Assessment of Pedophilia Using Hemodynamic Brain Response to Sexual Stimuli

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Context: Accurately assessing sexual preference is important in the treatment of child sex offenders. Phallometry is the standard method to identify sexual preference; however, this measure has been criticized for its intrusiveness and limited reliability.

Objective: To evaluate whether spatial response pattern to sexual stimuli as revealed by a change in the blood oxygen level–dependent signal facilitates the identification of pedophiles.

Design: During functional magnetic resonance imaging, pedophilic and nonpedophilic participants were briefly exposed to same- and opposite-sex images of nude children and adults. We calculated differences in blood oxygen level–dependent signals to child and adult sexual stimuli for each participant. The corresponding contrast images were entered into a group analysis to calculate whole-brain difference maps between groups. We calculated an expression value that corresponded to the group result for each participant. These expression values were submitted to 2 different classification algorithms: Fisher linear discriminant analysis and κ-nearest neighbor analysis. This classification procedure was cross-validated using the leave-one-out method.

Results: The highest classification accuracy was achieved by Fisher linear discriminant analysis, which showed a mean accuracy of 95% (100% specificity, 88% sensitivity).

Conclusions: Functional brain response patterns to sexual stimuli contain sufficient information to identify pedophiles with high accuracy. The automatic classification of these patterns is a promising objective tool to clinically diagnose pedophilia.

known to be involved in sexual processing such as the amygdala, hypothalamus, and prefrontal cortex in functional MRI (fMRI) studies. Exposure to sexual stimuli that matched their preferences (i.e., pictures of nude children), however, evoked preference-specific activations similar to those observed in healthy heterosexual adults. One study reported a hypoactivation of the orbitofrontal cortex and a hyperactivation of the dorsolateral prefrontal cortex; this evidence was interpreted as a sexual processing dysfunction in the prefrontal networks.

Although there is not consistent evidence of an abnormal activation profile in pedophiles, preference-specific tuning of the functional activation patterns evoked by sexual stimuli could be used to assess pedophilia. Using an automatic classification algorithm, Ponseti and colleagues tested whether brain activity in response to sexually preferred vs nonpreferred stimuli predicts sexual orientation in a sample of healthy heterosexual and homosexual men. They found that the algorithm's mean classification accuracy exceeded 85%, which indicates that the brain's functional response patterns to sexual stimuli contained sufficient information to predict sexual orientation with high accuracy. This finding ties in with an increasing body of research showing that automated classification techniques of whole-brain MRI scans can facilitate the diagnosis of neurological and psychiatric diseases. For example, a classification accuracy well above 85% has been obtained using structural MRI brain scans in patients with early Alzheimer disease, obsessive-compulsive disorder, and prodomal psychosis or with fMRI in patients with major depression.

Reliable assessment of a paraphilic sexual orientation is of great importance for the prediction of recidivism. Furthermore, the effective treatment of child sex offenders relies on an accurate assessment of a paraphilic sexual orientation, given that some interventions are appropriate for pedophilic offenders but not for nonpedophilic offenders and vice versa. In cases in which forensic records and convincing reports are absent (e.g., a first sexual offense), a valid assessment of sexual orientation can only be done using the phallometric measurement, the current standard to objectively assess sexual deviances. During phallometric measurements, participants are required to place a device around their penis to have their erectile responses recorded. Phallometry has been criticized not only for its intrusiveness but also because of its high proportion of nonresponders. According to a laboratory survey, up to 40% of phallometric test results are rejected owing to low response (which are commonly considered “random variation”). The proportion of nonresponders can be lowered to approximately 2% using volumetric phallometry, a more sensitive and accurate assessment of penile responses. Sildenafil citrate may also increase phallometric sensitivity. A more sensitive and accurate assessment of penile responses can be lowered to approximately 2% using volumetric phallometry, a more sensitive and accurate assessment of penile responses. Sildenafil citrate may also increase phallometric sensitivity.

This study examined whether an automated pattern classification of fMRI data can predict paraphilic sexual orientation. We tested this using a parametric classifier (Fisher linear discriminant analysis) and a nonparametric classifier (k-nearest neighbor analysis). We hypothesized that maps reflecting regional differences in participants' blood oxygen level–dependent (BOLD) response to sexual stimuli should indicate sexual orientation.

### METHODS

#### PARTICIPANTS

We recruited 25 male participants who met the diagnostic criteria for pedophilia according to the DSM-IV-R (exclusive and nonexclusive types) from 2 outpatient departments of Sexual Medicine involved in the prevention project Dunkelfeld, which offers anonymous treatment for self-identified pedophiles. The standard intake procedures of the prevention project Dunkelfeld, which include a semistructured clinical interview and a questionnaire to measure sexual interest, behavior, and child pornography consumption, assessed pedophilic interest. We excluded 1 participant from further analysis because his postcan rates of sexual stimuli revealed a preference for adult women. According to self-report, 11 of the remaining participants with pedophilia were sexually attracted to prepubescent girls (heterosexual pedophiles), and 13 were attracted to prepubescent boys (homosexual pedophiles). Of the 24 participants with pedophilia, 11 underwent phallometry to confirm the initial pedophilia diagnosis. In the remaining cases, forensic records supplied the diagnosis. Seven of the pedophilic participants declared to be sometimes sexually attracted to adults as well (i.e., they were of the nonexclusive type). Five of these nonexclusive pedophiles were heterosexual pedophiles; the remaining 2 were homosexual pedophiles. Twelve participants with pedophilia had committed sexual offenses previously. We recruited 32 healthy male volunteers to serve as a control group (also referred to as teleiophiles). Eighteen controls were sexually attracted to adult women (heterosexual teleiophiles), and 14 were sexually attracted to adult men (homosexual teleiophiles). Sexual orientation was ascertained using the Kinsey ratings of fantasy and behavior of 0 and 1 or 3 and 6, respectively.

Based on a structured interview, we verified that participants had no claustrophobia, implants or other metallic parts inside their body, history of head injury, sexual dysfunction, gender identity disorder, substance abuse during the last year, or any medication related to sexual functioning. In addition, we controlled participant histories for having histories of paraphilia or committing sexual offenses. Six participants with pedophilia and 2 volunteers were left handed.

Groups were matched for age (mean [SD], heterosexual pedophiles, 37 [5.9] years [range, 25-46 years]; homosexual pedophiles, 33.3 [18.2] years [range, 18-64 years]; heterosexual teleiophiles, 32.4 [8.2] years [range, 22-49 years]; homosexual teleiophiles, 28.6 [5.7] years [range, 23-42 years]; F, [3,52] = 1.81; P = .16) and intelligence as measured by the Wechsler Adult Intelligence Scale reasoning subtest matrix [mean (SD), heterosexual pedophiles, 11 [3.1] scaled scores [range, 5-16 scaled scores]; homosexual pedophiles, 10.2 [2.9] scaled scores [range, 4-14 scaled scores]; heterosexual teleiophiles, 11.8 [2.3] scaled scores [range, 5-15 scaled scores]; homosexual teleiophiles, 11.8 [2] scaled scores [range, 8-14 scaled scores]; F, [3,52] = 1.25; P = .30). All participants provided written informed consent before participating in this experiment. The local ethics committee of the Medical Faculty of Christian-Albrechts University approved this study.
We presented 14 different picture categories during an fMRI session: nude adults and children (either whole-body frontal views, genitals only, or face only) and nonsexual pictures with either high or low arousal scores from the International Affective Picture System. In each sexual picture, only 1 person (or 1 genitalia) was visible without additional context. In contrast to the child stimuli, many of the adult sexual stimuli displayed signs of genital arousal. We used this type of core sexual stimuli because research has found that these stimuli are highly selective in triggering neuronal responses according to the sexual preference of the observer. We presented 35 pictures within each category for a total of 490 photographs. However, for the purpose of pattern classification only, trials with pictures depicting whole-body frontal views or genitals only entered the analysis. This corresponds to 70 pictures (35 whole-body view + 35 genital) of boys, girls, men, and women each (and a total of 280 trials in the analysis).

We presented each image for 1 second with a variable interstimulus interval (range, 1-5 seconds) in a pseudorandom order. Participants were instructed to view each stimulus attentively. To ensure that participants paid attention to the stimuli, they manually responded when an oddball stimulus (green circle) appeared on-screen. The oddball was presented 20 times during the fMRI session. Stimuli were projected to a mirror mounted on a standard head coil. Immediately afterward, participants rated the stimuli in terms of valence and arousal using the 9-point Self-Assessment Manikin Likert-type scale. For each sexual stimulus, we multiplied valence and arousal ratings to obtain a combined index that we previously found to be closely correlated with sexual attractiveness ratings.

**IMAGING PROCEDURE AND DATA PREPROCESSING**

A 3-T whole-body MRI scanner (Achieva; Philips, Best, the Netherlands) imaged participants. A 3-dimensional spoiled gradient echo acquisition with sagittal volume excitation (1 × 1 × 1-mm voxels) acquired a structural T1 volume for each participant, followed by 3 fMRI runs. Each fMRI run consisted of 352 volumes. The functional MRI measurements of the BOLD signal were performed using an echo planar imaging (EPI) sequence with a repetition time of 2500 milliseconds, echo time of 36.8 milliseconds, and a flip angle of 90°. The field of view covered the whole brain (38 axial slices; slice thickness: 3 mm; interslice gap: 0.3 mm). We acquired axial slices parallel to the anterior-posterior commissural plane.

We performed data preprocessing and statistical analyses using SPM8 software (http://www.fil.ion.ucl.ac.uk/spm/) on Matlab 7.7.0 (MathWorks, Natick, Massachusetts). We realigned the EPI images to their mean and spatially normalized scans using the Montreal Neurological Institute template. The spatial normalization was realized by applying the SPM segmentation algorithm to individual T1-weighted images to estimate the parameters of the nonlinear spatial normalization transform. We then coregistered the realigned EPI images to the corresponding individual T1-weighted image and used the normalization parameters of the segmentation step to write normalized versions of the EPI images (2 × 2 × 2-mm voxels). This procedure optimizes spatial normalization using the high-resolution T1-weighted image to determine the complex nonlinear spatial normalization function and incorporates a bias correction to cope with potential brightness heterogeneities in the T1-weighted structural images. Finally, a gaussian kernel of full-width half-maximum 8 mm spatially smoothed the normalized EPI images to reduce anatomical differences in participants and enabled gaussian random field theory application.

**STATISTICAL ANALYSES AND SUBJECT CLASSIFICATION**

Whole-brain pattern classification of cerebral activity was done using the same algorithm we previously applied to another sample. This algorithm has 4 steps:

Step 1 (first-level analysis): We specified a general linear model for fMRI time series of each subject using a separate regressor for each stimulus condition (boys' body, boys' genital, men's body, men's genital, girls' body, girls' genital, women's body, women's genital) and 6 regressors with movement parameters as estimated in the realignment step. Each stimulus-related response was convolved with the standard hemodynamic response function. Regression coefficients (parameter estimates) for all regressors were estimated within a subject-specific fixed-effects model. A high-pass filter with a cutoff of 128 seconds was used to remove low-frequency drifts in BOLD signal. Based on subject-specific general linear model estimates, we calculated t-statistic maps by contrasting the stimulus conditions from (1) pictures of boys compared with pictures of men and (2) pictures of girls compared with pictures of women for each voxel. For each subject, we got 2 t-statistic maps: the first reflecting the spatial pattern of regional differences in the BOLD response to male-child sexual stimuli as opposed to male-adult sexual stimuli and the second reflecting regional differences in the BOLD response to female-child sexual stimuli as opposed to female-adult sexual stimuli across the whole brain.

Step 2 (second-level analysis): We built a (3-way) flexible factorial design with the parameter estimates of each stimulus condition (n=8) for each subject as a stimulus factor. The remaining 2 factors within this design were group (2 levels) and subject (56 levels) and as covariate of no interest, age and intelligence. The covariates age and intelligence were included to correct group differences for age- or intelligence-related variance. Both covariates were centered to the global mean value. The subject factor was aimed to capture any further subject-related variance not modeled by any of the other factors (eg, handedness). We then calculated statistical maps (t contrasts) between groups to quantify regional differences in the preferential BOLD response to boys vs men and to girls vs women between pedophiles and healthy volunteers.

Step 3 (t-map projection): To assess and quantify subject-specific effects, contrast images calculated in the first step were projected onto the group-specific difference maps determined in second-level analysis (step 2). These statistical maps express the spatial pattern of difference in BOLD response as revealed by the between-groups comparison. The projection is implemented by summing up the voxelwise products of the subject-specific contrast images (boy < men and girl < women) determined in the first-level analysis (step 1) and the t maps of the group difference maps determined in the second-level analysis (step 2). This sum mathematically corresponds to a vector dot product. The procedure was performed separately for the boys vs men and the girls vs women difference maps. The summed voxelwise product is referred to as the “individual expression value.” It represents the degree to which the brain response of one subject (ie, its t statistical difference map) matches the average brain response of one group (ie, the group t statistical difference map gathered in step 2). High individual expression values, either negative or positive, usually indicate a good correspondence with the (difference) pattern of one group. Moderate individual expression values indicate that the respective individual expresses a brain response lying somewhere between the expression patterns found in the groups.

Step 4 (classification and cross-validation): Finally, we submitted the resulting individual expression values (2 values for...
each subject) to 2 different pattern classification algorithms: a parametric Fisher linear discriminant analysis and a nonparametric \( \kappa \)-nearest neighbor classification (taking into account the 7 nearest neighbors).

To calculate the ability of classifying previously unknown data sets (test the generalization ability), we cross-validated both classification methods using the leave-one-out method (ie, we omitted 1 proband at a time from the original sample). For the remaining 55 participants, we calculated new \( t \) statistical difference maps (step 2). Individual expression values were then calculated for the “left-out” participant (one for the boys < men and one for the girls < women comparison; step 3). Subsequently, we classified the participant according to these values using Fisher linear discrimi-
Table 1. The Discriminative Pattern Underlying Pedophilic vs Control Group Classificationa

<table>
<thead>
<tr>
<th>Brain Area</th>
<th>Side</th>
<th>Cluster Size, Voxels</th>
<th>t Value Maximum</th>
<th>z Score Maximum</th>
<th>MNI Coordinates, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedophiles &lt; controls (boys &lt; men)</td>
<td>L</td>
<td>50195</td>
<td>6.72</td>
<td>6.53</td>
<td>x = −38, y = −62, z = −24</td>
</tr>
<tr>
<td>Cerebellum</td>
<td>R</td>
<td>6.36</td>
<td>6.19</td>
<td>4</td>
<td>x = −40, y = −64, z = −22</td>
</tr>
<tr>
<td>Lingual gyrus</td>
<td>L</td>
<td>6.05</td>
<td>5.91</td>
<td>−12</td>
<td>x = −10, y = −60, z = −2</td>
</tr>
<tr>
<td>Anterior thalamus</td>
<td>L</td>
<td>6.05</td>
<td>5.90</td>
<td>−2</td>
<td>x = −6, y = −6, z = 0</td>
</tr>
<tr>
<td>Hippocampus</td>
<td>R</td>
<td>5.99</td>
<td>5.85</td>
<td>4</td>
<td>x = 6, y = 6, z = 0</td>
</tr>
<tr>
<td>Occipital lobe</td>
<td>L</td>
<td>5.96</td>
<td>5.82</td>
<td>−34</td>
<td>x = −34, y = −62, z = 16</td>
</tr>
<tr>
<td>Lingual gyrus</td>
<td>R</td>
<td>5.87</td>
<td>5.74</td>
<td>14</td>
<td>x = 34, y = 0, z = 0</td>
</tr>
<tr>
<td>Fusiform gyrus</td>
<td>L</td>
<td>5.82</td>
<td>5.69</td>
<td>−38</td>
<td>x = −38, y = −74, z = 16</td>
</tr>
<tr>
<td>Inferior temporal gyrus</td>
<td>R</td>
<td>5.72</td>
<td>5.60</td>
<td>−46</td>
<td>x = −46, y = −44, z = 12</td>
</tr>
<tr>
<td>Angular gyrus</td>
<td>R</td>
<td>5.61</td>
<td>5.55</td>
<td>38</td>
<td>x = 38, y = −66, z = 44</td>
</tr>
</tbody>
</table>

Pedophiles < controls (girls < women)

| Nucleus caudate                 | R    | 17577                | 5.59            | 5.47            | x = 12, y = 18, z = −8 |
| Nucleus caudate                 | L    | 5.27                 | 5.18            | −8               | x = 14, y = −8, z = −8 |
| Superior parietal gyrus         | R    | 5.27                 | 5.18            | 32               | x = −62, y = 52, z = 0 |
| Inferior temporal gyrus         | L    | 5.24                 | 5.14            | −42              | x = −44, y = −40, z = 10 |
| Fusiform gyrus                  | L    | 5.21                 | 5.11            | −38              | x = −46, y = −10, z = 0 |
| Cingulate                       | L    | 5.07                 | 4.98            | −2               | x = 4, y = 28, z = 0 |
| Occipital lobe                  | L    | 4.77                 | 4.70            | −38              | x = −78, y = 0, z = 0 |
| Amygdala                        | L    | 4.75                 | 4.68            | −18              | x = 0, y = 12, z = 0 |
| Superior parietal gyrus         | L    | 4.66                 | 4.59            | −26              | x = −56, y = 46, z = 24 |
| Fusiform gyrus                  | R    | 4.59                 | 4.52            | 44               | x = −42, y = −14, z = 0 |
| Inferior temporal gyrus         | R    | 4.51                 | 4.45            | 54               | x = −56, y = −8, z = 0 |
| Insula                          | L    | 4.25                 | 4.19            | −32              | x = 12, y = −10, z = 0 |
| Inferior frontal gyrus          | R    | 4.21                 | 4.16            | 44               | x = 24, y = 22, z = 0 |
| Thalamus                        | L    | 4.04                 | 4.00            | −16              | x = −8, y = 10, z = 0 |
| Cerebellum                      | R    | 3.46                 | 3.43            | 28               | x = 28, y = −48, z = −30 |

Abbreviation: MNI, Montreal Neurological Institute.

aSignificant clusters only (uncorrected threshold: P < .001).

Table 1 displays the individual expression values for all 56 participants. The predictive power of the individual expression values depends on the proportion of significant vs nonsignificant voxels of the group t statistical difference map, which was taken into account. For instance, if individual expression value calculations are based on the whole-brain t statistical difference map, more “noise” would be accumulated in the individual expression values. In contrast, restricting individual expression values to significant areas of the group t statistical difference map would reduce the influence of noise. In the absence of previous experiences with statistical thresholds in this regard and its effect on subsequent classification accuracy, we tested 4 different thresholds (whole brain; t > 2; t > 3; and t > 4). Accordingly, we performed steps 3 and 4 and subsequent cross-validations based on these thresholds to determine the effect of whole-brain t maps vs a more region-specific analysis.

RESULTS

BEHAVIORAL RESPONSES

Ratings corresponded to participant sexual preferences (Figure 1). Repeated-measures analyses of variance revealed main effects of stimulus type in the groups of heterosexual teleiophiles ($F_{3,30} = 26.25; P < .001$), homosexual pedophiles ($F_{3,30} = 22.62; P < .001$), and homosexual pedophiles ($F_{3,30} = 22.62; P < .001$). Interestingly, heterosexual pedophiles rated pictures of women and girls as sexually attractive, and the difference between these ratings was not significant ($t_{15} = 1.45; P = .18$). This result is in accordance with the clinical assessment of our sample showing that the nonexclusive pedophiles were predominantly heterosexual pedophile participants.

AUTOMATIC CLASSIFICATION

Analysis of variance (step 2) revealed significant differences of the individual difference maps between pedophilic and teleiophilic participants in widespread brain areas. This was found in the boys vs men as well as the girls vs women contrast (Figure 2 and Table 1). However, as shown in Figure 2 and Table 1, group differences were more extended in the boys vs men than in the girls vs women contrast.

In each participant, the individual brain response was characterized by 2 expression values, one for the girls < women contrast and one for the boys < men contrast. Figure 3 displays the individual expression values based on whole-brain t maps for all 56 partici-
To our knowledge, this study is the first to apply a neurofunctional pattern classification to assess pedophilia. Relying solely on the spatially distributed between-group differences in functional brain response to sexual stimuli, a pattern classification algorithm distinguished participants with pedophilia from healthy controls with a high degree of accuracy. Classification accuracy was robust when classifying previously unseen participant fMRI activation maps.

We chose a mixed sample of heterosexual and homosexual men who were either attracted to adults or children to test automatic classification accuracy under the realistic condition of not knowing whether a supposed pedophile is homosexual or heterosexual. By integrating these 2 comparisons (boys vs men) and (girls vs women), we were able to reliably discriminate teleiophilic participants from pedophilic participants (no matter whether the latter were exclusive pedophilic, nonexclusive pedophilic, heterosexual pedophilic, or homosexual pedophilic). As Figure 3 demonstrates, the boys vs men comparison was able to discriminate within the homosexual participants those attracted to adults from those attracted to children. Conversely, the girls vs women comparison was more sensitive to discriminate with regard to the heterosexual probands.

When applying a neurofunctional pattern classification algorithm, diagnostic accuracy relies on the discriminative power of the spatially distributed brain response as triggered by stimuli. In the present study, we presented core sexual stimuli that triggered a highly discriminative response pattern in participants. This result is consistent with previous research showing that core sexual stimuli reliably trigger preference-specific responses independent of either the sex of the participant or the stimulus.54

We consistently found preference-specific brain activity in a distributed set of brain areas, most of them known to be involved in processing sexually arousing stimuli, such as the caudate nucleus, cingulate cortex, insula, fusiform gyrus, temporal cortex, occipital cortex, thalamus, amygdala, and cerebellum.37 The highly consistent activation differences in these brain areas account for our algorithm’s high classification accuracy, but only when classified by means of Fisher linear discriminant analysis. When we restricted the calculation of the individual expression values to these brain areas (by increasing the t threshold), the mean classification accuracy improved from 89% to 95% (Table 2).

Apparently, the classification algorithm performs less optimally in cases of participants with ambiguous sexual preferences. All of the 3 misclassified participants (Fisher linear discriminant, t > 4) (Table 2) were pedophiles of the nonexclusive type (2 heterosexual pedophiles and 1 homosexual pedophile). Most of the nonexclusive pedophiles in our sample were heterosexual (5 of 7 nonexclusive pedophiles). This might account for the smaller group differences in the girls vs women contrast in comparison with the boys vs men contrast and in turn with the misclassification of the 2 heterosexual pedophiles.
Comparing neurofunctional pattern classification with the phallometric assessment in terms of accuracy yields a heterogeneous picture. When administered to pedophiles who admit their sexual orientation, the phallometric assessment shows perfect sensitivity (100%) whereas fMRI-based classification shows a maximal sensitivity of 92%. In contrast, specificity of fMRI-based classification reaches 100%. Specificity scores of the phallometric assessment are reported to be around 81% when pedophiles were compared with a group of healthy controls. In total, mean classification accuracy of the neurofunctional pattern classification approach was somewhat superior as opposed to the phallometric assessment.

However, the present study only included individuals who openly admit to pedophilia. Objective assessment of sexual preferences is generally needed when there is doubt about the subject's sexual preference, for instance, in single-victim child sexual offenders who declare not to be pedophilic. Sensitivity of the phallometric assessment in nonadmitting pedophiles is reported to be about 78% for heterosexual pedophiles and 89% for homosexual pedophiles. The decrease from 100% sensitivity in admitting pedophiles to 78% and 89%, respectively, in nonadmitting pedophiles can be attributed to the ability of some men to manipulate their penile responses during the phallometric measurement. Currently, it is not known whether phallometric assessment technique should be tested more extensively. For example, test-retest reliability has to be evaluated. This issue is crucial, and it has been repeatedly criticized in phallometry. Moreover, future studies should include pedophiles who do not admit their sexual orientation. Finally, fMRI research should test whether participants are able to falsify their response to sexual stimuli.

### Table 2. Sensitivity and Specificity Scores of Fisher Linear Discriminant Analysis and KNN Analysis After Cross-validation for Various t Levels

<table>
<thead>
<tr>
<th>Classification Algorithm</th>
<th>Brain Area Considered for Expression Values</th>
<th>No. of False Positives</th>
<th>Specificity, %</th>
<th>No. of False Negatives</th>
<th>Sensitivity, %</th>
<th>Mean Accuracy, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>KNN</td>
<td>Whole brain</td>
<td>3</td>
<td>91</td>
<td>4</td>
<td>83</td>
<td>88</td>
</tr>
<tr>
<td></td>
<td>t &gt; 2</td>
<td>2</td>
<td>94</td>
<td>3</td>
<td>88</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>t &gt; 3</td>
<td>3</td>
<td>91</td>
<td>6</td>
<td>75</td>
<td>84</td>
</tr>
<tr>
<td></td>
<td>t &gt; 4</td>
<td>5</td>
<td>84</td>
<td>9</td>
<td>63</td>
<td>75</td>
</tr>
<tr>
<td>Fisher</td>
<td>Whole brain</td>
<td>4</td>
<td>88</td>
<td>2</td>
<td>92</td>
<td>89</td>
</tr>
<tr>
<td></td>
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<td>2</td>
<td>94</td>
<td>2</td>
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<td>93</td>
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<tr>
<td></td>
<td>t &gt; 3</td>
<td>2</td>
<td>94</td>
<td>3</td>
<td>88</td>
<td>91</td>
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<tr>
<td></td>
<td>t &gt; 4</td>
<td>0</td>
<td>100</td>
<td>3</td>
<td>88</td>
<td>95</td>
</tr>
</tbody>
</table>

Abbreviation: KNN, K-nearest neighbor.

*We calculated expression values entered into the classification algorithm with respect to either whole-brain t maps or t maps restricted by a threshold of t > 2 to t > 4.*
REFERENCES


