Research report

Avoiding boredom: Caudate and insula activity reflects boredom-elicited purchase bias

Dennis E. Dal Mas and Bianca C. Wittmann*

Department of Psychology, Justus Liebig University, Giessen, Germany

ARTICLE INFO

Article history:
Received 22 April 2016
Reviewed 12 September 2016
Revised 2 November 2016
Accepted 9 March 2017
Action editor Alan Sanfey
Published online 28 March 2017

Keywords:
Boredom
Caudate nucleus
Decision making
fMRI
Insula

ABSTRACT

People show a strong tendency to avoid boring situations, but the neural systems mediating this behavioural bias are yet unknown. We used functional magnetic resonance imaging (fMRI) to investigate how the anticipation of a boring task influences decisions to purchase entertainment. Participants accepted higher prices to avoid boredom compared to control tasks, and individual differences in boredom experience predicted the increase in price. This behavioural bias was associated with higher activity in the caudate nucleus during music purchases driven by boredom avoidance. Insula activation was increased during performance of the boring task and subsequently associated with individual differences in boredom-related decision making. These results identify a mechanism that drives decisions to avoid boring situations and potentially underlies consumer decisions.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

Boredom is a common experience that is associated with a strong desire to change or escape the current situation. It is generally defined as an aversive motivational state resulting from an unfulfilled desire to be engaged in satisfying activity (Eastwood, Frischen, Fenske, & Smilek, 2012). Workers often report being bored when they have to perform a repetitive, monotonous task lacking in novelty, and they may employ coping strategies such as daydreaming and motor restlessness (Smith, 1981). Outside of a constrained work setting, when people are free to choose their activity, boredom increases the propensity to eat unhealthy food (Koball, Meers, Storfer-Isser, Domoff, & Musher-Eizenman, 2012; Moynihan et al., 2015), triggers impulsive shopping (Dittmar & Drury, 2000; Geuens, Vantomme, & Brengman, 2004; Mano, 1999), and motivates leisure activities such as listening to music (Mitchell, MacDonald, Knussen, & Serpell, 2007; North, Hargreaves, & O’Neill, 2000). These findings are consistent with economic theories on the role of mood and emotions for consumer behaviour (Alba & Williams, 2013; Andrade, 2015; Holbrook & Hirschman, 1982). In daily life, boring situations can often be anticipated and may affect choice, for example when purchasing entertainment for an upcoming long-distance flight. What drives such decisions to avoid boredom?

Evidence on the neural basis of the motivational effects of boredom has been mostly indirect. Individual differences in trait...
boredom comprise a subscale of Zuckerman's sensation-seeking scale (Zuckerman, 1971; Zuckerman, Eysenck, & Eysenck, 1978) and contribute to the dimension of novelty seeking in Cloninger's Tridimensional Personality Questionnaire (TPQ; Cloninger, 1987; Cloninger, Pryzbeck, & Svrakic, 1991). Differences in these traits are associated with changes in striatal activity, dopamine release, and dopamine receptor densities (for a review, see Jupp & Dalley, 2014). More directly, boredom susceptibility has been shown to moderate the subjective effects of amphetamine administration (Hutchison, Wood, & Swift, 1999), making the dopaminergic system a candidate for the investigation of the motivational effects of boredom.

Experiencing or anticipating boredom is likely to act as a contextual factor driving decisions towards avoidance of boring tasks and situations. Previous studies of contextual influences on decisions demonstrated a role for regions in the dopaminergic system. Dopamine neurons respond to reward cues and unpredicted reward (Schultz, Dayan, & Montague, 1997), and the substantia nigra/ventral tegmental area (SN/VTA) mediates individual differences in novelty bonuses (Wittmann, Daw, Seymour, & Dolan, 2008). The main target of dopaminergic projections from the SN/VTA is the striatum, with the largest input projecting into the dorsal striatum (for a review, see Haber & Behrens, 2014). While all striatal subregions are involved in reward processing, the dorsomedial striatum has been shown to play a larger role in goal-directed choices (for a review Balleine & O'Doherty, 2009; Kim & Hikosaka, 2013; Tanaka, Balleine, & O'Doherty, 2008; Yin, Ostlund, Knowlton, & Balleine, 2005), such as choices involving forward planning (Wunderlich, Dayan, & Dolan, 2012).

Recent studies addressed possible emotional correlates of boredom as a state. In one study, participants were scanned in functional magnetic resonance imaging (fMRI) while playing a violent video game (Mathiak, Klasen, Zvyagintsev, Weber, & Mathiak, 2013). Periods of inactivity during the game were analysed with respect to pre- to post-scan changes in positive and negative affect. Decreased positive affect was correlated with activation in a cluster encompassing insula and amygdala during inactive game periods, while increased negative affect was associated with activation of ventromedial prefrontal cortex (vmPFC). Another recent study confirmed differential insula activation when subjects viewed a boring compared to an interesting movie (Danckert & Merrifield, 2016). The insula and amygdala are central for affective processing, representing both appetitive and aversive valence (Ball et al., 2009; Chang, Yarkoni, Khaw, & Sanfey, 2013; Hayes, Duncan, Xu, & Northoff, 2014; Paton, Belova, Morrison, & Salzman, 2006). Both regions are also involved in regulating the autonomic effects of arousal (Critchley, 2005), which is increased in a state of boredom (Eastwood et al., 2012; Fahman, Mercer-Lynn, Flora, & Eastwood, 2013; Merrifield & Danckert, 2014). As decision making is modulated by activity in amygdala (De Martino, Kumaran, Seymour, & Dolan, 2006; Guitart-Masip, Talmi, & Dolan, 2010; Weber et al., 2007) and insula (Furl & Averbeck, 2011; Kuhnen & Knutson, 2005; McCabe et al., 2009), these regions may contribute to both the affective experience of boredom and its effects on decisions.

In this experiment, we used fMRI to investigate the influence of boredom anticipation on decisions to purchase music.

Participants first experienced a boring task and two control tasks and were then asked to make a series of decisions between purchasing individually selected pieces of music and each of the tasks. In each trial of the decision making task, participants chose either between two of the tasks, which were free of charge, or between one of the tasks and purchasing a piece of music of moderate individual value. Prices were adapted for each participant and condition based on the percentage of music pieces that were chosen, and a subset of trials was randomly drawn for implementation at the end of the session. We predicted that participants would avoid the boring task, accepting to pay higher prices for music when the alternative option was a boring task compared to the control tasks. Based on previous studies, we expected the SN/VTA and caudate nucleus to be associated with decisions to avoid boredom (Balleine & O'Doherty, 2009; Wittmann et al., 2008) and the insula and amygdala to reflect the experience and anticipation of boredom (Mathiak et al., 2013).

### 2. Experimental procedures

#### 2.1. Participants

A total of 41 healthy, right-handed adults participated in the study. Six participants were excluded from the study because they did not meet the task-related inclusion criteria (see details below). Thirty-five participants were included in the behavioural analysis (mean age ± SD: 25.2 ± 2.4 years, 16 men). Data from five participants was excluded from the fMRI analysis due to excessive head motion, defined as volume-to-volume motion exceeding 1 mm of translation or .5° of rotation. Thirty participants remained in the fMRI sample (mean age ± SD: 25.1 ± 2.5 years, 12 men). All participants had normal or corrected-to-normal vision and reported taking no medication. Participants were reimbursed for their participation with €10/h. The study was approved by the ethics committee of the Department of Psychology and Sports Science at Justus Liebig University Giessen and all participants gave written informed consent.

#### 2.2. Experimental paradigm

The study required volunteers to participate on three different days. On day 1, we administered personality questionnaires and a music questionnaire designed to individually select pieces of music with moderate subjective value for the decision-making task. On day 2, participants were familiarized with the pictures to be used in the boredom-eliciting and control tasks. Tasks on day 1 and 2 were accessed by participants through an internet-based survey system (Leiner, 2014). They were instructed to participate in an attentive and conscientious manner and to eliminate distractions such as conversation, e-mail, music or mobile phones. On day 3, participants completed the fMRI session containing the boredom manipulation and decision-making task.

##### 2.2.1. Day 1

Via the online survey system, participants completed a music questionnaire that was hierarchically structured to evaluate
their interest in musical genres and pieces of music on a 7-point Likert scale (from 1 = very uninteresting to 7 = very interesting) with an additional check box for unknown items. Participants first reported how much they were interested in music in general. If they found music sufficiently interesting (rating ≥3), the names of musical genres were presented. For each genre that was rated ≥3, participants next rated individual musicians. For each musician rated ≥3, participants then evaluated individual pieces of music. The music questionnaire contained a total of 1804 pieces of music from a range of genres covering classical and popular music styles. The questionnaire continued until 36 pieces of music had received a rating of 5 (rather interesting). Participants then completed three personality questionnaires addressing individual differences related to trait boredom: the subscale Boredom Susceptibility from the Sensation Seeking Scale (Zuckerman & Neel, 1979) and the Boredom Proneness Scale (Farmer & Sundberg, 1986), which have been shown to measure different aspects of trait boredom (Mercer-Lynn, Flora, Fahman, & Eastwood, 2013), and the TPQ (Cloninger et al., 1991; Richter, Eisemann, & Richter, 2000).

2.2.2. Day 2

Two to fourteen days later and approx. 24 h (±3 h) before the scheduled fMRI session, participants were familiarized with 143 greyscale landscape photographs matched for dimension, luminance, and contrast. Stimuli were presented once and in randomized order (duration: 2000 msec, ISI: 2000 msec). For each picture, participants indicated by keypress whether the image contained man-made structures such as buildings or roads, or a natural, untouched landscape.

2.2.3. Day 3

The fMRI experiment consisted of two parts. In the first part, participants underwent a task designed to elicit boredom and two control tasks. To induce temporally extended effects of mood, each task was carried out continuously for 5 min. Task order and response buttons for each task were counterbalanced across participants. All three tasks were based on the familiarized landscape pictures, which were presented surrounded by an ochre frame. In half of the trials, this frame was visibly blurred.

In the boredom task (Fig. 1A), each participant was presented with the same landscape picture in all trials. Six landscape pictures were used across participants to minimize stimulus-dependent effects. In each trial, participants indicated by button press whether the ochre frame was blurred or not. The task consisted of 86 trials (2000 msec stimulus presentation, 1500 msec ITI). In material for participants, this task was referred to as a value-neutral term (“blur task”) throughout the study. In the two control tasks, a different picture was shown in each trial. In the first control task (“liking task”, Fig. 1B), participants indicated by button press whether they liked or disliked the presented picture. Number of trials and presentation duration were identical to the boredom task. In the second control task (“search task”, Fig. 1C), a small image of either a key or a padlock was overlaid on each landscape image at a random position within the picture. In each trial, participants indicated which of the two objects was shown. After the 4500 msec response time limit, a red circle highlighted the position of the overlaid object. The search task included 34 trials (4500 msec stimulus presentation, 1000 msec feedback, 2500 msec ITI). Task timings were selected to enable high performance levels in each task based on pilot data, thus eliminating potential confounds such as flow experiences arising from a satisfying task challenge or overload arising from overly demanding tasks (Ulrich, Keller, Hoenig, Waller, & Grön, 2014).

At the end of each task block, participants rated how bored they had felt during the task (0–10 rating scale, from 0 = not at all bored to 10 = extremely bored) and how interesting they found the task (1–7 rating scale, identical to the online music rating scale on day 1). Participants for whom the boredom manipulation was not successful (boredom ratings <5 in the boredom task) were excluded from the study by terminating the fMRI session at this point (four participants). We also calculated the difference in boredom ratings between the boredom task and each of the two control tasks. Participants were excluded if the difference was <3 for both tasks (two participants).

In the second part of the fMRI session, participants underwent a decision-making task (Fig. 1D). Participants received a starting capital of €6. Each trial involved a decision between two options. Possible options were one of the tasks (boredom, liking, or search task) or a piece of music rated as moderately interesting on day 1. Participants were informed that seven trials would be randomly selected for implementation in a lottery at the end of the decision phase. Decisions entailed either performing one of the three tasks for 5 min or listening to the piece of music (mean duration ± SEM: 4.7 ± .2 min). The options were presented in text format showing the option price and the name of the task or the musician and title of the piece of music. An option pair could be either two tasks (task trial) or one task and one piece of music (music trial). In each trial, the options were first presented sequentially (4000 msec each), followed by a choice screen with the two options presented side by side (2000 msec) and a jittered ITI of 1600–5400 msec. During choice screen presentation, participants made their choice by left/right button press. Trial types, sequence of options, and the side of the options at choice (left/right) were counterbalanced.

While tasks were free of charge, music options had to be purchased. The price of music options was determined for each condition (boredom, liking, and search) by an adaptive algorithm implemented to ensure a sufficient number of choices of each option for fMRI analysis. The starting price was set to approx. half of the market price at online retailers and randomly determined for each condition to be €0.45, €0.50 or €0.55. For each condition, all subsequent prices depended on previous choices: if more than 60% of all previous choices were in favour of music, the price was raised by €0.10. If fewer than 40% of all previous choices were in favour of music, the price was lowered by €0.10. The minimum price was set to €0.05 unless fewer than 30% of all previous choices were in favour of music. To ensure that participants did not notice the adaptability of prices, a stochastic element was added: starting from the fifth trial of each music trial type, on every third trial either €0.05 or €0.10 was added or €0.10 was subtracted from the current music price. This method was chosen to ensure a sufficient number of choices per condition.
while providing a measure of willingness to pay for music in each condition as well as a measure of binary choice. Because the same pieces of music were used in each condition, and because each piece received the same interest rating in the online questionnaire, the baseline value of the music options in each condition was equal, so that differences in price reflected the influence of the alternative option (condition). Other methods such as a Becker–DeGroot–Marschak (BDM) auction (Becker, DeGroot, & Marschak, 1964) would not have provided the same measures: a BDM auction before the experiment would equalize the baseline music value in each condition but would not ensure a sufficient number of choices of each option in each condition for fMRI analysis. A BDM auction during the choice phase would provide a measure of willingness-to-pay on each trial, but participants would not make binary choices, so that an fMRI analysis based on the chosen option would not be possible. The fMRI analysis would instead reflect subjective value, which is known to be represented in the same brain areas across different goods and conditions (Chib, Rangel, Shimojo, & O’Doherty, 2009; FitzGerald, Seymour, & Dolan, 2009; Levy & Glimcher, 2011; Plassmann, O’Doherty, & Rangel, 2007).
Each of the 36 music pieces was presented as an option three times (once per condition). To improve estimability of the fMRI design and provide a behavioural measure of subjects’ task preferences, 12 additional trials were included for each combination of two tasks (boredom-search, boredom-liking, search-liking), yielding a total of 144 trials in three runs of approx. 11 min. At the end of the decision phase, participants gave additional ratings for the three tasks on 0–10 scales for effort (from 0 = not at all effortful to 10 = extremely effortful) and pleasantness (from 0 = not at all pleasant to 10 = extremely pleasant). After the decision phase, two trials of each music trial type and one trial of the task trial type were randomly drawn and implemented (Supplementary Methods).

2.3. fMRI acquisition

Magnetic resonance images were collected on a 3 T whole-body scanner (Magnetom Prisma, Siemens Medical Systems, Erlangen, Germany) with a 64-channel head coil. For functional imaging, gradient-echo echo-planar images (EPI) were acquired [repetition time (TR) = 2000 msec, echo time (TE) = 30 msec, 36 slices, voxel size = 2.5 × 2.5 × 3 mm, slice thickness = 3 mm; gap = .6 mm; FoV = 192 mm × 192 mm; matrix size = 64 × 64, flip angle = 90°, acceleration factor = 3] in an interleaved sequence with an orientation of −30° to the anterior commissure-posterior commissure line. Functional data were acquired in six separate runs (three task runs of approx. 175 volumes and three decision-making runs of approx. 340 volumes). To improve distortion correction of the functional images, a gradient-echo field map sequence (TE ≈ 340 volumes). To improve distortion correction of the functional images, a gradient-echo field map sequence (TE = 175 volumes and three decision-making runs of approx. 11 min. At the end of the decision phase, participants gave additional ratings for the three tasks on 0–10 scales for effort (from 0 = not at all effortful to 10 = extremely effortful) and pleasantness (from 0 = not at all pleasant to 10 = extremely pleasant). After the decision phase, two trials of each music trial type and one trial of the task trial type were randomly drawn and implemented (Supplementary Methods).

2.3. fMRI acquisition

Magnetic resonance images were collected on a 3 T whole-body scanner (Magnetom Prisma, Siemens Medical Systems, Erlangen, Germany) with a 64-channel head coil. For functional imaging, gradient-echo echo-planar images (EPI) were acquired [repetition time (TR) = 2000 msec, echo time (TE) = 30 msec, 36 slices, voxel size = 2.5 × 2.5 × 3 mm, slice thickness = 3 mm; gap = .6 mm; FoV = 192 mm × 192 mm; matrix size = 64 × 64, flip angle = 90°, acceleration factor = 3] in an interleaved sequence with an orientation of −30° to the anterior commissure-posterior commissure line. Functional data were acquired in six separate runs (three task runs of approx. 175 volumes and three decision-making runs of approx. 340 volumes). To improve distortion correction of the functional images, a gradient-echo field map sequence (TE = 175 volumes and three decision-making runs of approx. 340 volumes). To improve distortion correction of the functional images, a gradient-echo field map sequence (TE = 175 volumes and three decision-making runs of approx. 11 min. At the end of the decision phase, participants gave additional ratings for the three tasks on 0–10 scales for effort (from 0 = not at all effortful to 10 = extremely effortful) and pleasantness (from 0 = not at all pleasant to 10 = extremely pleasant). After the decision phase, two trials of each music trial type and one trial of the task trial type were randomly drawn and implemented (Supplementary Methods).

2.3.1. fMRI analysis

Preprocessing and data analysis were performed using the software package Statistical Parametric Mapping implemented in Matlab (SPM8; Wellcome Trust Centre for Neuroimaging, London, UK). First, raw functional data quality was checked using the ArtRepair toolbox (Mazaika, Hoeft, Glover, & Reiss, 2009). Bad volumes (mean: 1.6% of all volumes; range: .9–2.3%) were repaired by linear interpolation of the adjacent volumes. The following preprocessing steps were carried out: realignment and unwarping, slice time correction, spatial normalization based on segmentation of the anatomical image and with resampling to 2 × 2 × 2 mm, and smoothing using an 8 mm Gaussian kernel.

Data for the decision-making runs were high-pass filtered (cut-off: 128 sec) and whitened using an AR(1) model. For statistical analysis, trial-related activity for each participant was modelled by a vector of trial onsets convolved with a canonical haemodynamic response function. Decisions were specified at the time of second option presentation because 77% of the participants reported having made their decisions at this time (13% reported having made their decisions at choice screen presentation, and 10% were not sure). Prices were integrated as parametric modulators. Four boxcar regressors captured activity related to the presentation of the first option: music, boredom task, search task, liking task. Six boxcar regressors were specified to represent choices in music trial types during presentation of the second option: music choices in each of the three conditions, and task choices in each of the three conditions. For the task trial type, three boxcar regressors specified the task presented as second option. The regressors for first and second option presentation were set to the presentation duration (4 sec). For all trial types, an additional boxcar regressor specified the presentation of the choice screen, with the duration set to trial-by-trial reaction times. Note that task regressors were separable because each option was paired with each other option and further separated according to choice. This design was found to be superior to alternative designs with varying jitters and varying trial combinations using the efficiency estimation in FEAT (FMRIB software library; Jenkinson, Beckmann, Behrens, Woolrich, & Smith, 2012). A general linear model (GLM) was calculated for each participant to model the effects of interest and six regressors capturing residual motion-related artefacts. A partitioned-error ANOVA was specified for music trial types by modelling the main effects of task option (boredom/control) and choice (task/music) and their interactions for each participant, followed by a random-effects second-level analysis to assess group effects. To investigate the influence of individual differences in task experience, the following covariates were included: differences in ratings of boredom, interest, effort, and pleasantness between the boredom task and the mean of the two control tasks; and the difference in median music price between these conditions. The median music price for the control tasks was calculated across all accepted prices in the search and liking conditions.

Although an investigation of the temporally extended effects of enduring boredom was not the main aim of this study, we carried out an exploratory analysis of the task blocks. Because the three 5-min blocks were designed to elicit temporally extended effects of internal state, an event-related analysis of these runs was not feasible. We therefore used an independent component analysis (ICA), which is suitable for analysis of long blocks such as resting-state (Calhoun, Kiehl, & Pearlson, 2008; Tanabe et al., 2011). ICA was performed using the group ICA for fMRI toolbox (GIFT; Correa, Adali, Li, & Calhoun, 2005). Tasks were entered as three separate sessions and group ICA was performed across all participants. For estimation of independent sources, we used the Infomax algorithm (Bell & Sejnowski, 1995) as it allows separation of super-Gaussian sources, which are the sources of interest in fMRI (Calhoun & Adali, 2006). The minimum description length criterion was used to determine the number of components that would accurately represent the data, and thirty-two components were extracted from the fMRI dataset. In order to select components for further analysis, for every session, each component was inspected according to the following criteria: (1) activation in at least two of the a priori regions of interest (ROIs) (insula, amygdala, striatum), (2) no ventricle activation exceeding 30 voxels, and (3) no active
voxels outside the brain. One component fulfilled the criteria for further investigation. Visual inspection of discarded components suggested that most of them represented cardiac-induced pulsatile artefacts, eye movements, or head motion. Data of the selected component were entered into SPM8 for random-effects group analyses. Because of constraints of the GIFT software, the two control blocks could not be combined in the statistical analysis. Since the liking task was rated as more boring than the search task ($t_{34} = 2.15$, $p = .04$, $d = .36$) and six participants did not reach the criterion of rating the liking task $<3$ on the boredom scale compared to the boredom task, we compared the boredom task with the search task using a whole-brain family-wise error rate (FWE)-corrected threshold.

Brain regions for analysis of the decision making phase were determined based on previously reported involvement in processing reward, decision making and boredom. Results were initially thresholded at $p < .005$ (uncorrected) and corrected for multiple comparisons using small volume correction (SVC) in a priori ROIs ($p < .05$, FWE corrected). Accordingly, for display purposes, all SVC significant activations are displayed at the initial threshold. SVC was carried out using an anatomical mask of bilateral caudate nucleus from the Harvard–Oxford probabilistic atlas (Harvard Center for Morphometric Analysis) and a recently developed probabilistic anatomical mask of bilateral SN/VTA (Keuken et al., 2014). The caudate nucleus was selected because of its role in goal-directed decisions (Balleine & O’Doherty, 2009). The SN/VTA ROI was motivated by its role in coding reward values and its link to dopaminergic function (Duzel et al., 2009), as well as its role in decision making (Wittmann et al., 2008). To investigate whether regions involved in signalling a state of boredom during the task phase were also involved in decision making, functional ROIs of insula and amygdala were defined from significant activations in the task phase for analysis during the decision making phase. We additionally carried out an SVC analysis using a bilateral anatomical mask of the nucleus accumbens taken from the Harvard–Oxford probabilistic atlas to investigate the anatomical selectivity of our caudate findings.

Activations are displayed overlaid onto the averaged structural MRI scan of the study participants. Stereotaxic coordinates are given in Montreal Neurological Institute (MNI) space. Behavioural averages are given as mean values ± SEM except where indicated otherwise.

3. Results

3.1. Task ratings

We first verified that participants were engaged in all task blocks and that the boredom manipulation was successful (Supplementary Results). Task performance in all conditions was high, and the tasks significantly differed on all rating scales (boredom: $F_{2,68} = 163.12$, $p < .001$; pleasantness: $F_{2,68} = 8.66$, $p < .001$; interest: $F_{2,68} = 55.23$, $p < .001$; effort: $F_{2,68} = 15.73$, $p < .001$). Post-hoc tests confirmed our predictions that the boredom task would be rated as more boring (search task: $t_{34} = 17.78$, $p < .001$, $d = 2.64$; liking task: $t_{34} = 15.88$, $p < .001$, $d = 1.89$), less pleasant (search task: $t_{34} = 2.99$, $p = .005$, $d = .78$; liking task: $t_{34} = 3.93$, $p < .001$, $d = .97$) and less interesting (search task: $t_{34} = 12.49$, $p < .001$, $d = 2.23$; liking task: $t_{34} = 7.17$, $p < .001$, $d = 1.67$) than either control task. As expected, the search task was rated as more effortful compared to the other tasks (boredom task: $t_{34} = 4.77$, $p < .001$, $d = .92$; liking task: $t_{34} = 5.77$, $p < .001$, $d = 1.26$). Overall, these results confirm that our boredom manipulation was successful. We also established that the boredom task was perceived as boring throughout the experiment by correlating the boredom ratings taken immediately after the task block with ratings taken at the end of the experiment (boredom task: $r = .49$, $p = .003$; all tasks: $r = .58$, $p < .001$). The influence of boredom-related personality traits on task ratings was assessed using the novelty-seeking scale of Cloninger’s TFQ (mean ± SD and range in the behavioural sample: $23.2 ± 6.8$, $11–35$), the boredom susceptibility scale of Zuckerman’s Sensation-Seeking scale (mean ± SD and range: $3.2 ± 1.8$, $0–7$), and the Boredom Proneness scale (mean ± SD and range: $83.9 ± 16.1$, $53–126$). We investigated the correlation of these scales with task ratings and prices and found no significant effects (all $p > .1$). However, the current behavioural sample of $n = 35$ was also included in a larger sample of $n = 77$ participants (mean age ± SD: $24.8 ± 3.1$ years, $34$ men) who experienced the boredom task and subsequently performed different tasks (mean ± SD and range: novelty-seeking $21.8 ± 6.7$, $8–36$; boredom susceptibility $3.0 ± 1.7$, $0–7$; boredom proneness $86.5 ± 16.6$, $53–126$). In the larger sample, a multiple linear regression analysis with boredom ratings as dependent variable and personality scores on the three scales, ratings of interest, effort, and pleasantness, and experimental group as independent variables indicated that boredom proneness significantly predicted boredom ratings ($\beta ± SEM = .03 ± .01, \beta = .30$, $p = .014$).
3.2. Anticipation of boredom drives market prices

We next analysed participants’ choices in the decision-making task (Fig. 3). As expected, the adaptive procedure for determining music prices succeeded in preventing extreme choice proportions (mean percentage of music choices ± SEM in the fMRI sample: boredom condition 44.4 ± 1.9%; search condition 44.4 ± 1.8%; liking condition 43.2 ± 2.1%), ensuring sufficient trial numbers for fMRI analysis. We also confirmed that participants strongly preferred the control tasks over the boredom task (Supplementary Table 1, Supplementary Results). We then tested the prediction that participants would accept higher prices for music when the alternative option was the boredom task compared to either of the control tasks ($X^2 = 17.84, p < .001$; Fig. 3A). As predicted, music prices were significantly higher in the boredom condition compared to the search condition (Wilcoxon signed-rank test, $Z = -3.90, p < .001, r = -.47$) and the liking condition ($Z = -3.72, p < .001, r = -.44$). There was no effect of the order in which participants experienced the boredom and control tasks on the subsequent price difference between the tasks (Kruskal–Wallis test; $H_2 = 4.38, p = .122$). We next investigated the hypothesis that individual differences in boredom experience drive differences in price between conditions. A multiple linear regression on the difference in accepted price between the boredom and combined control tasks with the differences in ratings of boredom, interest, effort, and pleasantness as independent variables confirmed that the individual difference in boredom ratings was the only significant predictor of price ($8 ± 3.44, \beta = .35, p = .046$). Fig. 3B shows the correlation between differences in price and boredom ratings. These findings support the conclusion that market prices of music were driven by the motivation to avoid boredom rather than other affective differences between the tasks.

3.3. Experience of boredom elicits activity in amygdala, insula and PFC

Although an investigation of the temporally extended effects of boredom experience was not the main aim of this study, we carried out an exploratory ICA analysis to compare the effects of performing the boring task during a 5-min block with the effects of performing the control task. An independent component comprising the right amygdala, bilateral insula, dorsal anterior cingulate cortex (dACC), bilateral dorsolateral prefrontal cortex (dlPFC) and right ventrolateral prefrontal cortex (vLPFC) was significantly stronger in the boredom task block compared with the search task block (Fig. 4).

3.4. Activity in caudate nucleus and insula reflects the influence of boredom on choice

We analysed the fMRI data from the decision-making phase in a 2 × 2 ANOVA with the factors task option (boredom/control) and choice (task/music) using a partitioned-error approach by modelling main effects and interactions on the first level, followed by a random-effects second-level analysis (Penny & Henson, 2007). To control for price differences between conditions, trial-by-trial music prices were included as parametric regressors on the first level. As between-subjects factors, we included individual differences in five task-related variables that significantly differed between conditions: four task ratings and the median accepted music price. For each participant, difference scores for each variable were calculated as the value in the boredom minus the mean rating (or median price) of the control conditions, yielding Δ-boredom, Δ-pleasantness, Δ-interest, Δ-effort, and Δ-price.

We tested for brain regions mediating the observed choice effect of boredom anticipation by analysing the interaction between task condition and choice. We expected that the decision to avoid boredom compared to control would elicit higher activation in the dorsomedial striatum and SN/VTA, regions known to be involved in representing value and mediating choice (Balleine & O’Doherty, 2009; Wittmann et al., 2008). In accordance with this prediction, there was a significant condition × choice interaction in the caudate nucleus ROI, largely driven by higher caudate activation when participants avoided boredom compared to avoiding the control.

![Fig. 3](image-url) – Choice behaviour. (A) Median price of music in each task condition. Error bars indicate median absolute deviation (MAD). ***$p < .001$. (B) Correlation between the difference in boredom ratings (Δ-boredom) and the difference in music price (Δ-price) between the boredom and control conditions, while controlling for differences in ratings of interest, pleasantness and effort. Individual scores are shown as standardized residuals from a regression analysis.
results of boredom-related decisions during the choice phase, we analysed activation in functional ROIs of the insula and amygdala found to be significantly activated during performance of the boredom versus search task. Insula activation was found to be significantly modulated by individual differences in accepted price (Fig. 5B, Table 1). Specifically, the interaction effect between task option and choice was significantly correlated with Δ-price. We therefore investigated the influence of increasing Δ-price on the neural interaction effect by grouping participants into those with relatively higher and lower Δ-price based on median split to display the groups’ parameter estimates (Fig. 5B, right panel). For participants with higher Δ-price, activation in the insula was higher when participants chose the boredom task compared to choosing the music or control tasks. In contrast, insula activation did not reflect choice in participants with low Δ-price. Thus, insula activation to choice of the boredom task increases with increasing effects of boredom on decisions, being highest in participants who accepted the highest prices to avoid performing the boring task. To verify that these results did not arise from differences in personality measures related to boredom or novelty, we compared the high Δ-price and low Δ-price groups on these measures and found no significant differences (all ps > .3), confirming that activation in the insula was selectively modulated by the individual choice bias. Taken together, these results indicate that regions in the reward system differentially mediate the motivational effects of boredom anticipation.

4. Discussion

The current study provides evidence for a neural mechanism underlying the drive to avoid boredom. We go beyond previous findings on purchase behaviour elicited by a state of boredom to demonstrate that the mere anticipation of having to perform a boring task powerfully influences music purchases. Imaging results show that decisions to avoid boredom by purchasing a leisure activity are associated with activation of the caudate nucleus and that participants who accepted higher prices to avoid boredom showed higher insula activity when choosing the boring task. These findings support previous findings on an involvement of the insula in boredom and suggest that the anticipation of boredom exerts effects on choice behaviour through the dopaminergic system, leading us to seek out varied and interesting experiences.

Previous research demonstrated that being in a state of boredom triggers coping mechanisms such as emotional eating (Koball et al., 2012; Moynihan et al., 2015), impulsive shopping (Dittmar & Drury, 2000; Geuens et al., 2004) and listening to music (Mitchell et al., 2007; North et al., 2000). In these studies, the extended behavioural effects of boredom may have been partially caused by implicit biases due to lower mood, which has been shown to influence decision making in a range of settings (Cryder, Lerner, Gross, & Dahl, 2008; Harle & Sanfey, 2007; Lerner, Small, & Loewenstein, 2004). In the current study, in contrast, overall mood during the decision phase was not manipulated; instead, participants’ choices on each trial reflect the expectation of subsequent experiences. Estimations of future internal states may have a strong influence on decisions because people overestimate their affective reactions to both positive (Wilson, Wheatley, Meyers, Gilbert, & Axsom, 2000) and negative (Gilbert, Pinel, Wilson, Blumberg, & Wheatley, 1998) future events, even for highly familiar events (Meyvis, Ratner, & Levav, 2010; Van Boven & Ashworth, 2007). These estimations of future affect (Mellers,
and the associated emotions experienced at the time of the decision (Gilbert, Gill, & Wilson, 2002; Pham, 1998) contribute to consumer decisions (see also Alba & Williams, 2013; Holbrook & Hirschman, 1982). The current study investigated how goal-directed, trial-wise purchase behaviour changes based on an anticipated future state of boredom. Our results demonstrate that people are willing to pay substantially more to avoid upcoming boredom compared to other tasks. There was no influence of the other task ratings (interest, pleasantness, effort) on music prices, suggesting that the anticipation of an overall lower mood did not contribute significantly to choices in the current study and supporting the interpretation of a specific effect of boredom.

The experience of boredom has been shown to comprise the five first-order factors of disengagement, high arousal, low arousal, inattention and changed time perception, plus a higher-order general boredom factor (Fahlman et al., 2013). The current results reflect the general experience of boredom associated with the tasks. Since performance in the boredom task was at ceiling, we conclude that the motivational effects of boredom were unlikely to be driven by inattention. In contrast, the disengagement scale contains several items related to wanting to engage in a more stimulating activity, suggesting that it may capture the motivational drive associated with a state of boredom and its anticipation. This interpretation is also supported by the results of the other task ratings, which did not influence purchase decisions. In line with this, higher task demands (effort), interest and positive

### Table 1 – ROI results.

<table>
<thead>
<tr>
<th>Region</th>
<th>MNI coordinates (x, y, z)</th>
<th>Peak statistics z-score</th>
<th>p-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interaction of task option and choice</td>
<td>–12, 16, 10</td>
<td>3.54</td>
<td>.036</td>
</tr>
<tr>
<td>Caudate nucleus</td>
<td>–12, 16, 10</td>
<td>3.54</td>
<td>.036</td>
</tr>
<tr>
<td>Δ-price correlation with interaction</td>
<td>–44, –10, –6</td>
<td>3.63</td>
<td>.023</td>
</tr>
<tr>
<td>Insula</td>
<td>–44, –10, –6</td>
<td>3.63</td>
<td>.023</td>
</tr>
</tbody>
</table>

Peak MNI coordinates and statistics for ROIs showing significant effects in a 2 × 2 ANOVA with the within-subjects factors task option (boredom/control) and choice (task/music) and the between-subject factors Δ-boredom, Δ-interest, Δ-effort, Δ-pleasantness and Δ-price. *FWE-corrected in the corresponding ROI.

Fig. 5 – Neural response to boredom-motivated decisions. (A) Significant interaction between task option and choice in the caudate nucleus (MNI peak coordinates: –12, 16, 10; SVC, p < .05). Panel on the right displays average percent signal change in the activated cluster to illustrate the direction of the interaction effect, showing that activation was higher when participants avoided boredom compared to avoiding the control tasks, and lower when they chose boredom compared to choosing the control tasks. (B) Activation in the insula was significantly modulated by individual differences in accepted price. In the insula (MNI peak coordinates: –44, –10, –6), the interaction effect between task option and choice was significantly correlated with Δ-price (SVC, p < .05). Middle panel illustrates the correlation between individual contrast values for this interaction and Δ-price. Panel on the right displays average percent signal change in the activated cluster separately for participants with low and high Δ-price (grouped by median split). For participants with higher Δ-price, activation to choosing the boredom task was higher relative to choosing the control tasks or music. Clusters are shown in neurological orientation at a display threshold of p < .005 (uncorrected), k = 5 voxels. Colour bars indicate t values.
emotions are not included in a recently validated short form of the multidimensional state boredom scale created to assess experimentally induced boredom (Hunter, Dyer, Cribbie, & Eastwood, 2016). Further studies will be needed to investigate the influence of the disengagement factor in more detail and assess the contribution of the other first-order boredom factors to boredom-related motivation. Taken together, our results on the general factor extend previous findings on parameters contributing to goal-directed decision making, such as anticipated effort or pain (Croxson, Walton, O’Reilly, Behrens, & Rushworth, 2009; Talmi, Dayan, Kiebel, Frith, & Dolan, 2009), by including the anticipation of a future affective-motivational state as an additional factor that influences the computation of option values.

Although personality did not affect task ratings in the current study sample, boredom proneness significantly predicted boredom ratings in a larger behavioural sample in which the current sample was included. This result is consistent with previous findings that boredom proneness is correlated with scores on the multidimensional state boredom scale (Fahlman et al., 2013; Mercer-Lynn et al., 2013) and further supports the validity of the boredom proneness scale (for a comparison of available boredom measures, see Vodanovich & Watt, 2016). The lack of a personality effect in the current smaller sample could be due to the sample size. However, since individual differences in boredom ratings significantly predicted variation in music prices in the current sample despite its size, it is also possible that the motivational effects of boredom on decisions are more closely related to differences in state boredom than in trait boredom.

The drive to avoid boredom was represented by activity in the nigrostriatal system. Activation in the caudate nucleus reflected an interaction of task condition and choice that was driven by higher activation during decisions to avoid the boring task. These results are consistent with evidence from animal and human experiments that the dorsomedial striatum mediates goal-directed decisions (Balleine & O’Doherty, 2009). Caudate activation has been shown to correlate with the value expected from actions in a strategic investment task (Tobia et al., 2014), to represent the values of future options (Croxson, Walton, O’Reilly, Behrens, & Rushworth, 2009; Talmi, Dayan, Kiebel, Frith, & Dolan, 2009), by including the anticipation of a future affective-motivational state as an additional factor that influences the computation of option values.

Importantly, the current results cannot be explained by value coding alone, as caudate activity was not increased by choices of music in the control condition despite participants’ willingness to spend money on music in these trials, suggesting that boredom avoidance specifically contributed to caudate activation. This interpretation is compatible with recent evidence that the caudate is involved in the integration of approach and avoidance tendencies during decision conflicts with appetitive or aversive emotional outcomes (Aupperle, Melrose, Francisco, Paulus, & Stein, 2015). This conflict-related caudate activation was higher in participants who exhibited higher avoidance behaviour, suggesting a role for the dorsomedial striatum in conflict-associated decision making. Although this earlier study did not differentiate activation on a trial-by-trial basis based on approach or avoidance decisions, the overall results are compatible with the idea that the caudate nucleus mediates avoidance decisions at the cost of forgoing rewards (Aupperle et al., 2015) or of paying higher prices (in the current study).

A comparison of the exploratory analysis of the task phase with the decision-making phase suggests both differences and commonalities in neural processing between the experience and anticipation of boredom. During performance of the boredom task, there was higher activity in dLPFC, VLPFC and dACC, regions that were not activated in the decision-making phase. Maintaining task performance in spite of boredom requires attentional control and associated executive processes (Eastwood et al., 2012) in a similar manner as in vigilance tasks, which are known to involve the dLPFC, VLPFC and dACC (Langner & Eickhoff, 2013; Nelson, McKinley, Golob, Warm, & Parasuraman, 2014). In contrast, the caudate nucleus was selectively involved in decision making, but did not differentiate between experience of the boredom and control tasks. These exploratory results suggest that executive control could play a role in maintaining task performance in a state of boredom, but is not recruited by choices involving anticipated boredom, which are mediated by the motivational drive to avoid boredom and seek out stimulation.

In contrast, the insula results are consistent with a representation of both the experience and the anticipation of boredom. Insula activation during the boredom task confirms previous results indicating its involvement in experiencing boredom (Danckert & Merrifield, 2016; Mathiak et al., 2013). Activation of the insula during choices of the boredom task in participants with higher price difference between the tasks suggests that the insula also signals the expectation of boredom. Two main mechanisms could contribute to this finding: One possibility is that insula activity reflects individual differences in boredom-related motivational drive, such that participants who are willing to accept higher costs for avoiding boredom show higher activation in trials in which they do not follow this behavioural tendency. The insula could thus represent the aversiveness of anticipated boredom or the cognitive control required for these choices. Another possibility is that insula activation signalled the higher cost of the music option in these trials, guiding choices towards the less costly option. While the current analysis cannot fully disambiguate the processes carried out by the insula, the overlap in activity between the boredom block and the decision phase is compatible with the interpretation that insula activity signalled the experience and anticipation of being bored.
The current findings may also relate to theories of subsequent task effects, such as resource depletion after exerting self-control, an effect reported across a range of tasks (e.g. Baumeister, Bratslavsky, Muraven, & Tice, 1998; Muraven, Tice, & Baumeister, 1998), yet questioned in recent attempts at meta-analysis and replication (Carter, Kofler, Forster, & McCullough, 2015; Hagger & Chatzisarantis, 2016). Recently, a process model of self-control proposed possible mechanisms that could mediate a reduction in self-control after a demanding task through homoeostatic regulation (Inzlicht & Schmeichel, 2012). According to this model, exerting self-control in a task leads to a shift in attention in a subsequent task, directing attention away from cues indicating a need for control and towards reward cues. A related recent model of lasting task effects proposes that the insula represents high levels of resource mobilization and perceived effort in the face of challenge, which leads to reduced motivation to exert control after repeated subjective exertion (Tops, Schlinkert, Tjew-A-Sin, Samur, & Koole, 2014). Thus, self-control and high resource mobilization during performance of the boredom task could lead to reduced self-control and increased attention to reward in the subsequent decision-making task. As all participants in the current study experienced the boredom task, however, we could not assess whether boredom avoidance selectively increases after exerting self-control during performance of the boring task. Future studies could include a subject group with no experience of boredom to reveal potential lasting differences in choices and neuronal processing across groups. In the current study, a selective effect of attention to reward in boredom trials is a possibility: The caudate activation could reflect an increase in perceived reward value of the chosen music pieces through contrasting of the music option against the boredom alternative, perhaps in a similar manner to representation of choice-induced preference change in the caudate (Sharot, De Martino, & Dolan, 2009).

In summary, we show that the drive to avoid a boring task increases the willingness to pay for music and that the caudate nucleus supports such boredom-motivated purchase decisions. These results suggest that anticipated future affective-motivational states can bias financial decision making, and outline a mechanism mediating everyday decisions about leisure activities. A similar mechanism may also underlie more extreme behaviours connected to boredom, such as overeating, impulsive shopping, and addictive behaviours.

Acknowledgments

We thank Marc Guitart-Masip for helpful comments on a previous version of the manuscript. This research was supported by the German Research Foundation (DFG) grant SFB/TRR 135, project B01.

Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.cortex.2017.03.008.

REFERENCES


