NeuroImage

www.elsevier.com/locate/ynimg
NeuroImage 34 (2007) 1782 – 1789

Striatal dopamine (D2) receptor availability predicts socially desirable responding

Suzanne J. Reeves,[a,*] Mitul A. Mehta,[b] Andrew J. Montgomery,[c] Dimitri Amiras,[d] Alice Egerton,[e] Robert J. Howard,[f] and Paul M. Grasby[g]

[a]*Section of Old Age Psychiatry, Institute of Psychiatry, De Crespigny Park, London SE5 8AF, UK*
[b]*Centre for Neuroimaging Sciences, Department of Neurology, Institute of Psychiatry, King's College London, UK*
[c]*MRC Clinical Sciences Centre CSC, Hammersmith Hospital, Imperial College, London, UK*
[d]*MRC Clinical Sciences Centre, Hammersmith Hospital, Imperial College, London, UK*
[e]*Clinical Sciences Centre, Hammersmith Hospital, Imperial College, London, UK*
[f]*Section of Old Age Psychiatry, Institute of Psychiatry, London, UK*
[g]*MRC Clinical Sciences Centre CSC, Hammersmith Hospital, London, UK*

Received 3 August 2006; revised 5 October 2006; accepted 8 October 2006
Available online 26 December 2006

Research in non-human primates has implicated striatal dopamine (D2) receptor function in the expression of social dominance—a fundamental component of social extraversion. We predicted that trait extraversion – indexed by the revised Eysenck Personality Questionnaire (EPQ-R) – would correlate with striatal DA (D2) receptor measures – indexed by [^{11}C]-Raclopride binding potential (BP) – in 28 healthy post-menopausal females (mean age = 75 years; range = 58–91 years). Region of interest (ROI) and voxel-based statistical parametric mapping (SPM) analyses were performed, using a reference tissue model for [^{11}C]-Raclopride. ROI analysis showed moderately significant negative correlations between extraversion and BP measures in the left caudate and between psychoticism scores and BP in the right putamen. Unexpectedly, scores on the Lie scale, a measure of socially desirable responding, were significantly and negatively correlated with BP measures in the putamen and survived Bonferroni correction on the right side. After controlling for the potential confounding of self-report bias in high Lie scorers, only the correlation between Lie scores and BP measures in the right putamen remained significant. Voxel-based analysis showed only Lie scores to be significantly and negatively correlated with BP measures in the right putamen. We explored this association further by applying an ROI-based approach to data on a previously scanned sample of young adults (n = 13) and found a similar pattern of association, which achieved trend level significance in the right putamen. Although unanticipated, the relationship observed between BP measures in the right putamen and Lie scores is consistent with dopaminergic involvement in socially rewarding behaviour. How this relates to dopaminergic tone will need to be further explored.

Keywords: Dopamine; Personality; EPQ; Socially desirable responding; Lie scale; Positron emission tomography

Introduction

Dopamine (DA) has been implicated in a variety of neurological and neuropsychiatric disorders and is considered to have a central, integrative role in the control of cognitive as well as motor processes (Middleton and Strick, 2000). A growing body of evidence suggests that brain DA might also influence expression of behavioural and emotional characteristics that constitute personality. Evidence supportive of the putative role of striatal DA (D2) receptors in trait extraversion (reviewed by Depue and Collins, 1999) has been largely accrued through research on social dominance in non-human primates – believed to reflect extraversion or 'social potency' in humans (Wiggins and Trapnell, 1996) – and by pharmacological manipulation in humans. These data have demonstrated reduced responsivity of striatal DA (D2) receptor function in submissive than dominant monkeys (Shively, 1998; Morgan et al., 2002) and in introverts compared to their extraverted peers (Depue et al., 1994; Rammsayer, 1998). Positron emission tomography (PET) ligand studies which have investigated the personality correlates of striatal DA (D2) receptor function – largely in healthy young adults – have used a variety of scales. For example, three studies have reported significant negative correlations with 'detachment' (a tendency towards social and emotional withdrawal), as defined by the Karolinska Scales of Personality (KSP; Schalling et al., 1987) and markers of striatal DA function — DA (D2) receptor or DA transporter availability (Farde et al., 1997; Breier et al., 1998; Laakso et al., 2000). However, this finding was not replicated in an older, mixed-sex sample (see Kaasinen et al., 2002). A single study (Gray et al., 1994), which defined personality using the Eysenck Personality Inventory (EPI; Eysenck and Eysenck, 1975), reported a significant correlation between striatal DA (D2) receptor availability – indexed by [^{123}I] iodo-benzoamide IBZM SPECT – and psychoticism (denoting 'tough-mindedness', or 'lacking in sensitivity and empathy').

* Corresponding author. Fax: +44 207 848 0632.
E-mail address: s.reeves@iop.kcl.ac.uk (S.J. Reeves).
Available online on ScienceDirect (www.sciencedirect.com).

1053-8119/$ - see front matter © 2006 Elsevier Inc. All rights reserved.
doi:10.1016/j.neuroimage.2006.10.042

Our study aimed to investigate the influence of striatal DA (D2) receptor function upon the expression of social extraversion, within the context of healthy ageing. Data on striatal DA (D2) receptor availability – indexed by [^{11}C]-Raclopride binding – were being collected in healthy post-menopausal women as part of an ongoing study of the role of striatal DA (D2) receptor function in predicting spatial cognitive performance (Reeves et al., 2005). This offered us the opportunity to examine the effects of DA (D2) receptor measures upon trait extraversion in a healthy older sample, without the potential confound of gender upon personality trait expression (Nilsson and Persson, 1984) or of oestrogen upon striatal dopaminergic function (Pohjalainen et al., 1998; Nordstrom et al., 1998).

We wanted to test the hypothesis that extraversion would be significantly associated with striatal DA (D2) receptor measures—indexed by [^{11}C]-Raclopride [^{11}C]-RAC binding potential (BP), after controlling for age. No prediction was made about the direction of the association, as [^{11}C]-RAC competes with endogenous DA for DA (D2) receptor sites and hence lower BP measures may reflect a lower B_{max}/K_d ratio or higher endogenous DA occupancy of DA (D2) receptor sites. The short form of the revised Eysenck Personality Questionnaire (EPQ-R; Eysenck and Eysenck, 1975) was chosen as an appropriate measure of personality in this sample for two reasons

(i) The extraversion (E) construct largely reflects 'social extraversion' and shows less overlap with psychoticism (P) than previous versions of the scale (Loo, 1979; Torrubia and Muntaner, 1987).
(ii) In addition to extraversion (E), neuroticism (N) and psychoticism (P) measures, the EPQ-R also incorporates a Lie scale (L), which measures the tendency to respond in a socially desirable way or to 'fake good'. As older women show a greater tendency to this type of response bias than their younger counterparts (Nilsson and Persson, 1984), it was important to control for this as a potential confounding factor (Michaelis and Eysenck, 1971).

Materials and methods

Participants

Thirty healthy post-menopausal female volunteers (28 right-handed) were recruited from day centres, luncheon clubs and other community-based groups in the local area (South East London). A full medical and psychiatric history was conducted, including dementia screening with the Mini-Mental State Examination (MMSE; Folstein et al., 1975). Exclusion criteria included (i) history of psychiatric or neurological illness; (ii) MMSE score of less than 26 out of a total score of 30; (iii) current or past psychiatric illness, including drug and substance abuse; (iv) history of any cerebrovascular event; and (v) use of oestrogen replacement therapy or other medications which may have affected brain DA activity. Structural imaging (MRI) data were available for eight of the older (>75 years) participants, owing to their involvement in ongoing MRI studies (Gould et al., 2006; Jones et al., 2005), but were not routinely carried out as part of the screening process. Recruitment and selection of young adult participants ($n=13$) were carried out during a previously conducted study (see Montgomery et al., 2006).

Personality assessment

The short 48-item version of the revised Eysenck Personality Questionnaire (EPQ-R) was used to assess the sample of older women, whereas the second sample of young adults were assessed using the full 90-item version of the EPQ-R. Both questionnaires provide a measure of trait extraversion (E), neuroticism (N) and psychoticism (P) and also incorporate a measure of socially desirable responding, described as the Lie scale (L) (see Table 1). Participants were required to give categorical yes/no responses to descriptive self-statements. For example, a 'Yes' response to the statement 'Are you rather lively?' scores '1' on the extraversion (E) subscale and a 'No' response scores zero. The Lie (L) scale was originally constructed as a means of assessing the reliability of personality scales, by providing a measure of the tendency to present oneself in a socially desirable way and consists of statements such as 'If you say you will do something, do you always keep your promise no matter how inconvenient it might be?' ('Yes' scores 1 point), 'Were you ever greedy by helping yourself to more than your share of anything? ('No' scores 1 point), 'Have you ever blamed someone for doing something you knew was really your fault?' ('No' scores 1), 'Do you always practice what you preach? ('Yes' scores 1 point). L scores are intrinsically related to other personality subscales from the EPQ-R generally showing a positive association with E and negative associations with N and P. The strength of the relationship between N and L is used as a means of determining whether conditions of personality testing are such to provide high motivation to 'fake good' or dissimulate. When conditions are such that there is little or no motivation to dissimulate, the correlation between L and N is minimal. When the relationship approaches statistical significance, the potential confounding influence of dissimulation can be examined by excluding the highest 5% of L scorers (Michaelis and Eysenck, 1971; Eysenck and Eysenck, 1975). Both versions of the EPQ-R have been extensively validated (Eysenck and Eysenck, 1975) and the short form specifically has been shown to provide a

Table 1
Eysenck personality trait scores in older women (short form of the revised EPQ)

Subscale	Mean SD	Correlation coefficient (Pearson's r)					
		Age	Education	E	N	P	L
Extraversion (E) 'Sociable, gregarious, lively, optimistic'	6.9 (3.1)	−0.28	0.27	–	−0.16	−0.01	0.26
Neuroticism (N) 'Sensitive, worries a lot, emotionally unstable'	5.1 (3.4)	−0.04	−0.09	−0.16	–	−0.17	−0.37*
Psychoticism (P [a]) 'Impulsive, tough-minded, lacking in empathy'	1.65 (1.7)	0.12	0.21	0.01	−0.17	–	0.32
Lie (L) 'Overly positive self-presentational style'	7.0 (2.5)	0.24	−0.20	0.26	−0.37*	0.32	–

[a] Log-transformed p scores were used in the correlational analysis.
* $p=0.056$.

reliable estimate of the above personality dimensions in older adults (Mackinnon et al., 1995).

PET procedure

[^{11}C]-RAC PET is an established in vivo method for estimating the availability of DA (D2) receptors in the brain. All participants attended a single scanning session, which consisted of the following sequence of scans on a 953B-Siemens/CTI PET camera (Spinks et al., 1992) in 3D mode: (i) a short transmission scan to enable correction for tissue attenuation of radioactivity; and (ii) dynamic scanning, involving the collection of 22 serial time frames over a 60-min period, following an intravenous bolus injection of 370 MBq of [^{11}C]-RAC (Farde et al., 1986). Binding potential in the form of parametric maps was calculated using the simplified reference tissue model (Lammertsma et al., 1996; Gunn et al., 1997). The younger volunteers from an independent study were scanned on an ECAT 966 camera using bolus followed by infusion administration of [^{11}C]-RAC over 105 min (Watabe et al., 2000). BP was calculated as ratio of [$\text{counts}_{\text{ROI}}/\text{counts}_{\text{cb}}-1$] between 38 and 53 min after the initiation of [^{11}C]-RAC administration.

Region-of-interest (ROI) analysis

Image analysis

ROI templates were defined for caudate, putamen and cerebellum on an integral image (Bench et al., 1993), for both elderly and young cohorts, using Analyze™ software (Mayo Biomedical Engineering; Rochester, MN, USA) (Robb and Hanson, 1991) on a SUN Ultra 10 Workstation. A circular ROI (diameter 15 mm) was positioned by inspection upon right and left cerebellar regions; and striatal subregions were defined by elliptical ROIs, which were positioned over the right and left caudate (5 × 7 mm) and putamen (6 × 16 mm) (mean values were obtained by placing ROI templates over 4 consecutive slices). Templates were applied first to the dynamic images to produce the time–activity curve of the reference region (cerebellum), which was in turn used to generate the parametric maps on which the striatal ROIs were overlaid. For the elderly cohort, a secondary analysis was carried out to decrease potential problems due to partial volume effects related to age-associated cerebral atrophy, which could lead to an under-estimation of tracer uptake (Morris et al., 1999). This analysis used elliptical regions of interest ROI (again placed over 4 consecutive slices), which were smaller than the structures that they represented (Yu et al., 1993): The caudate nucleus was defined by an ellipse 2 × 4 mm in diameter, whereas 3 ellipses of diameter 3 × 5 mm were used to define the putamen (for further details, see Reeves et al., 2005).

Statistical analysis

Data were analyzed using the Statistical Package for Social Sciences SPSS 12.0. Correlation coefficients (Pearson's r) were used to describe possible associations between personality measures, age and educational level. A partial bivariate correlation analysis, controlling for the potential confounding effects of age and educational level, was used to examine the relationship between [^{11}C]-RAC BP ROI measures and personality subscale scores. Stepwise linear regression analyses were used to assess the relative importance of the contribution of regional [^{11}C]-RAC BP measures, age and educational level to the variance in each of the personality trait measures. We chose a forward method of selection, which identifies the independent variable that contributes most significantly to the variance in the dependent variable R^2 and builds the regression model by sequentially including other variables which lead to an increase in R^2.

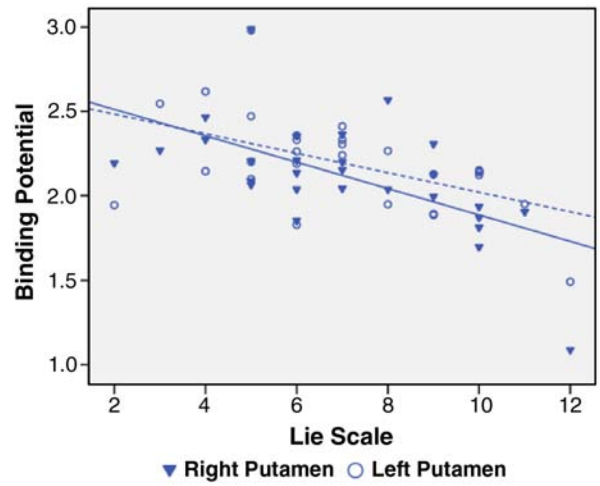

Fig. 1. Relationship between [^{11}C]-Raclopride ([^{11}C]-RAC) binding potential (BP) measures in the right putamen and Lie scale scores from the short form (48-item version) of the EPQ-R in older women ($r=-0.57$, $p=0.002$, $n=28$).

Statistical parametric mapping

In addition to the ROI analysis, voxel-based analysis using statistical parametric mapping version 2 (SPM2; www.fil.ion.ucl.ac.uk/spm) (Friston et al., 1995) was undertaken to confirm the findings of the correlational analysis. As this was a hypothesis-led analysis the search area was localised to the voxels of interest (VOI) by the application of an explicit spatial mask (see Hammers et al., 2006), which excluded voxels outside the striatal region. Parametric (BP) images were spatially normalized into Montreal Neurological Institute (MNI) space using a [^{11}C]-RAC template (Meyer et al., 1999). Normalised BP images were smoothed with a Gaussian filter to 8 mm full-width half maximum. The same comparisons of personality measures and BP were made using SPM2 as for the ROI analyses, with age and educational level being included as nuisance variables in the design matrix. For technical reasons, only 26 (93%) of the original 28 images were available for this analysis.

Results

Older sample: characteristics

Personality data were available on 28 subjects. The mean age of the sample was 75 years (SD = 8 years; range = 58–91 years). The mean educational level was 10 years of full-time education (SD = 3; range = 4–18). Twenty-six (93%) subjects were right-handed and 27 (96%) were non-smokers. All participants scored 28 or above during MMSE testing. There was a significant negative association between age and educational level ($r=-0.52$, $p=0.005$), which reflected differences in the educational system between older participants (who tended to be educated between the ages of 5–14 years) and younger participants, two of whom had obtained a higher degree. As reported previously (Reeves et al., 2005), BP measures in the four striatal subregions (right/left, caudate/putamen) were all negatively, but non-significantly, associated with age (Table 2). Neither the exclusion of two left-handed participants nor the use of small regions of interest ROI templates altered these findings.

Mean scores for individual subscales and their correlations with age and educational level are shown in Table 1. Extraversion (E), neuroticism (N) and Lie (L) scales were normally distributed. Psychoticism (P) scores showed a skewed distribution (mean=1.6, range=0–6); hence, log-transformed (logP) values were used for the purposes of statistical analysis. Scores on all of the scales were in line with normative data on this age group (Mackinnon et al., 1995). However, the negative relationship between L and N approached statistical significance ($r=-0.37$, $p=0.056$), indicating that the tendency to 'fake good' was relatively high in our sample. The following approaches were used to control for the potential confounding effects of this type of response bias upon personality subscale scores.

(i) N was included as a potential confounding factor in the correlational analysis.
(ii) The strength of the relationship between L and N was re-examined after exclusion of the highest 5% of Lie scorers (scoring 11 and 12, respectively, out of a maximum of 12 points). The correlation in the remaining sample ($n=26$) was non-significant ($r=-0.28$, $p=0.16$). In order to control for the influence of potential dissimulation upon relationships between personality and DA (D2) receptor measures, correlational and regression analyses were carried out before and after excluding the highest 5% of Lie scorers (Michaelis and Eysenck, 1971).

Personality measures and [11C]-RAC BP

Correlational analysis

The relationships between BP measures and personality subscale scores after controlling for the potential confounding effects of age and educational level are shown in Table 2. Prior to the exclusion of high Lie scorers, we found a negative correlation between E scores and [11C]-RAC BP in all striatal regions, which achieved moderate significance in the left caudate ($r=-0.41$, $p=0.04$). LogP scores were also negatively correlated with BP in the right putamen ($r=-0.41$, $p=0.04$). Unexpectedly, L was significantly and negatively correlated with [11C]-RAC BP in the right putamen ($r=-0.57$, $p=0.002$) and left putamen ($r=-0.48$, $p=0.01$) (Fig. 1). The extent of the correlation in the right putamen survived correction for multiple comparisons (p values <0.003 denotes significance) and was unaffected by the inclusion of N as a covariate (right putamen, $r=-0.58$, $p=0.002$; left putamen, $r=-0.51$, $p=0.01$). When the correlational analysis was repeated after excluding the two highest L scorers, only the correlation between L and BP measures in the right putamen remained significant ($r=-0.44$, $p=0.031$, shown in Table 2). Similarly, when data obtained using small ROIs were substituted into the correlational analysis, the correlation in the right putamen remained significant ($r=-0.45$, $p=0.02$) and a similar trend was shown on the left side ($r=-0.36$, $p=0.06$).

Regression analysis

The relative contributions of independent variables – regional BP measures right/left; caudate/putamen, age and educational level – to each of the personality subscales were investigated, in turn, using forward stepwise regression. None of the independent variables were found to contribute significantly to the variance in E, N or logP scores. BP measures in the right putamen were found to be the only significant predictor of L (adjusted $R^2=0.34$, $F_{1,26}=14.6$, $p=0.001$). Exclusion of high L scorers made no difference to the regression models for E, P and N and the contribution of [11C]-RAC BP in the right putamen to the variance in L remained highly significant (adjusted $R^2=0.22$, $F_{1,24}=8.2$, $p=0.008$). When data obtained using small ROIs were substituted into the regression analysis, BP measures in the left putamen were found to be the most significant predictor of Lie scores (adjusted $R^2=0.20$, $F_{1,26}=7.3$, $p=0.01$).

Voxel-based analysis

The results obtained using a hypothesis-led analysis in SPM2 were similar to those obtained with the ROI analysis. Increases in BP in association with lower Lie scores were seen bilaterally in the striatum (Fig. 2) and achieved a significance level of $p<0.0001$ uncorrected (FWE-corrected $p=0.057$) on the right side (MNI peak coordinates: $x=31$, $y=4$, $z=-2$). No significant relationships were found between BP and any of the other personality subscales.

Reproducibility of Lie scale/BP association

It was possible that our findings were specific to older women because of their tendency to score more highly on the Lie (and

Table 2
[11C]-RAC binding potential BP in older women: associations with age and personality measures

[11C]-RAC BP	Mean (SD)	Correlation with age (r)	Correlation with personality subscale scores [a]			
			E	N	logP	L
Right caudate	2.19 (0.28)	−0.26	−0.26 (−0.12)	0.02 (−0.08)	0.01 (−0.04)	−0.21 (−0.03) [b]
Left caudate	2.26 (0.32)	−0.10	−0.41 * (−0.28)	0.003 (−0.17)	0.01 (0.03)	−0.15 (−0.14) [b]
Right putamen	2.12 (0.33)	−0.27	−0.36 (−0.25)	0.08 (−0.15)	−0.41 * (−0.37)	−0.57 ** (−0.44 *) [b]
Left putamen	2.19 (0.28)	−0.25	−0.33 (−0.22)	0.05 (−0.12)	−0.26 (−0.22)	−0.48 * (−0.34) [b]

r values shown in brackets represent partial correlation coefficient after excluding the highest 5% of Lie scorers ($n=2$).
[a] Partial correlation coefficient r after controlling for age and educational level.
[b] Partialling out the influence of N upon L did not alter p values.
* $p\leq 0.05$.
** $p\leq 0.01$.

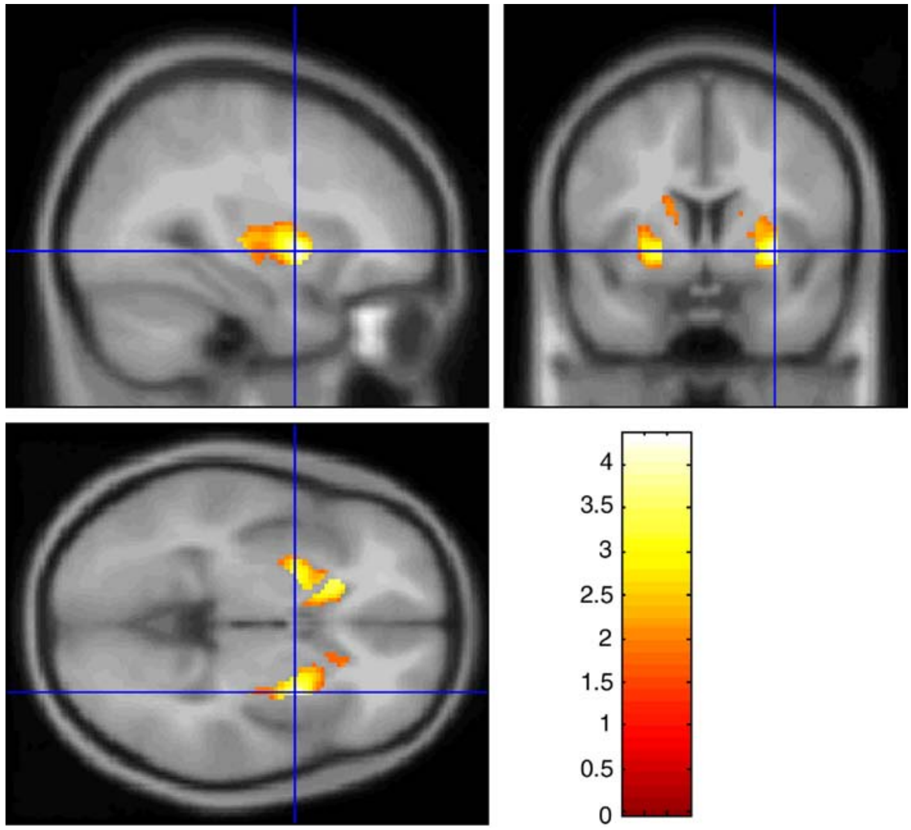

Fig. 2. Voxel-based statistical analysis, showing areas where a negative correlation was seen between DA (D2) receptor binding potential (BP) measures and Lie scores in healthy older women ($n=26$). The search volume was limited to the striatum (total search volume=2330 voxels; 7.4 resels). The colour intensity represents T-statistic values at the voxel level (T threshold for display=2.51, $p<0.01$). The results are visualized on a magnetic resonance imaging (MRI) template image derived from 152 healthy people and presented in neurological convention (right is right).

lower on the psychoticism scale) than younger males (Nilsson and Persson, 1984). In order to explore this further, we examined data on an independent sample of 13 healthy young adults (9 males; mean age 36 years; range 25–56), who had completed the 90-item version of the revised EPQ during their involvement in an earlier [^{11}C]-Raclopride study (Montgomery et al., 2006). [^{11}C]-RAC BP was determined using the same region-of-interest (ROI) analysis as in the elderly sample. Age was negatively correlated with BP measures in all striatal subregions and this achieved significance in the caudate nuclei (right caudate $r=-0.61$, $p=0.03$; left caudate $r=-0.68$, $p=0.01$; right putamen $r=-0.54$, $p=0.06$; left putamen $r=-0.51$, $p=0.08$). Mean (SD) scores for the EPQ-R are shown in Table 3: L and N scores were not significantly related ($r=-0.27$, $p=0.38$). The relationship between personality and BP measures was investigated using a partial correlational analysis, which controlled for the interaction between age and [^{11}C]-RAC BP. A negative correlation was found between L and BP measures in all striatal subregions and a trend towards significance was shown in the right putamen ($r=-0.55$, $p=0.06$, see Table 3 and Fig. 3). There were no significant correlations between BP measures and other personality subscale scores.

Discussion

The finding of a significant correlation between [^{11}C]-RAC BP in the left caudate and trait extraversion in the ROI analysis was consistent with our original hypothesis. However, the extent of this association achieved only moderate significance and was no longer present when the two highest scorers on the Lie scale were excluded from the analysis (as advocated in the scoring manual).

Table 3
Associations between [^{11}C]-RAC binding potential BP and personality measures in young adults

Personality subscale (maximum score)	Mean (SD)	Correlation r with [^{11}C]-RAC BP scores			
		Right caudate	Left caudate	Right putamen	Left putamen
Extraversion (21)	14.0 (3.8)	0.04	−0.003	0.24	0.22
Neuroticism (23)	6.8 (4.9)	0.29	0.45	0.26	0.37
Psychoticism (25)[a]	3.9 (2.1)	0.42	0.50	0.33	0.33
Lie (21)	7.0 (5.1)	−0.42	−0.30	−0.55*	−0.37

[a] Log-transformed p scores were used in the correlational analysis.
* $p=0.06$.

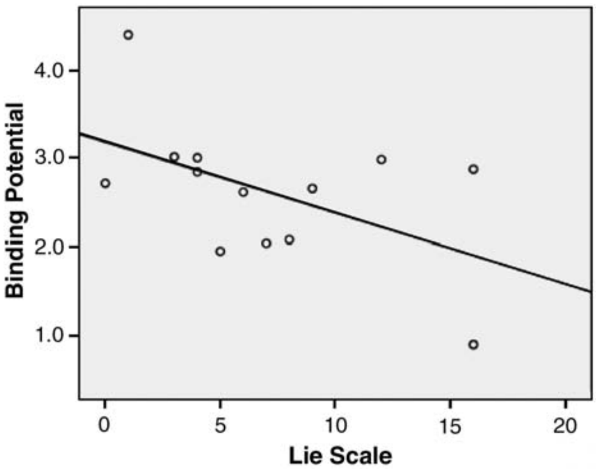

Fig. 3. Relationship between [11C]-Raclopride ([11C]-RAC) binding potential (BP) measures and Lie scale scores from the 90-item version of the EPQ-R in young adults are shown in the right putamen ($r=-0.55$, $p=0.06$, $n=13$, males=9).

The association also failed to achieve significance using a voxel-based approach.

Although unanticipated, we found a highly significant, negative correlation between Lie scores and [11C]-RAC BP bilaterally in the putamen using an ROI approach, which survived correction for multiple comparisons on the right side and was not explained by the association of Lie scores with trait neuroticism. Stepwise linear regression analyses showed BP measures in the right putamen to account for at least 20% of the variance in Lie scores, even after excluding the potential confounding effects of dissimulation. A hypothesis-led SPM analysis supported the findings of the ROI analysis and showed more clearly the bilateral nature of the correlation in the putamen.

Our findings strongly replicate those in a mixed-sex ($n=42$) sample of young adults: Huang et al. (2005) reported a highly significant negative correlation between (mean) striatal DA (D2) receptor availability and Lie scores from the Maudsley Personality Inventory (MPI, an earlier version of the EPI, prior to the inclusion of psychoticism; see Eysenck and Eysenck, 1975) using [123I] iodo-benzoamide (IBZM) SPECT. These findings, plus our observation of a similar trend in a young, predominantly male sample, would strongly suggest that the association is not a spurious one and is not specific to older women. Furthermore, social desirability scores from the KSP – which show considerable overlap with Lie scores (Ortet et al., 2002) – have been shown to correlate positively with markers of DA uptake and DA synthesis within the striatum, particularly on the right side (Laakso et al., 2000, 2003). Thus, our findings and those of Huang would be consistent with Laakso, assuming that lower DA (D2) receptor availability in individuals who scored more highly on the Lie scale reflects increased baseline DA levels. However, in the absence of information on endogenous DA levels, it remains unclear how individual differences in Lie scores relate to basal dopaminergic tone and this should perhaps be the focus of future studies.

The failure to confirm our original hypothesis regarding extraversion merits discussion. First it is not likely to be explained by inadequate sample size, as previous D2 receptor availability studies (for example, see Breier et al., 1998) have reported significant associations with personality variables in smaller, mixed-sex samples. Furthermore, we show significant correlations between DA (D2) receptor availability and another personality variable (Lie scale) with similar variance. As previous associations with extraversion/social dominance have measured responsivity of striatal DA (D2) receptor function (Shively, 1998; Morgan et al., 2002; Depue et al., 1994; Rammsayer, 1998), it could be argued that imaging paradigms that measure the change in endogenous DA levels in the striatum (see Laruelle, 2000) may have been a more effective method of testing our hypothesis than our static baseline measures.

More general study limitations include the absence of structural MRI data for co-registration of PET data in this elderly sample which limited our ability to correct for age-related partial volume effects (Morris et al., 1999). However, the substitution of small region-of-interest ROI templates that are less susceptible to partial volume effects (Yu et al., 1993) made little difference to the results reported. Age-related vascular changes – or differences in arousal in relation to the extraversion–introversion domain (see Fischer et al., 1997) – are also unlikely to have confounded BP measures, as blood flow makes a relatively small contribution to [11C]-RAC BP bolus or bolus infusion measurements (Logan et al., 1994; Carson et al., 1993).

Socially desirable responding and DA (D2) receptor availability

Although originally designed as a screening tool, the Lie construct is believed to represent a stable personality construct, denoting some degree of social conformity or conservatism (Michaelis and Eysenck, 1971; reviewed by Paulhus, 2002). Davies et al. (1998) have shown that Lie scores do not simply reflect the conscious biasing of responses to create a positive self-image, but also correlate highly with 'self-deceptive enhancement', an overly positive, self-favouring response style, which acts to protect self-esteem. Others view high Lie scores as being indicative of defensiveness, or a 'repressive' coping style, whereby threatening or negative self-related information is avoided through the use of unconscious mechanisms (Paulhus, 2002; Furnham et al., 2003). The Lie scale is thus a complex construct and we can only speculate as to the possible mechanisms which might underpin the observed association between Lie scores and striatal DA (D2) receptor function.

If Lie scores are viewed as a marker of social conformity or conciliatory social behaviour, our findings would be consistent with the reduced striatal DA (D2) function observed in animals lower down the social hierarchy, compared to their dominant peers (Shively, 1998; Morgan et al., 2002).

Alternatively, if scoring high on the Lie scale is viewed as a socially rewarding behaviour, our findings are consistent with the postulated role of the striatum and dopaminergic system in reward-based decision making (Schultz, 1998; Hollerman et al., 2000; O'Doherty et al., 2004) and incentive motivation (Depue and Collins, 1999). The strength of the relationship between L and N scores in the two samples suggests that older women were more motivated to dissimulate in order to gain social approbation than their younger counterparts.

More speculative is the interpretation that Lie scores might reflect attributional mechanisms such as the self-serving bias, in which the dorsal striatum (right or bilateral) has been implicated through the use of fMRI (Blackwood et al., 2003). The self-serving bias reflects both the tendency to take credit for success ('selfenhancing' bias) and to deny responsibility for failure ('self-protective' bias) and is generally believed to serve a positive motivational function, by protecting self-esteem (see Blackwood et al., 2003).

Intriguingly, Rabiner et al. (2002) have reported a similar unanticipated negative correlation between EPQ-R Lie scores and post-synaptic cortical and limbic 5-HT1A receptors (indexed by [^{11}C] WAY-100635 PET) in young healthy volunteers and have subsequently replicated this finding in an independent sample (Rabiner, personal communication).These data, the work reported here and the recent findings of Huang et al. (2005) indicate that the Lie scale represents a psychological construct that can be related to a quantifiable biological substrate.

Acknowledgments

This research was supported by the Medical Research Council. The authors would like to thank all of the volunteers who participated in the study. AJM was supported by a grant from the Wellcome Trust.

References

Bench, C.J., Lammertsma, A.A., Dolan, R.J., Grasby, P.M.S., Fracowiak, R.S.J., 1993. Dose dependent occupancy of central dopamine (D2) receptors by the novel neuroleptic CP-88, 059-01: a study using positron emission tomography and [^{11}C]-Raclopride. Psychopharmacology 112, 308–314.

Blackwood, N.J., Bentall, R.P., ffytche, D.H., Simmons, A., Murray, R. M., Howard, R.J., 2003. Self-responsibility and the self-serving bias: an fMRI investigation of causal attributions. NeuroImage 20, 1076–1085.

Breier, A., Kestler, L., Adler, C., Elman, I., Wiesenfeld, N., Malhotra, A., Pickar, D., 1998. Dopamine (D2) receptor density and personal detachment in healthy subjects. Am. J. Psychiatry 155, 1440–1442.

Carson, R.E., Channing, M.A., Blasberg, R.G., Dunn, B.B., Cohen, R.M., Rice, K.C., Herscovitch, P., 1993. Comparison of bolus and infusion methods for receptor quantitation: application to [18F]cyclofoxy and positron emission tomography. J. Cereb. Blood Flow Metab. 13, 24–42.

Davies, M.F., French, C.C., Keogh, E., 1998. Self-deceptive enhancement and impression management correlates of EPQ-R dimensions. J. Psychol. 132, 401–406.

Depue, R.A., Collins, P., 1999. Neurobiology of the structure of personality: dopamine, facilitation of incentive motivation, and extraversion. Behav. Brain Sci. 22, 491–569.

Depue, R., Luciana, M., Arbisi, P., Collins, P., Leon, A., 1994. Dopamine and the structure of personality: relation of agonist-induced dopamine (D2) activity to positive emotionality. J. Pers. Soc. Psychol. 67, 485–498.

Eysenck, H.J., Eysenck, S.B.G., 1975. Manual of the Eysenck Personality Questionnaire. University of London Press, London.

Farde, L., Hall, H., Ehrin, E., Sedvall, G., 1986. Quantitative analysis of (D2) dopamine receptor binding in the human brain by PET. Science 231, 258–261.

Farde, L., Gustavsson, J.P., Jonsson, E., 1997. (D2) dopamine receptors and personality traits. Nature 385, 590.

Fischer, H., Wik, G., Fredrikson, M., 1997. Extraversion, neuroticism and brain function: a PET study of personality. Pers. Indiv. Differ. 23, 345–352.

Folstein, M.F., Folstein, S.E., McHugh, P.R., 1975. 'Mini-Mental State': a practical method for grading the cognitive state of patients for the clinician. J. Psychiatr. Res. 12, 189–198.

Friston, K.J., Holmes, K.J., Worsley, A.P., Poline, K.J., Frith, J.-B., Frackowiak, C.D., 1995. Statistical parametric maps in functional imaging: a general linear approach. Hum. Brain Mapp. 2, 189–210.

Furnham, A., Petrides, K.V., Sisterson, G., Baluch, B., 2003. Repressive coping style and positive self-presentation. Br. J. Health Psychol. 8, 223–249.

Gould, R.L., Brown, R.G., Owen, A.M., Bullmore, E.T., Howard, R.H., 2006. Task-induced deactivations during successful paired associates learning: an effect of age but not Alzheimer's disease. NeuroImage 2, 818–831.

Gray, N.S., Pickering, A.D., Gray, J.A., 1994. Psychoticism and dopamine (D2) binding set in the basal ganglia using single photon emission tomography. Pers. Individ. Differ. 3, 431–434.

Gunn, R.N., Lammertsma, A.A., Hume, S.P., Cunningham, V.J., 1997. Parametric imaging of ligand-receptor binding in PET using a simplified reference region model. NeuroImage 6, 279–287.

Hammers, A., Chen, C.-H., Lemieux, L., Allom, R., Vossos, S., Free, S.L., Myers, R., Brooks, D.J., Duncan, J.S., Koepp, M.J., 2006. Statistical neuroanatomy of the human inferior frontal gyrus and probabilistic atlas in a standard stereotaxic space. Hum. Brain Mapp. (Electronic publication 2nd May, 2006).

Hollerman, J.R., Tremblay, L., Schultz, W., 2000. Involvement of basal ganglia and orbitofrontal cortex in goal-directed behaviour. Prog. Brain Res. 126, 193–215.

Huang, C.L., Yang, Y.K., Chu, C.L., Lee, I.H., Yeh, T.L., Chen, P.S., Chiu, N.T., 2005. The association between the Lie scale of the Maudsley personality inventory and striatal dopamine (D2)/D3 receptor availability of healthy Chinese community subjects. Eur. Psychiatry 21, 62–65.

Jones, D.K., Catani, M., Pierpaoli, C., Reeves, S.J., Shergill, S.S., O'Sullivan, M., Maguire, P., Horsfield, M.A., Simmons, A., Williams, S.C., Howard, R.J., 2005. A diffusion tensor magnetic resonance imaging study of frontal cortex connections in very-late-onset schizophrenia-like psychosis. Am. J. Geriatr. Psychiatry 13, 1092–1099.

Kaasinen, V., Nurmi, E., Bergman, J., Solin, O., Kurki, T., Rinne, J.O., 2002. Personality traits and striatal 6-[^{18}F]fluoro-L-dopa uptake in healthy elderly subjects. Neurosci. Lett. 332, 61–64.

Laakso, A., Vilkman, H., Kajander, J., Bergman, J., Haaparanta, M., Solin, O., Hietala, J., 2000. Prediction of detached personality in healthy subjects by low dopamine transporter binding. Am. J. Psychiatry 157, 290–292.

Laakso, A., Wallius, E., Kajander, J., Bergman, J., Eskola, O., Solin, O., et al., 2003. Personality traits and striatal dopamine synthesis capacity in healthy subjects. Am. J. Psychiatry 160, 904–910.

Lammertsma, A.A., Bench, C.J., Hume, S.P., Osman, S., Gunn, K., Brooks, D.J., Fracowiak, R.S.J., 1996. Comparison of methods for analysis of clinical [^{11}C]-Raclopride studies. J. Cereb. Blood Flow Metab. 16, 42–52.

Laruelle, M., 2000. Imaging synaptic neurotransmission with in vivo binding competition techniques: a critical review. J. Cereb. Blood Flow Metab. 20, 423–451.

Logan, J., Volkow, N.D., Wang, J.S., Dewey, G.J., MacGregor, S.L., et al., 1994. Effects of blood flow on [^{11}C] raclopride binding in the brain: model simulations and kinetic analysis of PET data. J. Cereb. Blood Flow Metab. 14, 995–1010.

Loo, R., 1979. A psychometric investigation of the Eysenck Personality Questionnaire. J. Pers. Assess. 43, 54–58.

Mackinnon, A., Jorm, A.F., Christensen, H., Scott, L.R., Henderson, A.S., Korten, A.E., 1995. A latent trait analysis of the Eysenck Personality Questionnaire in an elderly community sample. Pers. Individ. Differ. 18, 739–747.

Meyer, J.H., Gunn, R.N., Myers, R., Grasby, P.M., 1999. Assessment of spatial normalization of PET ligand images using ligand specific templates. NeuroImage 9, 545–553.

Michaelis, W., Eysenck, H.J., 1971. The determination of personality inventory factor patterns and intercorrelations by changes in real-life motivation. J. Genet. Psychol. 118, 223–234.

Middleton, F.A., Strick, P.L., 2000. Basal ganglia output and cognition:

evidence from anatomical, behavioral, and clinical studies. Brain Cogn. 42, 183–200.

Montgomery, A.J., Mehta, M., 2006. Is psychological stress in man associated with increased striatal dopamine levels?: a [(11)C]raclopride PET study. Synapse 60, 124–131.

Morgan, D., Grant, K.A., Gage, H.D., Mach, R.H., Kaplan, J.R., Prioleau, O., et al., 2002. Social dominance in monkeys: dopamine (D2) receptors and cocaine self-administration. Nat. Neurosci. 5, 169–174.

Morris, E.D., Chefer, S.I., Lane, M.A., Muzic, R.F., Wong, D.F., Dannals, R.F., et al., 1999. Loss of (D2) receptor binding with age in rhesus monkeys: importance of correction for differences in striatal size. J. Cereb. Blood Flow Metab. 19, 218–229.

Nilsson, L.V., Persson, B., 1984. Personality changes in the aged. Acta Psychiatr. Scand. 69, 182–189.

Nordstrom, A.L., Olsson, H., Halldin, C., 1998. A PET study of (D2) dopamine receptor density at different phases of the menstrual cycle. Psychiatry Res. 83, 1–6.

O'Doherty, J., Dayan, P., Schultz, J., Deichmann, R., Friston, K., Dolan, R.J., 2004. Dissociable roles of ventral and dorsal striatum in instrumental conditioning. Science 304, 452–454.

Ortet, G., Ibáñez, M.I., Llerena, A., Torrubia, R., 2002. Underlying traits of the Karolinska Scales of Personality KSP. Eur. J. Psychological Assess. 18, 139–148.

Paulhus, D.L., 2002. Socially desirable responding: the evolution of a construct. In: Braun, H., Jackson, D.N., Wiley, D.E. (Eds.), The Role of Constructs in Psychological and Educational Measurement. Erlbaum, Hillsdale, NJ, pp. 67–88.

Pohjalainen, T., Rinne, J.O., Nagren, K., Syvalahti, E., Hietala, J., 1998. Sex differences in the striatal dopamine (D2) receptor binding characteristics in vivo. Am. J. Psychiatry 155, 768–773.

Rabiner, E.A., Messa, C., Sargent, P.A., Husted-Kjaer, K., Montgomery, A., Lawrence, A.D., et al., 2002. A database of [^{11}C]WAY-100635 binding to 5-HT1A receptors in normal male volunteers: normative data and relationship to methodological, demographic, physiological, and behavioral variables. NeuroImage 15, 620–632.

Rammsayer, T.H., 1998. Extraversion and dopamine: individual differences in responsiveness to changes in dopaminergic activity as a possible biological basis of extraversion. Eur. Psychol. 3, 37–50.

Reeves, S.J., Grasby, P.M., Howard, R.J., Bantick, R.A., Asselin, M.-C., Mehta, M.A., 2005. Positron emission tomography PET investigation of the role of striatal dopamine (D2) receptor availability in spatial cognition. NeuroImage 28, 216–226.

Robb, R.A., Hanson, D.P., 1991. A software system for interactive and quantitative visualization of multidimensional biomedical images. Australas. Phys. Eng. Sci. Med. 76, 172–182.

Schalling, D., Asberg, M., Edman, G., Oreland, L., 1987. Markers for vulnerability to psychopathology: temperament traits associated with platelet MAO activity. Acta Psychiatr. Scand. 78, 172–182.

Schultz, W., 1998. Predictive reward signal of dopamine neurons. J. Neurophysiol. 80, 1–27.

Shively, C.A., 1998. Social subordination stress, behavior, and central monoaminergic function in female cynomolgus monkeys. Biol. Psychiatry 44, 882–891.

Spinks, T.J., Jones, T., Bailey, D.L., Townsend, D.W., Grootoonk, S., Bloomfield, P.M., et al., 1992. Physical performance of a positron tomograph for brain imaging with retractable septa. Phys. Med. Biol. 37, 1637–1655.

Torrubia, R., Muntaner, C., 1987. Relationship between Psychoticism and a number of personality measures: a comparison between the original and revised versions of the psychoticism scale. Pers. Individ. Differ. 8, 261–263.

Watabe, H., Endres, C.J., Breier, A., Schmall, B., Eckelman, W.C., Carson, R.E., 2000. Measurement of dopamine release with continuous infusion of [^{11}C] raclopride: optimization and signal-to-noise considerations. J. Nucl. Med. 41, 522–530.

Wiggins, J.S., Trapnell, P.D., 1996. A dyadic-interactional perspective on the five-factor model. In: Wiggins, J.S. (Ed.), The Five Factor Model of Personality. The Guilford Press, New York, p. 88.

Yu, D.C., Huang, S.C., Grafton, S.T., Melega, W.P., Barrio, J.R., Mazziotta, J.C., Phelps, M.E., 1993. Methods for improving quantitation of putamen uptake constant of FDOPA in PET studies. J. Nucl. Med. 34, 679–688.