3±20	$t(12) = 0.32$, $p = 0.75$
Heterosexual/homosexual, n	7/0	8/3	



analysis of the blood oxygen level-dependent (BOLD) signal change and the behavioral measures that showed significant results (fig. 3). The anatomical allocation of active clusters was defined with the Talairach Daemon (www.talairach.org) [24, 25].

Results

Demographics

The mean age ± standard deviation (SD) of the pedophilic subjects was 49 ± 12.5 years (range: 32–75 years). The mean age of the controls was 47 ± 8.6 years (range: 35–61 years). The mean IQ of the pedophilic subjects was 115.3 ± 20 (range: 74–137), while it was 118 ± 6 (range: 109–127) in the control subjects. Mean age and IQ did not differ significantly between groups in the two-tailed t test: $t(16) = 0.34$, $p = 0.74$, and $t(12) = 0.32$, $p = 0.75$. The sexual orientation in all subjects of the control group was heterosexual, while 3 subjects in the pedophilia group were homosexual (table 1).

Behavioral Results

Considering all subjects, the mean RT ± SD in the go condition was 331.19 ± 74.18 ms, and 429.6 ± 41.25 ms in the no-go condition. This difference was highly significant: $t(17) = 4.33$, $p < 0.001$. Mean differences between groups in 5 dependent variables (average RT on go trials;

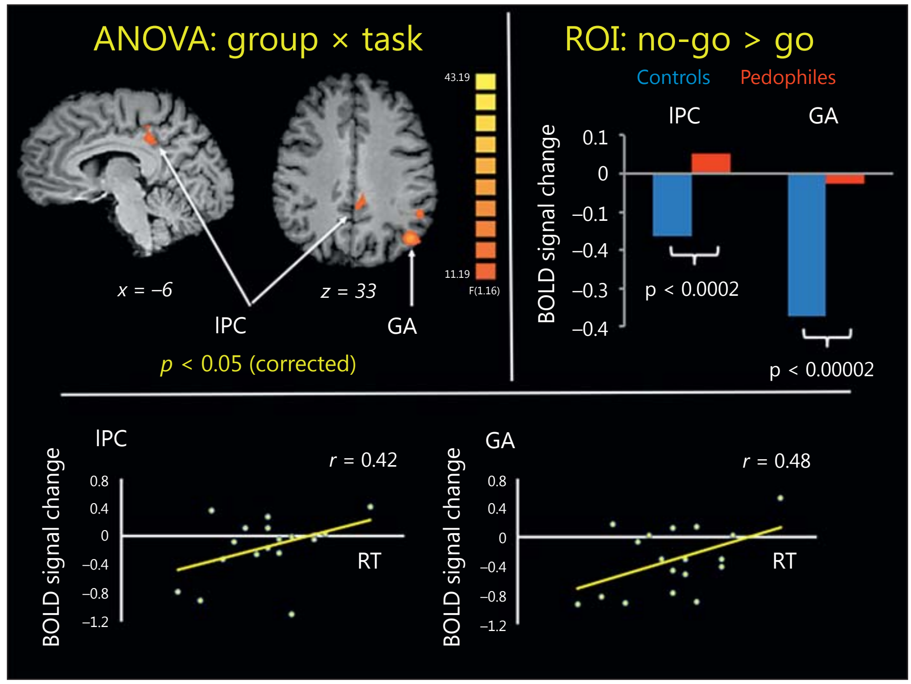


Fig. 3. Upper left part: results of voxel-level ANOVA for interaction task × group at a corrected p level of $p < 0.05$. Upper right part: results of contrast no-go > go for significant ROIs. Lower part: linear correlation (r) between BOLD signal change and RT. lPC = Left precuneus; GA = gyrus angularis.

Table 2. Behavioral results of controls and pedophilic subjects

	Controls	Pedophiles	t test (one-tailed)	Effect size (Cohen's d)
Mean RT go ± SD, ms	330.8±33	331.4±96	t(16) = 0.02, p = 0.49	0.01
Mean RT no-go ± SD, ms	407.3±39	443.7±40	t(16) = 1.9, p = 0.04*	0.98
Mean commission error ± SD	1±1.8	3.2±3.6	t(16) = 1.5, p = 0.08	0.61
Mean omission error ± SD	0.14±0.38	1.1±2.1	t(16) = 1.2, p = 0.13	0.75
d′	4.3±0.4	3.57±0.8	t(16) = 2.2, p = 0.02*	1.12

* p < 0.05.

Table 3. Correlation among demographic and behavioral variables

	Age	IQ	RT go	RT no-go	CE	OE	d′
Age	1						
IQ	0.14	1					
RT go	–0.14	–0.04	1				
RT no-go	0.3	0.16	–0.26	1			
CE	0.04	0.46*	–0.06	0.036	1		
OE	0.69**	0.33	0.03	0.18	0.27	1	
d′	–0.465*	–0.41	0.032	–0.16	–0.82**	–0.7**	1

CE = Commission error; OE = omission error. * p < 0.05, ** p < 0.01.

average RT on no-go trials; mean number of commission errors; mean omission errors; and mean d′ values) were subjected to a multivariate ANOVA. Overall, the mean differences between the two participant groups were not statistically significant: $F(5, 12) = 1.72$, $p = 0.21$. One-sided post hoc tests with Bonferroni adjustment showed, however, that the groups differed significantly with respect to mean d′ value ($p = 0.02$). Furthermore, the post hoc test with respect to mean RT during no-go trials was significant ($p = 0.04$).

As can be seen in table 2, the direction of the mean differences for d′ as well as for RT during no-go trials confirmed our hypothesis, with considerably higher values among pedophilic subjects than among controls. In both instances (d′ and RT during no-go task) the mean differences between groups represent strong effects by conventional standards (Cohen's $d > 0.80$). Table 2 summarizes the RT and performance data on the go/no-go task.

In order to evaluate the interrelation of the different behavioral items with age and IQ, we correlated the results with each other (table 3). Age showed a high correlation with omission error ($r = 0.69$, $p < 0.01$) and d′ ($r = -0.465$, $p < 0.05$). IQ correlated with commission error ($r = 0.46$, $p < 0.05$), whereas d′ showed a high correlation with commission error ($r = -0.82$, $p < 0.01$) and omission error ($r = -0.7$, $p < 0.01$).

Since age and intelligence may have affected the performance as summarized in the d′ indicator, we conducted an ANCOVA with age and IQ as covariates. The ANCOVA yielded a significant main effect of group membership for the dependent variable d′: $F(1, 10) = 8.64$, $p = 0.015$. The size of the effect was large (partial $\eta^2 = 0.46$). The pooled regression estimate was significant for one of the covariates (age) only: $F(1, 10) = 6.22$, $p = 0.032$. The regression estimate for the second covariate (IQ) came close to statistical significance: $F(1, 10) = 4.4$, $p = 0.064$. For the significant effect of group membership on mean RT during the no-go trials, a supplementary ANCOVA (involving age as a covariate) remained marginally significant: $F(1, 15) = 3.32$, $p = 0.089$.

fMRI Results

At a corrected level of $p < 0.05$, the voxel-level whole-brain ANOVA for the factor task revealed a widespread activation in the frontal lobes of both hemispheres. This activation included the dorsolateral prefrontal cortex bilaterally, the frontal eye fields and the supplementary motor areas. Also, both insular cortices showed activation. Furthermore, we found large clusters in both parietal lobes (for details on activation, see table 4).

The voxel-level contrast no-go > go implied that the clusters from the ANOVA responded more strongly to the no-go condition, except for the left anterior cingulate cortex, the precuneus and gyrus angularis, which all showed to be more active in the go condition (fig. 2; table 4).

At a corrected level of $p < 0.05$, the voxel-level ANOVA revealed no significant effect for the factor group. We did find a significant interaction between the factors group and task in the left precuneus and gyrus angularis, however (fig. 3). The ROI analysis of these clusters confirmed less deactivation in the left precuneus and gyrus angularis in pedophilic subjects than in controls (both $p < 0.001$).

BOLD signal change and no-go RT were significantly positively correlated in the precuneus ($r = 0.42$, $p < 0.05$) and gyrus angularis ($r = 0.48$, $p < 0.05$). The correlation value between BOLD signal change and d′ in both regions was $r = -0.3$, $p > 0.05$. The same applied to the correlation between BOLD signal change and age, which was significant neither in the gyrus angularis ($r = -0.21$, $p > 0.05$) nor in the precuneus ($r = -0.37$, $p > 0.05$).

Discussion

Wager et al. [17] have already described the critical network for response inhibition. According to their study, this network includes the anterior insula and anterior prefrontal cortex bilaterally as well as the dorsolateral prefrontal cortex of the right hemisphere, the supplementary motor area and parietal cortices. Thus the activation pattern that we found in our study is in line with their study as well as with the fMRI literature on no-go tasks [26–30]. Specifically, the activation of the supplementary motor area (middle frontal gyrus; Brodmann area 6) appears to be critical for the ability to select an appropriate behavior, i.e. for executing an appropriate or inhibiting an inappropriate response [30].

While the no-go task increased activation in the aforementioned brain regions, we found the left precuneus, anterior cingulate and gyrus angularis to be more active in the go condition. The precuneus is a brain region located in the posteromedial parietal cortex which has been linked to a wide spectrum of highly integrated tasks such as visuospatial imagery, episodic memory retrieval and self-processing operations [31]. The precuneus is strongly connected to the inferior parietal lobe [32]. Furthermore, it has been shown that the precuneus, together with lateral parietal regions, exhibits a high metabolic activity during baseline resting state conditions that decreases during goal-directed cognitive processes. This observa-

Table 4. Regions showing significant responses in voxel-level ANOVA/contrast

	Brain region	Hemisphere	BA	Talairach coordinates			Voxel	F or t[1]	p
				x	y	z			
Voxel-level ANOVA									
Task	inferior parietal lobe	R	40	53	–41	24	588	21.4	0.0003
	inferior parietal lobe	R	40	38	–50	45	77,635	64.6	0.000001
	insula	R	13	32	19	9	18,510	64.5	0.000001
	middle frontal gyrus	R	8	35	37	39	5,466	45.3	0.000005
	middle frontal gyrus	R/L	6	23	–8	48	30,524	81.7	<0.000001
	culmen	L	–	–10	–38	–15	688	17.1	0.0008
	insula	L	13	–37	10	12	8,618	38.8	0.00001
	superior parietal lobe	L	7	–25	–53	42	8,167	53.5	0.000002
	thalamus	L	–	–22	–32	12	1,517	39.9	0.00001
	precentral gyrus	L	9	–40	22	36	3,916	28.1	0.00007
	caudate	L	–	–37	–38	3	509	25.3	0.0001
	angular gyrus	L	39	–46	–65	30	1,418	41.9	0.000008
Interaction	cingulate gyrus	L	31	–7	–35	36	544	19.5	0.0004
	superior parietal lobe	L	7	–40	–62	48	598	19.4	0.0004
	angular gyrus	L	39	–46	–65	30	1,349	42.2	0.000007
	supramarginal gyrus	L	40	–52	–47	30	614	18.6	0.00005
Voxel-level contrast									
Go > no-go	anterior cingulate	L	32	–1	34	–6	5,605	5.82	0.00002
	precuneus	L	7	–7	–56	33	3,966	6.02	0.000014
	angular gyrus	L	39	–46	–65	30	6,045	9.78	<0.000001

BA = Brodmann area; R = right, L = left.
[1] F values for voxel-level ANOVA, t values for voxel-level contrast.

tion has been named 'task-induced deactivation' and contributes to the concept of a so-called 'default mode network' (DMN) of the brain [33]. According to this concept, brain regions that are more active in the resting state than in a given task are taken together to constitute the DMN. The DMN comprises midline areas of the posterior cingulate, the precuneus and the medial prefrontal cortex.

Applying this concept, the activation of the left precuneus, anterior cingulate and gyrus angularis that was observed in our data thus suggests a switch to resting state brain activity in the less challenging go condition. In our study, we found a significantly longer no-go RT in the pedophilic group. Furthermore, the pedophilic group displayed less accurate visual discrimination between target and distracter as measured by d′ even when controlling for age and intelligence as covariates. As already mentioned in the Introduction, the constellation of longer RT without increased numbers of commission errors indicates inattention rather than impulsivity [18]. Based on the finding that RT in the go condition were very similar in both groups, we feel confident in excluding general differences in motivation or processing speed between the groups as a potential explanation. Thus the behavioral findings in our data point to a higher degree of inattention in the pedophilic group.

From other studies on executive functions in pedophilia we know that pedophilic subjects showed a slower processing speed in combination with similar error rates in executive tasks [15, 16]. The authors of these studies concluded that pedophilic subjects display a more deliberate response pattern, which these authors related to stronger self-monitoring. However, the study by Schiffer and Vonlaufen [10] that also applied a go/no-go paradigm in pedophilia showed an increased error rate in comparison with controls, while RT did not differ. Unfortunately, this study did not report the two possible types of errors separately, so that we do not know whether the increased error rate in that study derived from commission or omission errors or from a combination of both. This differentiation, however, appears to be crucial, because a longer RT together with a decrease in target discrimination and stimulus detection, as present in our data, indicates inattention rather than impulsivity. In line with our interpretation that attentional processes might contribute to the findings in our study, Kruger and Schiffer [12] also reported a weaker performance in the d2 Attention Deficit test for pedophilia.

This interpretation of our behavioral findings would also explain why we did not find any group differences for prefrontal brain areas, which are responsible for the application of executive control. While frontal abnormalities were missing, ANOVA showed an interaction of the factors group and task in 2 of the 3 aforementioned brain regions belonging to the default network, namely the left precuneus and the gyrus angularis. An effective deactivation of the DMN during the no-go condition appeared to be attenuated in the pedophilic group. Additional analysis confirmed that BOLD signal change in these regions was positively correlated with RT. Hence, the reduced deactivation of the DMN is reflected in a measurable behavioral difference. Zhang and Li [34] concluded in their study on the default network that activity in this network indicates self-referential processes. Following this line of interpretation, we assume that during the no-go condition, the pedophilic study subjects were not only engaged in task-related processes but also in resting state activities such as thinking about the intentions of others, remembering the past or planning the future. This resting state activation is known to induce an interference between task performance and internal emotional states [35]. Our results suggest that pedophilic subjects might have been more engaged in self-referential processes while they performed the no-go task.

In contrast to previous studies suggesting prefrontal abnormalities in pedophilia, we did not find any differences in these brain regions. Thus our findings indicate a disturbed interplay between attentional and frontal control networks compared with the default network. More generally speaking, our findings therefore rather support the notion of Cantor et al. [6] that pedophilia is not related to a focal dysfunction of a localized brain region but has to be seen from a network perspective.

Eastvold et al. [15] have already pointed out that, for obvious reasons, pedophilic subjects tend to be more discreet about their sexual wishes, and that this might finally lead to a more deliberate response style. Following this chain of reasoning, it is not far-fetched to assume that, as they are aware of having a socially unaccepted sexual orientation and know that the study paradigm addresses this topic, pedophilic subjects might indeed display increased self-referential processes during the experimental condition. This might then lead to attenuated deactivation of the default network. Of course this does not necessarily mean that in pedophilia the default network, taken as a whole, does not work or is generally disturbed. Rather it underlines the need to interpret some of the neuropsychological findings in pedophilia against the background of a more complex interplay between cognitive processes during the test situation and the test itself. Further evidence for this interplay can be found in a recent fMRI study showing, for example, an immediate activation of brain regions involved in evaluating emotional salience and reward as well as in the regulation of emotional responses in pedophilic subjects when confronted with erotic pictures of children [36].

Taken together, the findings of our pilot study thus suggest tailoring future neurobiological research on pedophilia not only to structural differences but also to a functional interplay between self-referential processes and cognitive tasks following a network perspective on the brain.

However, some important limitations to the generalizability of our findings also need to be mentioned. In contrast to most of the aforementioned studies on pedophilia that included only 'hands-on' offenders, we included slightly more Internet child pornography users than 'hands-on' offenders. Also, our sample consisted only of outpatients, while other studies usually included inpatient pedophilic offenders from high-security wards [12]. There is at least some evidence indicating a higher educational background [37], intelligence level [38] and rate of employment [39] in Internet abusers than in 'hands-on' pedophilic offenders. These findings would indicate better frontal functioning in Internet abusers and might therefore contribute to the absence of frontal abnormalities in our study. Due to fact that most pedophilic activities likely occur in the so-called 'dark field' (i.e. without incurring a criminal justice response), it is difficult to decide which type of sample is suited best for studies on pedophilia. It is safe to assume that at least a clear differentiation between nonpedophilic child offenders and pedophilic child offenders has to be applied. In our study we sampled both 'hands-on' sexual abusers of children and Internet child pornography offenders. Both pedophilic subgroups acted on their sexual preference in a way that was breaking criminal law. In that sense, both groups of pedophilic participants fulfilled the stringent B criterion for paraphilias of the DSM, namely causing distress to themselves or others. Furthermore, as Eke et al. [40] showed in a prospective follow-up study on male child pornography offenders, about one quarter of these indi-

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viduals were subsequently sanctioned for violations of conditional release regulations; 4% were 'hands-on' sexual re-offenders. This recidivism rate is hardly lower than the rates observed for sex offenders in general. Therefore, individuals who committed sex offenses against children either through direct physical contact or virtually likely have much in common, especially if one considers the criminological dark field. Hence, in many regards it is probably due to circumstance whether a pedophilic individual who acts on his urges is caught for a contact offense or for the use of child pornography. Still, for further studies, we would like to suggest differentiating both groups whenever possible in order to see whether there are different behavioral or brain activation patterns that might prove useful in clinical work or as prognostic instruments.

Another limitation of our current study is its small sample size. While some groups have been able to conduct fMRI studies with larger sample sizes, in this research area it remains difficult to engage pedophilic subjects in such studies. The small sample size and the subsequently diminished ability to select subjects from a larger population lead to a certain heterogeneity of the study sample in terms of sexual preference (hetero- vs. homosexual) and age.

The first point in particular may have influenced brain activation, as other groups already demonstrated different brain responses in homo- and heterosexual pedophilia [41, 42]. Notwithstanding this potential limitation, our study primarily addressed response inhibition and not cerebral responses to visual erotic stimuli. To our knowledge there are no empirical data suggesting differences regarding sexual preference and go/no-go tasks. We therefore believe that this issue is only of minor importance in the present study design.

While not significant, we have to admit the heterogeneity of mean age and IQ with a trend toward older and less intelligent subjects in the pedophilic group. We tried to overcome this limitation by an additional ANCOVA and could at least show that age or IQ did not distort our findings. The results of our study might not necessarily generalize to pedophilia in early adulthood, but they still can be applied to a clinically highly relevant population in the field. The relatively high mean age of the pedophilic participants may be reflective of the average age of child sexual abusers in correctional settings, however. A large descriptive study by Eher and colleagues [43, 44], for instance, reported a mean age of 43.4 years (range: 16–71 years) for a sample of 430 sexual abusers of children from Austria.

Another shortcoming of our pilot study was that we were not able to include equal numbers of participants in both groups. But as the findings from the controls are perfectly in line with the fMRI literature on the DMN during performance of a given task [33], we feel confident that the results would have remained unchanged if, for example, more control subjects had been included. Still we suggest recruiting in a more balanced way in further studies on that matter.

Further limitations arise from the study design, as the no-go > go contrast includes a number of different cognitive processes besides response inhibition, such as sustained attention, target detection or remembering the task instruction for the current block. Unlike in an event-related design, these processes cannot be disentangled in our block design. We opted for a block design nonetheless because we suspected high individual variance due to the clinical heterogeneity of our sample and did not want to lose the subjects' motivation through a longer event-related paradigm.

Conclusion

Our fMRI pilot study is the first to combine fMRI with a continuous performance task in order to delineate the neuronal underpinnings of response inhibition in pedophilia as compared with controls. We found behavioral differences between controls and pedophilic subjects. These differences were associated with a reduced deactivation of regions known to be involved in the so-called default network of the brain. Our pilot study therefore indicates that in pedophilia, cognitive control might also be impaired due to a failure to stay focused on the task rather than representing a result of frontal pathology. Further studies on the interplay between attentional and frontal control networks in relation to the default network might be a promising approach to further our understanding of the neurobiology of pedophilia.

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