Social Cognitive and Affective Neuroscience, 2017, 1890–1901

doi: 10.1093/scan/nsx127
Advance Access Publication Date: 25 October 2017
Original article

Neural correlates of preferred activities: development of an interest-specific go/nogo task

Dienke J. Bos,[1,2] Eliana L. Ajodan,[1,3] Melanie R. Silverman,[1,3] Jonathan P. Dyke,[4] Sarah Durston,[2] Jonathan D. Power,[1,5] and Rebecca M. Jones[1,3]

[1]Weill Cornell Medicine, The Sackler Institute for Developmental Psychobiology, Department of Psychiatry, New York, NY, USA, [2]Department of Psychiatry, Brain Center Rudolf Magnus, University Medical Center Utrecht, Utrecht University, Utrecht, The Netherlands, [3]Weill Cornell Medicine, Center for Autism and the Developing Brain, Department of Psychiatry, New York, NY, USA, [4]Weill Cornell Medicine, Citigroup Biomedical Imaging Center, Department of Radiology, New York, NY, USA, and [5]Department of Psychiatry, New York Presbyterian Hospital, NY, USA

Correspondence should be addressed to Dienke J. Bos, The Sackler Institute for Developmental Psychobiology, Department of Psychiatry, Weill Cornell Medicine, Box 140, 1300 York Avenue, New York, NY 10065, USA. E-mail: dienkebos@gmail.com

Abstract

The activities we choose to spend our leisure time with are intrinsically motivating and vary across individuals. Yet it is unknown how impulse control or neural activity changes when processing a preferred stimulus related to a hobby or interest. Developing a task that assesses the response to preferred interests is of importance as it would be relevant to a range of psychiatric disorders that have hyper- or hypo-arousal to such cues. During functional Magnetic Resonance Imaging (fMRI), 39 healthy adults completed a novel task to test approach behavior and cognitive control to cues that were personalized to the participants' interests compared to stimuli the participants identified as being of non-interest and colored shapes. fMRI results showed that cues of one's interest elicited activation in the anterior insula compared to colored shapes. Interests did not change inhibition compared to non-interests and colored shapes and all stimuli equally engaged a frontostriatal circuit. Together the results suggest that adults were sensitive to their interests but were effective at regulating their impulses towards these cues, a skill that is critical for navigating the temptations and distractions in our daily environment.

Key words: motivational cues; interests; impulse control; go/nogo task; fMRI; anterior insula

Introduction

Motivation drives human behavior and decision-making. A large body of work shows that affective or rewarding stimuli such as faces, erotic images, food images and money can bias decision making and that individuals often have difficulty exerting cognitive control over their responses to these cues (Somerville *et al.*, 2011; Tottenham *et al.*, 2011; Geier and Luna, 2012; Demos *et al.*, 2012; Deuter *et al.*, 2013; Teslovich *et al.*, 2014). However, it is unknown how behavior or neural activity changes when processing stimuli related to one's preferred activities. Unlike money or social cues which are fundamental motivators (Daw and Doya, 2006; Jones *et al.*, 2011), individuals may differ in how they choose to spend their leisure time or what professional career they pursue, suggesting that certain hobbies or interests may be more intrinsically motivating to certain individuals. Intriguingly, individuals with Major Depressive Disorder often express less interest in engaging in leisure activities of all kinds

Received: 6 March 2017; **Revised:** 3 October 2017; **Accepted:** 23 October 2017

and conversely individuals with Autism Spectrum Disorder (ASD) often have an intense focus on a specific hobby or interest that disrupts daily functioning (American Psychiatric Association, 2013). Thus, understanding the typical response to stimuli relating to preferred activities and whether there are differences in cognitive control when presented with these stimuli may provide a foundation that ultimately can be applied to studying a range of disorders that demonstrate either hypo- or hyper- arousal to such stimuli.

Using various response inhibition paradigms, including go/nogo tasks, prior work has shown that accuracy (hit rate) and reaction times vary depending on the motivational content of stimuli. For example, healthy adults were faster to respond to positive versus negative facial expressions (Hare and Casey, 2005; Schulz *et al.*, 2007; Hare *et al.*, 2008; Tottenham *et al.*, 2011; Cohen-Gilbert *et al.*, 2014), and other positive cues such as food, monetary rewards or pleasant scenes also elicited speeding and/or increased accuracy (Geier and Luna, 2012; Deuter *et al.*, 2013; Teslovich *et al.*, 2014). Conversely, motivational stimuli may interfere with inhibitory responses [false alarms and/or d-prime (d′)], as it is harder to inhibit a motor response to a cue that is motivating or arousing. Adults were more impulsive to emotional faces as opposed to neutral faces (Tottenham *et al.*, 2011) or foods compared to non-foods (Teslovich *et al.*, 2014). Along similar lines, smokers and heavy drinkers were more impulsive towards smoking- and alcohol-related stimuli specifically (Ames *et al.*, 2014; Zhao *et al.*, 2016). However, the behavioral response to cues of one's interests is still unknown.

A network of brain areas that has been associated with the identification of relevant or motivating stimuli is the 'salience network', including the dorsal Anterior Cingulate Cortex (dACC) and the bilateral insula (Seeley *et al.*, 2007). The latter is broadly implicated in the processing of a wide range of affective stimuli including both positive and negative emotional faces and scenes. Specifically, processing positive stimuli demonstrated left dominance in anterior insula activity (for a comprehensive overview and meta-analysis, see Duerden *et al.*, 2013). In addition to detecting positive valence, the insula is thought to be closely tied to cognitive control, where this region may be crucial in initiating modulation of frontostriatal control areas (Dosenbach *et al.*, 2006; Menon and Uddin, 2010; Jiang *et al.*, 2015). Together these findings suggest the importance of the anterior insula in affective processing and promoting flexible cognitive control abilities.

Response inhibition tasks with specific, motivating stimuli have also provided deeper insight into the mechanisms of various psychiatric disorders. For example, food, non-food and physical activity cues have been used to study eating disorders (Brooks *et al.*, 2011; Kullmann *et al.*, 2014; Teslovich *et al.*, 2014), pictures of alcohol, drugs or gambling to study various addictions (Noël *et al.*, 2007; van Holst *et al.*, 2012; Pike *et al.*, 2013, 2015), and positive (happy) and negative (sad or threat) facial expressions or words to study mood disorders and schizophrenia (Elliott *et al.*, 2004; Erickson *et al.*, 2005; Wessa *et al.*, 2007; Hummer *et al.*, 2013; Krakowski *et al.*, 2016). There are currently no go/nogo tasks that utilize cues that reflect individual preferences. Using personalized interests may be particularly relevant to psychiatric disorders such as ASD or Major Depressive Disorder.

We developed a novel neuroimaging paradigm to test approach behavior and cognitive control to cues that reflected participants' preferences compared to stimuli that participants identified as non-interests. Participants performed the task during functional Magnetic Resonance Imaging (fMRI) to determine changes in blood oxygenation linked to accompanying neural activity. Participants also completed a well-established affective go/nogo paradigm, using facial expressions, where we expected to find results typical for this task (Hare and Casey, 2005; Shafritz *et al.*, 2006; Schulz *et al.*,2007). The social stimuli served as a comparison condition to the non-social stimuli in the interests conditions. We predicted that participants would have faster reaction times to their interests and would be more impulsive to these cues compared to their non-interests. We predicted these behavioral findings would be associated with increased activity in arousal circuitry, including anterior insula. We also predicted that successful inhibition to these cues would engage increased activity in cognitive control regions such as the inferior frontal gyrus (IFG) (Aron *et al.*,2014). Lastly, we explored whether healthy adults with more ASD-like traits or greater impulsivity [e.g. Attention Deficit Hyperactivity Disorder (ADHD)-like traits] would demonstrate increased sensitivity to cues of their interest.

Table 1. Demographic characteristics of the sample.

	Participants N = 40
Demographics	
Age—Mean ± SD	23.6 ± 3.3
Gender (M/F)	22/18
Handedness (right/left/ambidextrous)	39/0/1
Cognitive abilities	
VIQ—Mean ± SD	110.8 ± 16.6
NVIQ—Mean ± SD	103.4 ± 17.1
Self-Report Questionnaires	
SRS T-score—Mean ± SD	53.8 ± 9.1
AQ—Mean ± SD	16.9 ± 7.2
ASR Attention problems T-score—Mean ± SD	53.6 ± 6.8
ASR ADHD T-score—Mean ± SD	53.4 ± 5.6

Abbreviations: ADHD = Attention Deficit/Hyperactivity Disorder, ASR = Adult Self-Report, AQ = Autism Quotient, NVIQ = non-verbal intelligence quotient, SD = standard deviation, SRS = Social-Responsiveness Scale-2, VIQ = verbal intelligence quotient.

Materials and methods

Participants

Forty healthy adults (22 males, 18 females), aged 18–29 years (Table 1) were recruited to participate through the Sackler Institute for Developmental Psychobiology in Manhattan, New York. All participants reported no use of psychotropic medications, past diagnoses of, or treatment for, psychiatric or neurological disorders. Participants were right-handed except for one individual, as measured by the Physical And Neurological Examination for Soft Signs (Table 1, PANESS: (Denckla, 1985)). Informed written consent was obtained from all participants as approved by the Weill Cornell Medicine Institutional Review Board.

Cognitive testing and self-report questionnaires

Participants completed the Wechsler Adult Intelligence Scale (WAIS-IV)(Wechsler, 2008) so that each individual had standard scores for verbal and non-verbal IQ (Table 1). In addition, to measure general ASD symptoms, participants completed the Social Responsiveness Scale (SRS-2)(Constantino, 2012) and the Autism Quotient (AQ) (Baron-Cohen *et al.*, 2001). Individuals

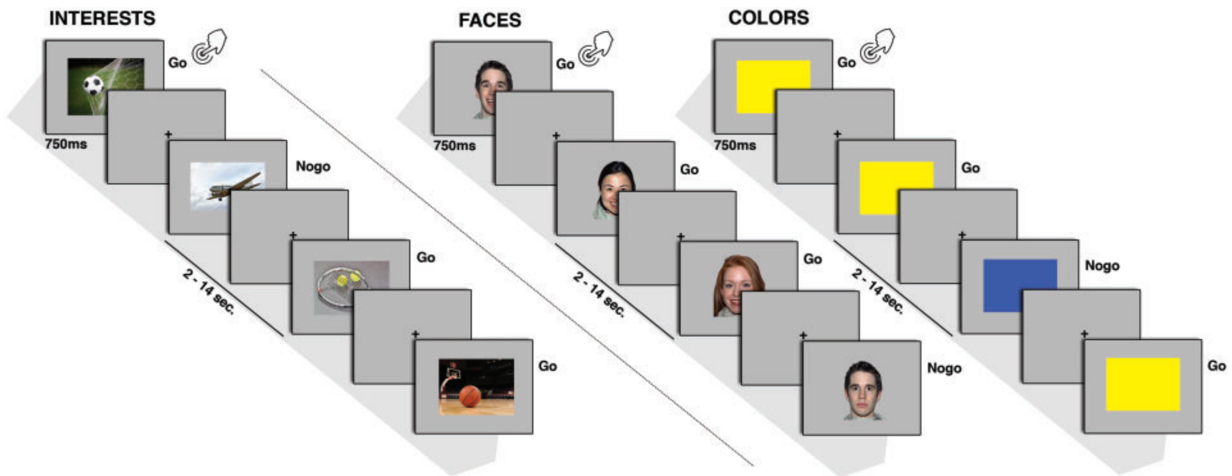

Fig. 1. Experimental design. Stimuli were presented for 750 ms, with a jittered 2–14 s intertrial interval. Interests and non-interests were both presented as target and nontarget. A similar design was used for happy and calm faces in the social runs and for colors in the neutral control condition.

with SRS-2 T-scores > 75 were excluded as these scores are considered in the range of severe social impairment. This resulted in the exclusion of one participant from behavioral and imaging analyses. Participants also completed the Adult Self Report (ASR: Achenbach and Rescorla, 2003) to measure ADHD-like traits such as impulsivity and hyperactivity.

Experimental task

Outside of the MRI scanner, participants were presented with images of 23 popular hobbies or activities such as cooking, sports, hiking, subway maps, Japanese anime or trucks and were asked to choose their *favorite* interest or hobby and their *least favorite* from the options. The 23 options were based upon prior informal polling of common adult interests or hobbies as well as common interests for individuals with ASD (Klin *et al.*, 2007) (described in detail in the Supplementary Material). Participants confirmed their preference and dislike by rating their choices on a 10-point rating scale and interests were rated as more pleasurable than non-interests [$t(39) = 15.6$, $P < .001$].

Participants completed five runs of go/nogo tasks during functional MRI (fMRI). There were three task conditions: 1) interests (non-social), 2) facial expressions (social) and 3) colored shapes (control). As depicted in Figure 1, within a single run, a specific category of cues served as a go (i.e. target) stimulus to which participants were instructed to press a button and another category of cues served as a nogo (i.e. nontarget) stimulus for which participants withheld a button press. For the interest conditions, 12 unique images of each participant's favorite activity (interest) and 12 unique images of the participant's least favorite activity (non-interest) were presented randomly as the target or nontarget and were reversed in a second run. In the social condition, similar to previous work (Hare and Casey, 2005), 12 (6 M, 6 F) happy and 12 (6 M, 6 F) calm faces from the NimStim set (Tottenham *et al.*, 2009) were presented as the target and nontarget stimuli and reversed as the target and nontarget in a second run. Finally, in the control condition, a single run of blue and yellow rectangles (colors) served as target and nontarget stimuli. The five runs were counterbalanced across subjects. Participants practiced the task outside of the scanner with colored shapes so that they understood the instructions.

Each run was 5 min and 58 s and contained 77 go-stimuli and 30 nogo-stimuli, presented in a pseudorandomized order. Within each trial, the go and nogo stimuli were presented for 750 ms followed by a jittered intertrial interval (2–14 s) (described in detail in the Supplementary Material). A five-button MR-compatible button box was used to record button responses and reaction times. The experimental task was presented using E-Prime 2.0 and was projected onto a flat screen mounted in the scanner bore.

fMRI data acquisition

Whole-brain fMRI data were acquired using a Siemens Magnetom Prisma 3 T scanner located at the Citigroup Biomedical Imaging Center (CBIC) at Weill Cornell Medicine. A high-resolution, T1-weighted magnetization-prepared rapid-acquisition gradient-echo sequence scan was acquired (TR/TE = 2400/2.12 ms, Field of View (FOV) = 256 mm, 1.0 mm isotropic). Two fieldmap images were acquired in opposing phase-encoding directions (TR/TE = 8860/80 ms, FOV = 216 mm, multiband factor = 6, echo spacing = 0.56 ms, 2.4 mm isotropic). Functional images were acquired using T2*-sensitive echo-planar pulse sequences covering the full brain. Sixty-six axial slices were acquired per 800 ms TR (TE = 30 ms, FOV = 216 mm, flip angle = 49°, multiband factor = 6, echo spacing = 0.56 ms, 2.4 mm isotropic)(Feinberg *et al.*, 2010; Moeller *et al.*, 2010; Setsompop *et al.*, 2012; Xu *et al.*, 2012).

Behavioral data analysis

Behavioral data and stimulus timing information were extracted and calculated using MATLAB and Statistics Toolbox Release 2016 b (MathWorks, Natick, USA). Analyses were conducted separately for the non-social and social conditions due to qualitative difference in how participants interacted with the stimuli prior to the experiment, i.e. participants were given a choice of stimuli in the non-social conditions, which was not the case in the social conditions. The color condition was added to both analysis designs to serve as a neutral control comparison. Participants were included in behavioral and imaging analyses if accuracy on go-trials was ≥70% and false alarms during nogo-trials was <50% (described in detail in the Supplementary Material). Three participants were excluded from analyses in the colors condition, six in the non-social condition and four in the social condition.

Mean reaction time (RT) to correct go-trials was computed for each condition. Trials with RT's faster than 200 ms were considered invalid responses and consequently excluded. In addition to mean RT, to better capture the characteristics of RTs across conditions, ex-Gaussian parameters were computed (*mu*, *sigma* and *tau*) by fitting the ex-Gaussian distribution with maximum likelihood estimation to the valid RT's for correct go-trials (Zandbelt, 2014). *Mu* is the mean and *sigma* is the standard deviation from a normal (Gaussian) distribution, and *tau* is the mean and standard deviation of the exponential distribution, thus *tau* typically reflects positive skew in the RT distribution. As an index of impulsive behavior, the number of false alarms to nogo-trials was calculated, including d' by subtracting normalized false alarm rate from normalized accuracy at go-trials (Macmillan and Creelman, 2004).

All statistical analyses were conducted using R (release 3.2.1). We tested for main effects of stimulus type in two analyses, non-social (including colors) and social (including colors) with the dependent variables mean RT, ex-Gaussian parameters *mu*, *sigma* and *tau*, d' and false alarms using Linear Mixed-Effects (LME) models (*lme4* in R: Bates *et al.*, 2014), with task condition as a repeated measures factor, and age as a covariate. Our age range of 18–29 years spans late adolescence into adulthood and prior work suggests age differences to motivational stimuli across this period (Cohen-Gilbert *et al.*, 2014; Cohen *et al.*, 2016). As there were no interactions with age for behavioral or imaging results, age was subsequently no longer included as a covariate in analysis models.

In the presence of a significant main effect, post-hoc pairwise comparisons of the least-square means were performed (*P*-values Tukey-adjusted). In addition, task performance measures that showed a main effect were further interrogated to determine whether there was an association with ASD traits as measured by the SRS and AQ, and ADHD-like traits as measured by the ASR (correlation *P*-values were Bonferroni-adjusted to $P < .016$ to account for the three conditions tested in each model).

fMRI analysis

Data were preprocessed using a standard pipeline in Analysis of Functional NeuroImages (AFNI) software [version AFNI_16.0.00: (Cox, 1996)] and FSL (FMRIB Software Library v5.8)(described in detail in the Supplementary Material). A general linear model (GLM) was created for each participant to estimate signal change in response to interests, non-interests, happy faces, calm faces and colors. Each participant's GLM included 21 regressors: five task regressors for correct responses to the go-stimuli in each condition, five task regressors for correct inhibitions to the nogo-stimuli in each condition, five additional task regressors for false alarms to the nogo-stimuli in each condition and six motion estimation parameters. Time points with a framewise displacement (Power *et al.*, 2014) greater than 0.5 mm were censored, along with the two successive time points. This resulted in the partial exclusion of one participant in the interests condition, as more than 20% of frames needed to be removed. Otherwise an average of 3% of frames were removed per run across all participants (with a maximum of 20% per run, Supplementary Table S2) (For details on the effects of this motion censoring procedure see the Supplementary Material). Baseline trends were estimated to capture shifts in signal change. Activation in response to the go and nogo stimuli was modeled with a gamma hemodynamic-response function (HRF). Individual-level regression coefficients for 39 participants were submitted to group LME analyses using *3dMEMA* (Chen *et al.*, 2013).

Group-level LME-analyses modeled main effects. First, LME analyses were performed with the non-social stimuli and colors, including a random intercept, versus baseline on correct go-trials and correct nogo-trials, respectively. A second LME approach included interests and colors versus baseline, and non-interests and colors versus baseline, on correct go-trials and correct nogo-trials respectively, in order to further interrogate interest-specific differences in impulse control. For facial expressions, two LME-analyses modeled the main effects of the social stimuli and colors, including random intercept, versus baseline on the respective correct go- and nogo-trials. For the non-social and social conditions, a frequently reported nogo > go contrast was performed, however, as expected based on recent suggestions that such a contrast may not be optimal to observe differences across the two constructs (go, nogo) (Criaud and Boulinguez, 2013) no clusters survived whole-brain correction.

Following recent recommendations, the threshold for individual voxels was set at $P < .001$ (Cox *et al.*, 2016; Eklund *et al.*, 2016). Estimates for image smoothness for the simulations were calculated using 3dFWHMx and subsequently fed into 3dClustSim (compile date = 01/01/2016). The cluster-size threshold, computed using 10 000 Monte Carlo simulations was set at 38 voxels ($P < .05$ after Family Wise Error correction for multiple comparisons).

Using a 6 mm sphere around the peak activation voxel, regression coefficients for individual participants were extracted from regions in the four LME-model maps that showed significant activation after whole brain correction as outlined above and were associated with emotion regulation, salience detection and cognitive control (regions highlighted in the Results section and Supplementary Tables S4–S7).

Subsequent LME analyses were performed on these ROIs (Supplementary Tables S4–S7) to determine condition main effects for non-social and social stimuli (all including colors). *P*-values were Bonferroni-adjusted according to the number of ROIs tested. Significant main effects were then followed up with post-hoc pairwise comparisons (difference in least-square means corrected for multiple comparisons using Tukey's test) and correlations with task performance and ASD and ADHD-like traits in R.

Results

Task performance for interests

Overall, Go accuracy was high (mean = 95.2, SD = 6.4, Figure 3, Supplementary Table S1), with a main effect ($F_{(2, 53)} = 4.1$, $P = .022$), demonstrating lower accuracy for non-interests compared to colors and a trend of lower accuracy for non-interests versus interests (Table 2).

Mean reaction times for go-trials differed across conditions ($F_{(2, 62)} = 69.0$, $P < .001$), as participants were significantly slower to their interests and non-interests compared to colors (Table 2, Figure 2A). A similar pattern was observed for the ex-Gaussian parameter *mu* ($F_{(2, 64)} = 51.2$, $P < .001$), where participants demonstrated significantly slower *mu* to interests and non-interests compared to colors (Table 2, Figure 2A). There were no differences in mean RTs or *mu* for interests versus non-interests. The ex-Gaussian parameter *tau* also showed a main effect ($F_{(2, 56)} = 8.4$, $P < .001$), with higher *tau* for non-interests as compared to colors (Table 2, Figure 2A). There was no difference in

Table 2. Pairwise comparisons of the behavioral measures.

	Go Accuracy					Mean RT					Mu				
	ß	s.e.	P	95% CI		ß	s.e.	P	95% CI		ß	s.e.	*p*	95% CI	
Interests				lower	upper				lower	upper				lower	upper
Colors—Interests	0.22	1.28	0.980	−2.78	3.22	**−76.5**	**8.19**	**<.001**	**−95.71**	**−57.35**	**−62.0**	**6.95**	**<.001**	**−78.32**	**−45.75**
Colors—Non-interests	**3.26**	**1.26**	**0.033**	**0.31**	**6.22**	**−86.8**	**8.03**	**<.001**	**−105.62**	**−67.97**	**−58.4**	**6.82**	**<.001**	**−74.36**	**−42.40**
Interests—Non-interests	3.04	1.30	0.055	0.03	6.06	−10.3	8.16	0.424	−29.38	8.84	3.66	6.93	0.858	−12.58	19.90
Facial expressions															
Colors—Happy faces						**−78.9**	**8.61**	**<.001**	**−99.03**	**−58.67**	**−57.7**	**7.97**	**<.001**	**−76.39**	**−39.00**
Colors—Calm faces	*No main effect*					**−103.7**	**8.67**	**<.001**	**−124.02**	**−83.37**	**−90.0**	**8.02**	**<.001**	**−108.83**	**−71.21**
Happy—Calm faces						**−24.8**	**8.63**	**.015**	**−45.07**	**−4.62**	**−32.3**	**8.00**	**<.001**	**−55.00**	**−13.59**

	σ					τ				
	ß	s.e.	*p*	95% CI		ß	s.e.	p	95% CI	
Interests				lower	upper				lower	upper
Colors—Interests						−14.11	6.70	0.118	−30.51	2.29
Colors—Non-interests	*No main effect*					**−28.15**	**6.90**	**<.001**	**−44.24**	**−12.06**
Interests—Non-interests						−14.04	7.00	0.119	−30.40	2.31
Facial expressions										
Colors—Happy faces	−5.29	3.50	0.288	−13.45	2.87					
Colors—Calm faces	**16.87**	**3.49**	**<.001**	**−25.05**	**−8.70**	*No main effect*				
Happy—Calm faces	**−11.58**	**3.49**	**0.004**	**−19.77**	**−3.40**					

	False alarms					d′-prime				
	ß	s.e.	P	95% CI		ß	s.e.	P	95% CI	
Interests				lower	upper				lower	upper
Colors—Interests						0.27	0.13	0.089	−0.02	0.57
Colors—Non-interests	*No main effect*					**0.54**	**0.13**	**<.001**	**0.24**	**0.84**
Interests—Non-interests						0.27	0.13	0.087	−0.02	0.57
Facial expressions										
Colors—Happy faces	**−5.22**	**1.70**	**0.009**	**−9.19**	**−1.24**	**0.65**	**0.13**	**<.001**	**0.35**	**0.94**
Colors—Calm faces	**−4.82**	**1.75**	**0.022**	**−8.92**	**−0.71**	**0.51**	**0.13**	**<.001**	**0.21**	**0.80**
Happy—Calm faces	0.40	1.50	0.961	−3.10	3.90	−0.14	0.12	0.508	−0.43	0.15

Notes: Pairwise comparisons are only reported in the presence of a significant main effect of task condition. Statistics of main effects are mentioned in the text. Significant pairwise comparisons are displayed in bold. CI = Confidence interval, RT = Reaction time, s.e. = Standard error.

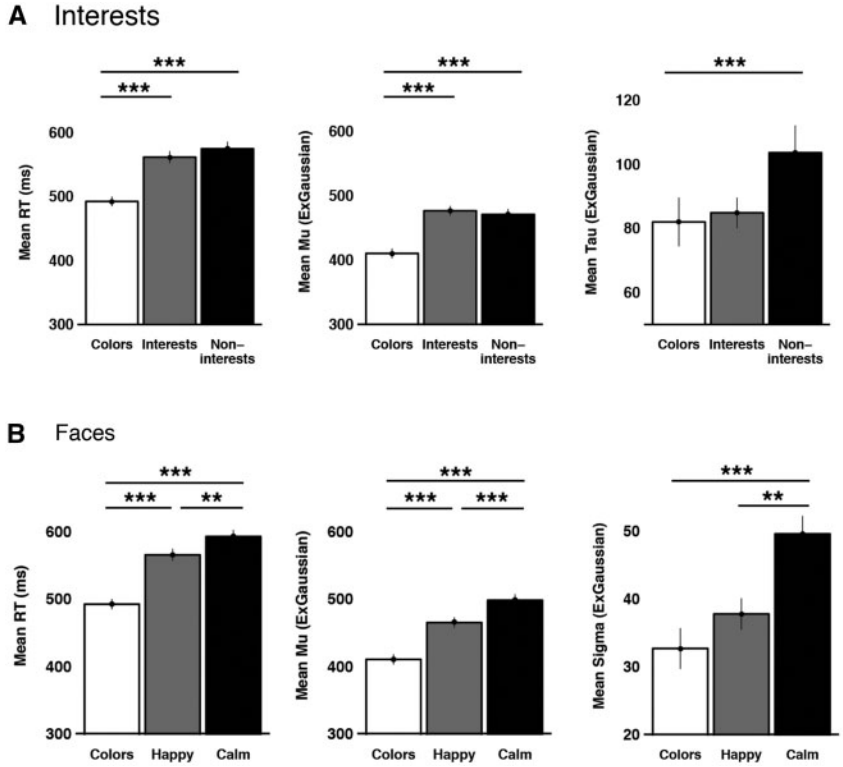

Fig. 2. Behavioral results on go-trials. Panel A displays the main effects for mean reaction time (RT), and the mean ex-Gaussian parameters *mu* and *tau*, for interests, non-interests and colors. Panel B displays main effects for mean reaction time (RT), and the mean ex-Gaussian parameters *mu* and *sigma* for happy- and calm faces and colors. Asterisks display significance of pairwise comparisons: *** for $P < .001$, ** for $P < .01$.

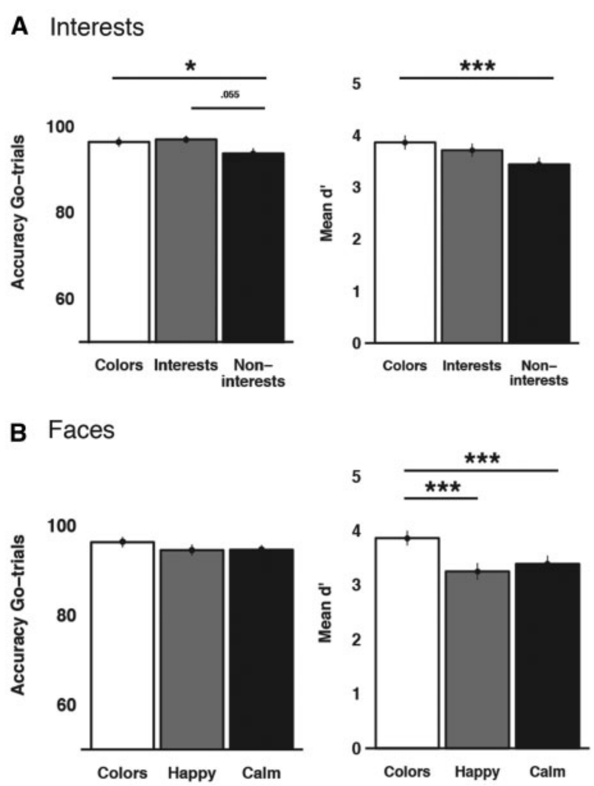

Fig. 3. Behavioral results for inhibition. Panel A displays the main effect for accuracy on go-trials and *d*′ for interests, non-interests and colors. Panel B displays the main effect for accuracy on go-trials and *d*′ for happy- and calm faces and colors. Asterisks display significance of pairwise comparisons: *** for $P < .001$.

tau between interests versus non-interests or interests versus colors. There was no main effect for the ex-Gaussian parameter *sigma* ($P = .195$).

D' varied across conditions ($F_{(2,\ 56)} = 9.23$, $P < .001$), driven by higher *d*' for colors compared to non-interests (Table 2, Figure 3A). There was no difference in *d*' between interests versus non-interests or interests versus colors (Table 2). There was no main effect with the number of false alarms for interests, non-interests and colors during nogo-trials ($P = .088$).

Task performance for facial expressions

Go accuracy (mean = 94.6, SD = 6.8, Figure 3, Supplementary Table S1) was similar for happy faces, calm faces and colors. Mean RT on go-trials varied across conditions ($F_{(2,\ 65)} = 78.2$, $P < .001$), showing participants were faster to colors versus happy and calm faces (Table 2, Figure 2B). Participants were also faster to happy faces versus calm faces. A similar pattern was observed for the ex-Gaussian parameter *mu* ($F_{(2,\ 68)} = 64.7$, $P < .001$), where all post-hoc pairwise comparisons reached significance with participants showing increasing speeding in their RTs to calm faces, happy faces and colors respectively (Table 2, Figure 2B). The ex-Gaussian parameter *sigma* was significant ($F_{(2,\ 71)} = 12.2$, $P < .001$), showing higher variability to calm faces as compared to colors and higher variability to happy faces versus colors (Table 2, Figure 2B). There was no difference for the ex-Gaussian parameter *tau*.$_{d'}$ varied across conditions ($F_{(2,\ 63)} = 14.5$, $P < .001$), as participants had lower *d*′ for both happy and calm faces compared to colors (Table 2, Figure 3B). A similar pattern was observed for the number of false alarms ($F_{(2,\ 51)} = 5.3$, $P = .008$) with more errors for happy and calm faces

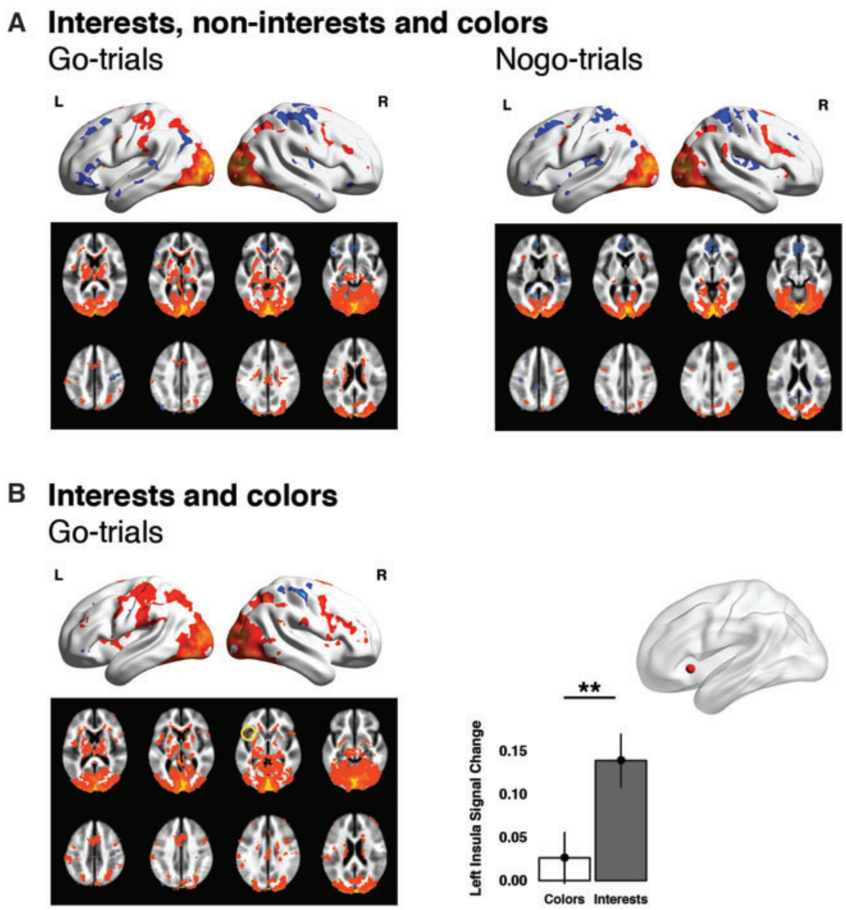

Fig. 4. fMRI results for interests. Panel A displays the whole-brain corrected group maps for interests, non-interests and colors during go- and nogo-trials. Slice intersections are displayed at z = −11, −3, 5, 13, 21, 29, 37, 45 respectively. Panel B displays the whole-brain corrected group maps for interests and colors during go-trials. Slice intersections are again displayed at z = −11, −3, 5, 13, 21, 29, 37, 45. The yellow circle on the intersection third from the left (upper row) marks the peak voxel for the left anterior insula cluster (x = −38, y = 18, z = 3) that showed greater activity for interests relative to colors during go-trials (Panel C). Asterisks display significance of pairwise comparisons: ** for P <.01.

compared to colors (Table 2). There were no differences in d′ or false alarms between happy and calm faces (Table 2).

Correlations between task performance and traits of ASD or ADHD

There was a significant negative correlation between SRS T-scores and mean reaction times on go-trials for Happy faces (r = −.42, P = .013), demonstrating adults with more ASD traits had faster mean RTs to happy faces. Participants with higher SRS T-scores (more ASD-like traits) showed less variability in their reaction times for calm faces (lower ex-Gaussian *sigma)* (r = −.41, P = .015). This correlation also remained significant when controlling for ADHD traits. There were no other significant correlations between SRS- or AQ-scores and task performance for interests or facial expressions during go or nogo-trials.

There was a significant correlation between T-scores on the ASR Attention Problems subscale and *tau* for the color stimuli (*r* = .44, P = .014) that survived Bonferroni-correction, suggesting that adults with more ADHD-like traits had very slow reaction times to the color stimuli in the tail of the RT distribution (higher *tau*). There were no other significant correlations between ASR scores and task performance for interests or facial expressions.

fMRI results for interests

Extensive patterns of activation throughout the visual, motor and prefrontal cortices were evident during go-trials to interests, non-interests and colors compared to baseline that included the contralateral precentral and fusiform gyrus as well as the orbitofrontal gyrus and insula and several subcortical regions including the putamen and caudate nucleus (Figure 4A, Supplementary Table S4). Successful inhibition (nogo-trials) to interests, non-interests and colors versus baseline demonstrated activation in inhibitory control regions including the bilateral IFG (Figure 4A, Supplementary Table S5). There were no condition effects in the regions that survived whole-brain correction.

A targeted approach interrogating interests and colors only compared to baseline (Figure 4B) showed significantly higher

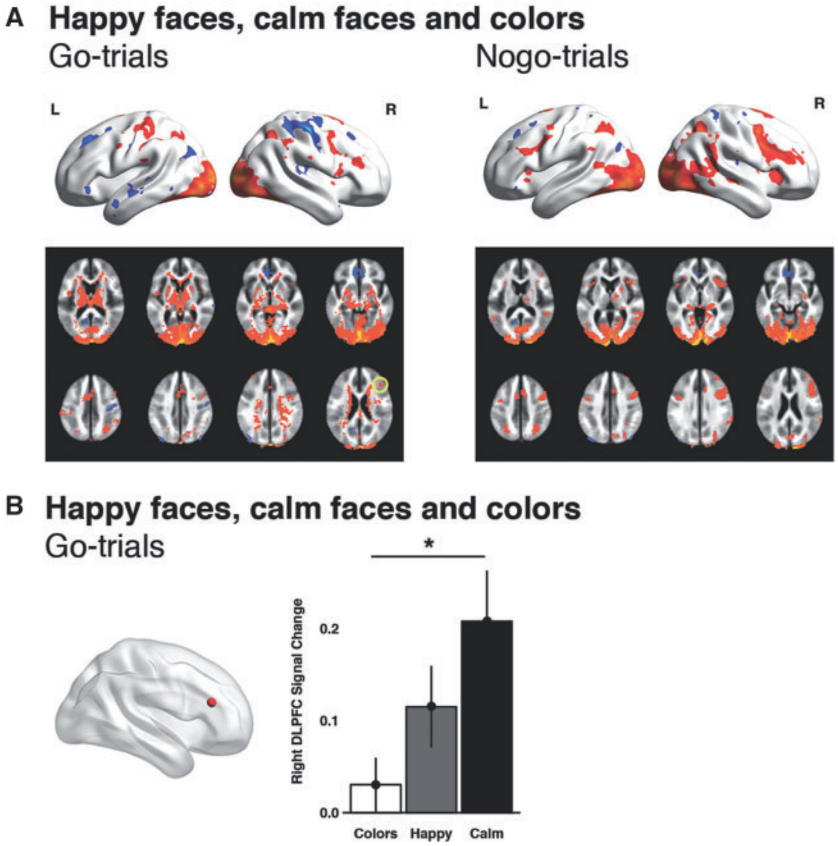

Fig. 5. fMRI results for facial expressions. Panel A displays the whole-brain corrected group maps for happy- and calm faces and colors during go- and nogo-trials. Slice intersections are displayed at $z=-11, -3, 5, 13, 21, 29, 37, 45$ respectively. The yellow circle on the bottom right intersection marks the peak voxel for the right dorsolateral prefrontal cortex (DLPFC) cluster that showed greater activity for calm facial expressions relative to colors during go-trials (Panel B). Asterisks display significance of pairwise comparisons: * for $P<.05$.

activation in the left anterior insula ($F_{(1,\ 32)}=8.0$, $P=.008$) during go-trials for interests compared to colors (Figure 4C). Remaining regions that were interrogated (left and right caudate nucleus, left and right putamen and left IFG) did not demonstrate condition effects during go-trials. A second model with non-interests and colors only compared to baseline demonstrated stronger deactivation in the right medial frontal gyrus (MFG) ($F_{(1,\ 34)}=10.0$, $P=.003$) during go-trials for non-interests compared to colors. No other regions (left caudate nucleus) demonstrated condition effects that survived correction. There were no condition effects that survived correction during nogo-trials.

fMRI results for facial expressions

There was activation in emotion regulation circuitry, including bilateral amygdala, dorsolateral prefrontal cortex (DLPFC) and ventromedial PFC (vmPFC) during go-trials to emotional faces and colors versus baseline (Figure 5A, Supplementary Table S6). There was a difference across conditions in the right DLPFC ($F_{(2,\ 66)}=5.2$, $P=.008$)(Figure 5B), with increased activation for calm faces as compared to colors ($M_{diff}=0.18$, $SE=0.06$, $P=.006$). There was no significant difference in DLPFC activation between happy faces and calm faces ($P=.351$) or colors ($P=.177$).

During successful inhibition to emotional faces and colors there was activation in both emotion regulation areas (e.g. amygdala, DLPFC and vmPFC), and inhibitory control areas (e.g. bilateral IFG) (Figure 5A, Supplementary Table S7). In the left DLPFC, close to left IFG ($F_{(2,\ 70)}=7.3$, $P=.001$), there was increased activation for calm faces as compared to colors ($M_{diff}=0.21$, $SE=0.06$, $P=.001$) and calm faces versus happy faces ($M_{diff}=0.15$, $SE=0.06$, $P=.021$) during successful nogo-trials.

Brain–behavior relationships for interests and facial expressions

Increased activity in the right DLPFC activation was correlated with increased accuracy during go-trials for emotional faces ($r=.35$, $P=.005$). No such correlation was observed with colors. No other correlations between ROIs identified in either the non-social or social conditions of the task, with any other task performance measure or ASD/ADHD traits were significant.

Discussion

The goal of the present study was to develop a neuroimaging paradigm that directly tested whether approach behavior and cognitive control were modulated by stimuli of the subjects' interest as compared to stimuli of non-interest. In healthy adults, we observed a trend in higher hit rates between interests versus non-interests. Further, interest-specific stimuli were associated with greater activation of the anterior insula. However, adults were quite effective at regulating their impulses towards interest cues, as there were no differences in

d', a skill that is critical for navigating the temptations and distractions in our daily environment.

Consistent with our hypotheses, there was a behavioral trend that adults were more accurate to respond to their preferred interest versus non-interest. Our findings were similar to studies that used monetary incentives (Geier and Luna, 2012; Paulsen *et al.*, 2015), speculatively suggesting that one's interests, like other types of rewarding stimuli, may improve accuracy. Participants' accuracy was at ceiling on the task, on average 95%, thus it is likely the subtle difference observed between interests and non-interests ($P = 0.055$) was due to little variability in overall response accuracy. There were no differences between interests versus non-interests in mean or *mu* RT, however, participants were slower to respond to both interests and non-interests relative to colors, suggesting that the colors were easier stimuli to process compared to the visually more complex images of interests and non-interests. There was no difference in accuracy to interests versus colors, which also highlights a potential attentional bias towards these visually complex, yet preferred stimuli.

There was increased activation to interests as compared to colors in left anterior insula which has consistently been associated with the processing of positive versus negative emotional experiences (Kurth *et al.*, 2010; Duerden *et al.*, 2013) and differentiating emotions (Gorno-Tempini *et al.*, 2001). Increased activity in the anterior insula has also been demonstrated during general arousal (Lewis *et al.*, 2007; Citron *et al.*, 2014), supporting the notion that interests may be differentially motivating for participants. Changes in insular functioning have been consistently reported in many psychiatric disorders that have difficulties with regulation and affective processing such as addiction (Droutman *et al.*, 2015), eating disorders (Schienle *et al.*, 2009; Kim *et al.*, 2012; Oberndorfer *et al.*, 2013), ASD (Uddin *et al.*, 2013; Cascio *et al.*, 2014; Odriozola *et al.*, 2015), depression (Hummer *et al.*, 2013; Iwabuchi *et al.*, 2014), or schizophrenia (Baas *et al.*, 2008; Moran *et al.*, 2013). Thus, the heightened activation observed for interests supports a role for the left anterior insula in an attentional bias to positive, motivating cues. Future work may explore how this pattern of activation is modulated by the intensity of one's interest.

Contrary to our hypotheses, individuals did not differ in their inhibition to cues depicting preferred hobbies relative to non-interests. However, similar to what was observed in the social condition, the non-social stimuli induced greater impulsivity relative to the control condition of colors. Further, similar to a large literature using go/nogo tasks with a variety of stimuli (Chikazoe *et al.*, 2007; Hare *et al.*, 2008; Wessa and Linke, 2009), frontostriatal control regions including the IFG and the caudate and putamen were engaged during successful inhibition, yet equally so to interests and non-interests. This suggests that although these interest-related stimuli elicit a subtle behavioral attentional bias, it is unlikely that in healthy adults they influence inhibition or decision making in the same way facial expressions or money do (Daw and Doya, 2006; Jones *et al.*, 2011). However, as we highlight in the limitations section below, the interest-specific stimuli were not fully personalized which may have attenuated the behavioral response to these stimuli.

The facial expressions elicited behavioral and neural activation patterns that were consistent with an extensive literature using variations of this task (Hare and Casey, 2005; Shafritz *et al.*, 2006; Schulz *et al.*, 2009). Participants were slower to respond to calm faces relative to happy faces, as reported previously (Hare and Casey, 2005; Schulz *et al.*, 2007; Somerville *et al.*, 2011), suggesting adults demonstrated a greater bias towards happy faces. Notably, faster responses to happy faces were associated with a higher level of ASD-like traits. Further research should determine whether this effect is specific for happy faces, as there is some evidence that individuals with ASD respond faster to emotional faces generally (Yerys *et al.*, 2013). A frontolimbic circuit including the amygdala and DLPFC was engaged during processing of facial expressions, similar to previous work demonstrating these regions are part of a critical circuit for explicit emotion regulation and appraisal (Phillips *et al.*, 2008; Etkin *et al.*, 2015). The DLPFC demonstrated heightened activation for calm and happy faces relative to colors, which was also related to increased accuracy to faces, supporting a role for this region in top down control in response to emotional stimuli. Although inhibition to the facial expressions differed significantly from colors, we did not find behavioral or neurobiological differences in impulsivity to happy versus calm faces.

Ultimately, the interest-specific go/nogo paradigm may be applied to study clinical populations that have aberrant responses to social and/or non-social stimuli. For instance, children with ASD showed increased activation in left anterior insula (Cascio *et al.*, 2014) and fusiform face area (FFA)(Foss-Feig *et al.*, 2016) when viewing images related to one's interest, illustrating the increased arousal and visual expertise for these stimuli in ASD. Also, the slight attentional bias found in this healthy adult sample may become more pronounced in clinical populations that have impairments in reward sensitivity, such as in ASD, ADHD or depression. We found no differences based on ASD-like traits in behavioral performance or neural activation to interests versus non-interests, yet it should be noted the majority of these healthy adults had scores within the typical range ($<$60 on the SRS and $<$26 on the AQ). Similarly, ASR scores relating to ADHD-like traits were in the typical range ($<$70 on the ADHD Subscale). In healthy adults, the ex-Gaussian parameter *tau* was highest for non-interests. The slow and infrequent responses captured by *tau* have been associated with higher intra-individual variability or attentional lapses, e.g. as seen in ADHD (Geurts *et al.*, 2008; Lin *et al.*, 2015). We found higher scores on the ASR attention problems correlated with higher *tau* for colors, but there were no differences in *tau* for interests, non-interests or facial expressions. Overall the findings with *tau* suggest that the ex-Gaussian parameters uncovered nuances in the behavioral responses to interests and non-interests as compared to neutral or social cues that may be informative for future work in clinical populations (Karalunas *et al.*, 2014).

Limitations

While there is a theoretical basis to directly compare the non-social cues (interests and non-interests) and social cues (facial expressions), such a contrast is problematic due to the nature of how participants engage with these stimuli prior to the task. Participant choice makes the interests and non-interests more personalized, thus future work that asks participants to also choose the social stimuli for the task would address these concerns. A second limitation is that an individual's hobby may not have been included in the options presented. Nevertheless, all participants expressed that they enjoyed and/or liked their selected hobby, suggesting that their choices were motivating and pleasurable for them. In the absence of independent ratings on the stimuli, future work is needed to assess the validity of the images presented. Despite these limitations, our results suggest this task provides new, valuable information about the processing of motivating stimuli and can be applied to study psychiatric populations.

Conclusions

We developed a paradigm to test impulse control in response to personalized preferred and non-preferred stimuli. Although no differences were observed in response inhibition, we observed a subtle attentional bias and increased activity in the anterior insula to one's interests. In our daily activities, at home, school or work, we are constantly exposed to a variety of personally motivating cues, but we are able to choose not to act at every impulse. Together the present findings help to understand how we exert self-control over the temptations in our environment in order to efficiently and successfully navigate the demands of our daily life.

Funding

This work was in part supported by the Leon Levy Foundation Fellowship in Neuroscience to RMJ, the Sackler Infant Psychiatry Program, and a generous gift from the Mortimer D. Sackler M.D. family. DJB was partially supported by the Consortium on Individual Development (CID is funded through the Gravitation program of the Dutch Ministry of Education, Culture, and Science and the Netherlands Organization for Scientific Research (NWO grant number 024.001.003)) and a KNAW Ter Meulen grant.

Supplementary data

Supplementary data are available at *SCAN* online.

Conflict of interest. None declared.

References

Achenbach, T.M., Rescorla, L.A. (2003). Manual for the ASEBA Adult Forms & Profiles. *Research Center for Children, Youth & Families*, Burlington, VT: University of Vermont.

American Psychiatric Association. (2013). *The Diagnostic and Statistical Manual of Mental Disorders: DSM* 5. Washington DC: American Psychiatric Publishing.

Ames, S.L., Wong, S.W., Bechara, A., *et al.* (2014). Neural correlates of a Go/NoGo task with alcohol stimuli in light and heavy young drinkers. *Behavioural Brain Research*, **274**, 382–9.

Aron, A.R., Robbins, T.W., Poldrack, R.A. (2014). Inhibition and the right inferior frontal cortex: one decade on. *Trends in Cognitive Science*, **18**(4), 177–85.

Baas, D., Aleman, A., Vink, M., Ramsey, N.F., Haan, EHF.d., Kahn, R.S. (2008). Evidence of altered cortical and amygdala activation during social decision-making in schizophrenia. *Neuroimage*, **40**(2), 719–27.

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., Clubley, E. (2001). The Autism-Spectrum Quotient (AQ): evidence from Asperger Syndrome/High-Functioning Autism, Males and Females, Scientists and Mathematicians. *Journal of Autism and Developmental Disorders*, **31**(1), 5–17.

Bates, D., Maechler, M., Bolker, B., Walker, S. (2014). lme4: linear mixed-effects models using Eigen and S4. *R Packag version 17*.

Brooks, S.J., O'Daly, O.G., Uher, R., *et al.* (2011). Differential neural responses to food images in women with bulimia versus anorexia nervosa. *PLoS One*, **6**(7), e22259.

Cascio, C.J., Foss-Feig, J.H., Heacock, J., *et al.* (2014). Affective neural response to restricted interests in autism spectrum disorders. *Journal of Child Psychology and Psychiatry Allied Disciplines*, **55**(2), 162–71.

Chen, G., Saad, Z.S., Britton, J.C., Pine, D.S., Cox, R.W. (2013). Linear mixed-effects modeling approach to FMRI group analysis. *Neuroimage*, **73**, 176–90.

Chikazoe, J., Konishi, S., Asari, T., Jimura, K., Miyashita, Y. (2007). Activation of right inferior frontal gyrus during response inhibition across response modalities. *Journal of Cognitive Neuroscience*, **19**(1), 69–80.

Citron, F.M.M., Gray, M.A., Critchley, H.D., Weekes, B.S., Ferstl, E.C. (2014). Emotional valence and arousal affect reading in an interactive way: neuroimaging evidence for an approach-withdrawal framework. *Neuropsychologia*, **56**, 79–89.

Cohen-Gilbert, J.E., Killgore, W.D.S., White, C.N., *et al.* (2014). Differential influence of safe versus threatening facial expressions on decision-making during an inhibitory control task in adolescence and adulthood. *Developmental Science*, **17**(2), 212–23.

Cohen, A.O., Breiner, K., Steinberg, L., *et al.* (2016). When is an adolescent an adult? assessing cognitive control in emotional and nonemotional contexts. *Psychological Science*, **27**(4), 549–62.

Constantino, J. (2012). Social Responsiveness Scale (SRS-2). *West Psychol Serv*.

Cox, R.W. (1996). AFNI: software for analysis and visualization of functional magnetic resonance neuroimages. *Computers and Biomedical Research*, **29**(3), 162–73.

Cox, R.W., Reynolds, R.C., Taylor, P.A. (2016). AFNI and clustering: false positive rates redux. *BioRxiv*, 065862.

Criaud, M., Boulinguez, P. (2013). Have we been asking the right questions when assessing response inhibition in go/no-go tasks with fMRI? A meta-analysis and critical review. *Neuroscience & Biobehavioral Reviews*, **37**(1), 11–23.

Daw, N.D., Doya, K. (2006). The computational neurobiology of learning and reward. *Current Opinion in Neurobiology*, **16**(2), 199–204.

Demos, K.E., Heatherton, T.F., Kelley, W.M. (2012). Individual differences in nucleus accumbens activity to food and sexual images predict weight gain and sexual behavior. *J Neuroscience*, **32**(16), 5549–52.

Denckla, M.B. (1985). Revised neurological examination for subtle signs. *Psychopharmacology Bulletin*, **21**(4), 773–800.

Deuter, C.E., Schilling, T.M., Kuehl, L.K., Blumenthal, T.D., Schachinger, H. (2013). Startle effects on saccadic responses to emotional target stimuli. *Psychophysiology*, **50**(10), 1056–63.

Dosenbach, N.U.F., Visscher, K.M., Palmer, E.D., *et al.* (2006). A core system for the implementation of task sets. *Neuron*, **50**(5), 799–812.

Droutman, V., Read, S.J., Bechara, A. (2015). Revisiting the role of the insula in addiction. *Trends in Cognitive Science*, **19**(7), 414–20.

Duerden, E.G., Arsalidou, M., Lee, M., Taylor, M.J. (2013). Lateralization of affective processing in the insula. *Neuroimage*, **78**, 159–75.

Eklund, A., Nichols, T.E., Knutsson, H. (2016). Cluster failure: why fMRI inferences for spatial extent have inflated false-positive rates. *Proceedings of the National Academy of Sciences*, **113**, 201602413.

Elliott, R., Ogilvie, A., Rubinsztein, J.S., Calderon, G., Dolan, R.J., Sahakian, B.J. (2004). Abnormal ventral frontal response during performance of an affective go/no go task in patients with mania. *Biological Psychiatry*, **55**(12), 1163–70.

Erickson, K., Drevets, W.C., Clark, L., *et al.* (2005). Mood-congruent bias in affective go/no-go performance of unmedicated patients with major depressive disorder kristine. *The American Journal of Psychiatry*, **162**, 2171–3.

Etkin, A., Büchel, C., Gross, J.J. (2015). The neural bases of emotion regulation. *Nature Reviews Neuroscience*, **16**(11), 693.

Feinberg, D.A., Moeller, S., Smith, S.M., *et al.* (2010). Multiplexed echo planar imaging for sub-second whole brain fmri and fast diffusion imaging. *PLoS One*, **5**(12), e15710.

Foss-Feig, J.H., McGugin, R.W., Gauthier, I., Mash, L.E., Ventola, P., Cascio, C.J. (2016). A functional neuroimaging study of fusiform response to restricted interests in children and adolescents with autism spectrum disorder. *Journal of Neurodevelopmental Disordorders*, **8**, 15.

Geier, C.F., Luna, B. (2012). Developmental effects of incentives on response inhibition. *Child Development*, **83**(4), 1262–74.

Geurts, H.M., Grasman, R.P.P.P., Verté, S., *et al.* (2008). Intra-individual variability in ADHD, autism spectrum disorders and Tourette's syndrome. *Neuropsychologia*, **46**(13), 3030–41.

Gorno-Tempini, M.L., Pradelli, S., Serafini, M., *et al.* (2001). Explicit and incidental facial expression processing: an fMRI study. *Neuroimage*, **14**(2), 465–73.

Hare, T.A., Casey, B.J. (2005). The Neurobiology and development of cognitive and affective control. *Brain, IX* 273–86.

Hare, T.A., Tottenham, N., Galvan, A., Voss, H.U., Glover, G.H., Casey, B.J. (2008). Biological substrates of emotional reactivity and regulation in adolescence during an emotional go-nogo task. *Biological Psychiatry*, **63**(10), 927–34.

Holst, R.J., van Holstein, M., *et al.* (2012). Response inhibition during cue reactivity in problem gamblers: an fMRI study. *PLoS One*, **7**, 1–10.

Hummer, T. a., Hulvershorn, L. a., Karne, H.S., Gunn, A.D., Wang, Y., Anand, A. (2013). Emotional response inhibition in bipolar disorder: a functional magnetic resonance imaging study of trait- and state-related abnormalities. *Biological Psychiatry*, **73**(2), 136–43.

Iwabuchi, S.J., Peng, D., Fang, Y., *et al.* (2014). Alterations in effective connectivity anchored on the insula in major depressive disorder. *European Neuropsychopharmacology*, **24**(11), 1784–92.

Jiang, J., Beck, J., Heller, K., Egner, T. (2015). An insula-frontostriatal network mediates flexible cognitive control by adaptively predicting changing control demands. *Nature Communications* **6**, 8165.

Jones, R.M., Somerville, L.H., Li, J., *et al.* (2011). Behavioral and neural properties of social reinforcement learning. *Journal of Neuroscience*, **31**(37), 13039–45.

Karalunas, S.L., Geurts, H.M., Konrad, K., Bender, S., Nigg, J.T. (2014). Annual research review: reaction time variability in ADHD and autism spectrum disorders: measurement and mechanisms of a proposed trans-diagnostic phenotype. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, **55**(6), 685–710.

Kim, K.R., Ku, J., Lee, J.H., Lee, H., Jung, Y.C. (2012). Functional and effective connectivity of anterior insula in anorexia nervosa and bulimia nervosa. *Neuroscience Letters*, **521**(2), 152–7.

Klin, A., Danovitch, J.H., Merz, A.B., Volkmar, F.R. (2007). Circumscribed interests in higher functioning individuals with autism spectrum disorders: an exploratory study. *Research and Practice for Persons with Severe Disabilities*, **32**(2), 89–100.

Krakowski, M.I., Sanctis, P.D., Foxe, J.J., *et al.* (2016). Disturbances in response inhibition and emotional processing as potential pathways to violence in schizophrenia: a high-density event-related potential study. *Schizophrenia Bulletin*, **42**, 963–74.

Kullmann, S., Giel, K.E., Hu, X., *et al.* (2014). Impaired inhibitory control in anorexia nervosa elicited by physical activity stimuli. *Social Cognitive and Affective Neuroscience*, **9**(7), 917–23.

Kurth, F., Zilles, K., Fox, P.T., Laird, A.R., Eickhoff, S.B. (2010). A link between the systems: functional differentiation and integration within the human insula revealed by meta-analysis. *Brain Structure and Function*, **214**(5-6), 519–34.

Lewis, P.A., Critchley, H.D., Rotshtein, P., Dolan, R.J. (2007). Neural correlates of processing valence and arousal in affective words. *Cerebral Cortex*, **17**(3), 742–8.

Lin, H.-Y., Hwang-Gu, S.-L., Gau, S.S.-F. (2015). Intra-individual reaction time variability based on ex-Gaussian distribution as a potential endophenotype for attention-deficit/hyperactivity disorder. *Acta Psychiatrica Scandinavica*, **132**(1), 39–50.

Macmillan, N.A., Creelman, C.D. (2004). *Detection Theory: A User's Guide*. Psychology press.

Menon, V., Uddin, L.Q. (2010). Saliency, switching, attention and control: a network model of insula function. *Brain Structure Function*, **214**(5-6), 655–67.

Moeller, S., Yacoub, E., Olman, C. a., *et al.* (2010). Multiband multislice GE-EPI at 7 Tesla, with 16-fold acceleration using partial parallel imaging with application to high spatial and temporal whole-brain FMRI. *Magnetic Resonance Medicine*, **63**(5), 1144–53.

Moran, L.V., Tagamets, M.A., Sampath, H., *et al.* (2013). Disruption of anterior insula modulation of large-scale brain networks in schizophrenia. *Biological Psychiatry*, **74**(6), 467–74.

Noël, X., Linden, M. Van Der, D'Acremont, M., *et al.* (2007). Alcohol cues increase cognitive impulsivity in individuals with alcoholism. *Psychopharmacology (Berl)*, **192**(2), 291–8.

Oberndorfer, T. a., Frank, G.K.W., Simmons, A.N., *et al.* (2013). Altered insula response to sweet taste processing after recovery from anorexia and bulimia nervosa. *The American Journal of Psychiatry*, **170**(10), 1143–51.

Odriozola, P., Uddin, L.Q., Lynch, C.J., Kochalka, J., Chen, T., Menon, V. (2015). Insula response and connectivity during social and non-social attention in children with autism. *Social cognitive and affective neuroscience* **11**(3), 433–44.

Paulsen, D.J., Hallquist, M.N., Geier, C.F., Luna, B. (2015). Effects of incentives, age, and behavior on brain activation during inhibitory control: a longitudinal fMRI study. *Developmental Cognitive Neuroscience*, **11**, 105–15.

Phillips, M.L., Ladouceur, C.D., Drevets, W.C. (2008). A neural model of voluntary and automatic emotion regulation: implications for understanding the pathophysiology and neurodevelopment of bipolar disorder. *Molecular Psychiatry*, **13**(829), 833–57.

Pike, E., Marks, K.R., Stoops, W.W., Rush, C.R. (2015). Cocaine-related stimuli impair inhibitory control in cocaine users following short stimulus onset asynchronies. *Addiction*, **110**(8), 1281–6.

Pike, E., Stoops, W.W., Fillmore, M.T., Rush, C.R. (2013). Drug-related stimuli impair inhibitory control in cocaine abusers. *Drug and Alcohol Dependence*, **133**(2), 768–71.

Power, J.D., Mitra, A., Laumann, T.O., Snyder, A.Z., Schlaggar, B.L., Petersen, S.E. (2014). Methods to detect, characterize, and remove motion artifact in resting state fMRI. *Neuroimage*, **84**, 320–41.

Schienle, A., Schäfer, A., Hermann, A., Vaitl, D. (2009). Binge-eating disorder: reward sensitivity and brain activation to images of food. *Biological Psychiatry*, **65**(8), 654–61.

Schulz, K.P., Clerkin, S.M., Halperin, J.M., Newcorn, J.H., Tang, C.Y., Fan, J. (2009). Dissociable neural effects of stimulus valence and preceding context during the inhibition of responses to emotional faces. *Human Brain Mapping*, **30**(9), 2821–33.

Schulz, K.P., Fan, J., Magidina, O., Marks, D.J., Hahn, B., Halperin, J.M. (2007). Does the emotional go/nogo task really measure behavioral inhibition? convergence with measures on a non-emotional analog. *Archives of Clinical Neuropsychology*, **22**(2), 151–60.

Seeley, W.W., Menon, V., Schatzberg, A.F., *et al.* (2007). Dissociable intrinsic connectivity networks for salience processing and executive control. *Journal of Neuroscience*, **27**(9), 2349–56.

Setsompop, K., Gagoski, B.A., Polimeni, J.R., Witzel, T., Wedeen, V.J., Wald, L.L. (2012). Blipped-controlled aliasing in parallel imaging for simultaneous multislice echo planar imaging with reduced g-factor penalty. *Magnetic Resonance in Medicine*, **67**(5), 1210–24.

Shafritz, K.M., Collins, S.H., Blumberg, H.P. (2006). The interaction of emotional and cognitive neural systems in emotionally guided response inhibition. *Neuroimage*, **31**(1), 468–75.

Somerville, L.H., Hare, T., Casey, B.J. (2011). Frontostriatal maturation predicts cognitive control failure to appetitive cues in adolescents. *Journal of Cognitive Neuroscience*, **23**(9), 2123–34.

Teslovich, T., Freidl, E.K., Kostro, K., *et al.* (2014). Probing behavioral responses to food: development of a food-specific go/no-go task. *Psychiatry Research*, **219**(1), 166–70.

Tottenham, N., Hare, T.A., Casey, B.J. (2011). Behavioral assessment of emotion discrimination, emotion regulation, and cognitive control in childhood, adolescence, and adulthood. *Frontiers in Psychology*, **2**, 39.

Tottenham, N., Tanaka, J.W., Leon, A.C., *et al.* (2009). The NimStim set of facial expressions: judgments from untrained research participants. *Psychiatry Research*, **168**(3), 242–9.

Uddin, L.Q., Supekar, K., Lynch, C.J., *et al.* (2013). Salience network-based classification and prediction of symptom severity in children with autism. *JAMA Psychiatry*, **70**(8), 869–79.

Wechsler, D. (2008). Wechsler adult intelligence scale—Fourth Edition (WAIS-IV). San Antonio, TX: NCS Pearson, 22, 498.

Wessa, M., Houenou, J., Paillère-Martinot, M.-L., *et al.* (2007). Fronto-striatal overactivation in euthymic bipolar patients during an emotional go/noGo task related content. *The American Journal of Psychiatry* **164**(4), 638–46.

Wessa, M., Linke, J. (2009). Emotional processing in bipolar disorder: behavioural and neuroimaging findings. *International Review of Psychiatry*, **21**(4), 357–67.

Xu, J., Moeller, S., Strupp, J., *et al.* (2012). Highly accelerated whole brain imaging using aligned-blipped-controlled-aliasing multiband EPI. *Proc 20th Annu Meet ISMRM* 2306.

Yerys, B.E., Kenworthy, L., Jankowski, K.F., Strang, J., Wallace, G.L. (2013). Separate components of emotional go/no-go performance relate to autism versus attention symptoms in children with autism. *Neuropsychology*, **27**(5), 537–45.

Zandbelt, B. (2014). Exgauss: a MATLAB toolbox for fitting the ex-Gaussian distribution to response time data. *figshare*.

Zhao, X., Liu, X., Zan, X., Jin, G., Maes, J.H.R., Rao, H. (2016). Male smokers' and non-smokers' response inhibition in go/no-go tasks: Effect of three task parameters. *PLoS One*, **11**(8), e0160595.