Differential patterns of nucleus accumbens activation during anticipation of monetary and social reward in young and older adults

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Recent studies have reported inconsistent results regarding the loss of reward sensitivity in the aging brain. Although such an age effect might be due to a decline of physiological processes, it may also be a consequence of age-related changes in motivational preference for different rewards. Here, we examined whether the age effects on neural correlates of reward anticipation are modulated by the type of expected reward. Functional magnetic resonance images were acquired in 24 older (60-78 years) and 24 young participants (20-28 years) while they performed an incentive delay task offering monetary or social rewards. Anticipation of either reward type recruited brain structures associated with reward, including the nucleus accumbens (NAcc). Region of interest analysis revealed an interaction effect of reward type and age group in the right NAcc: enhanced activation to cues of social reward was detected in the older subsample while enhanced activation to cues of monetary reward was detected in the younger subsample. Our results suggest that neural sensitivity to reward-predicting cues does not generally decrease with age. Rather, neural responses in the NAcc appear to be modulated by the type of reward, presumably reflecting age-related changes in motivational value attributed to different types of reward.

Keywords: reward anticipation; social reward; monetary reward; age; nucleus accumbens

INTRODUCTION
Throughout the life span, reward seeking constitutes an important motive for goal-directed behavior. On the neural level, anticipation and approach toward rewards is mediated by the mesolimbic dopamine system. Dopamine neurons projecting from the ventral tegmental area (VTA) to the nucleus accumbens (NAcc) in the ventral striatum have been implicated in the coding of the ‘incentive salience’ of potential rewards (Robinson and Berridge, 2000), which varies with subjective preference (McClure et al., 2004; O’Doherty et al., 2006).

Despite a plethora of functional imaging studies trying to unravel the neural base of reward processing in healthy and patient populations, little is still known about how reward-oriented behavior is affected by normal aging. The present study addressed this question by comparing neural activation in response to cues predictive of potential reward in young and older subjects. By offering two different types of rewards (i.e. monetary and social), we explored the possibility that differential patterns of reward-related brain activity reflect a shift in motivational preference rather than a general decline in reward sensitivity with age.

The role of dopamine in coding the expected value of potential rewards has been established in both animal and human research (Schultz et al., 1993; Mirenowicz and Schultz, 1996; Zoghbi et al., 2009). Unexpected rewards have been found to yield phasic activity of dopamine neurons in the VTA projecting to the NAcc and the prefrontal cortex. If the reward is preceded by a predictive cue, creating an anticipation phase, the dopaminergic response is shifted from the time of reward delivery to cue presentation. Studies using functional magnetic resonance imaging (fMRI) to monitor reward anticipation have found structures of the mesolimbic dopamine system activated by cues predictive of different types of reward such as money (Knutson et al., 2001a,b), juice (O’Doherty et al., 2002), or smiling faces (Spreckelmeyer et al., 2009, 2013; Rademacher et al., 2010). Activation of the NAcc during cued reward anticipation in these ‘incentive delay tasks’ has been found to increase with expected reward value (e.g. Knutson et al., 2005; Spreckelmeyer et al., 2009), and has been suggested to reflect positive arousal at the prospect of receiving a reward (Knutson and Greer, 2008).

Studies using positron emission tomography (PET) to examine age-dependent changes of dopamine function, point toward a degeneration of the dopamine system. However, although PET studies examining dopamine receptor availability or dopamine transporter function suggest a decrease in dopamine function with age, studies focusing on presynaptic dopamine availability provide less consistent results (see Kaasinen and Rinne, 2002; Reeves et al., 2002; Kumakura et al., 2010 for reviews). Some, but not all, fMRI studies targeting age effects on neural reward processing reported changes in neural activation in brain structures innervated by dopamine. Using a cued reward task in which participants had to solve an arithmetic task to receive monetary reward, Schott et al. (2007) found that older adults show NAcc activation in response to reward outcomes but fail to show the neural response shift from reward to the preceding cue observed in young participants. Similarly, Dreher et al. (2008) reported reduced ventral striatal activity in older subjects compared with young adults in response to cues that are predictive of upcoming monetary reward. However, contrary to the study by Schott and colleagues, no ventral striatal activity was detected for the outcome period.

In contrast, Samanez-Larkin et al. (2007) found no significant differences in NAcc activation between young and older subjects during cued reward anticipation or outcome processing of monetary rewards. Cox et al. (2008) also did not find significant changes in striatal recruitment between older and younger adults when using a card-guessing task to investigate the processing of rewarding outcomes.
These divergent findings may be explained in part by the fact that some studies included a reward anticipation phase whereas others did not. Another important aspect seems to be that previous studies differ to the extent in which they incorporated a learning component into the presented task. Age differences appear to be larger in studies requiring learning than in those that do not. For example, studies on probabilistic reward learning report age differences in frontal striatal function (e.g. Mell et al., 2009; Samanez-Larkin et al., 2010; Samanez-Larkin et al., 2012). Also, participants in the study by Dreher et al. (2008) were instructed to choose between response buttons on seeing different types of reward-predicting cues. Thus, the task required not only a motor response, but also a decision between different response options. In the study by Schott et al. (2007), reward was instrumental on the participant’s correct response in an arithmetic task. Hence, in both studies, reward cue processing was combined with the requirement to perform a complex task. This raises the possibility that diminished responses of older subjects in these studies may be due to age influences in more cognitively demanding paradigms rather than reflecting age differences in the neural responses to explicit reward signaling cues (Samanez-Larkin et al., 2010). In line with this possibility, Samanez-Larkin et al. (2007) found no significant differences between young and older subjects during either cued reward anticipation or outcome processing in a monetary incentive delay task (Knutson et al., 2000). Using a simple response instruction and explicit reward cues, which were learned before the experiment, Samanez-Larkin and colleagues minimized the cognitive demand of the task and focused on the signals of simple reward prediction. This seems to imply that the neural mechanisms coding the salience of potential rewards are largely unaffected by age.

However, one important aspect that has received relatively little attention in previous research is the possibility that aging might be accompanied by a change of salience across reward types as a consequence of age-related changes in subjective preference. Previous research on age-related changes in reward anticipation has been restricted to tasks offering only one type of reward (money), implicitly assuming that money was of equal importance to both age groups. In the present study, we added social reward in the form of smiling faces to account for the possibility that different reward types have varying value at different stages of the life cycle. Smiling faces are a form of social reward and can serve as motivational incentive. In previous studies, we were able to show that anticipating smiles instead of money in the monetary incentive delay task (Knutson et al., 2000) similarly recruits the NAcc and increases motivated behavior (social incentive delay task; Rademacher et al., 2010; Spreckelmeyer et al., 2009, 2013).

Social reward might be of particular salience in old age. The life span theory of social-emotional selectivity (SST) (Carstensen, 2006) posits that the subjective sense of how much lifetime one has left shapes the motivational salience of potential incentives. The theory predicts that as long-term goals become less relevant, immediate rewards that directly help increase subjective well-being are attributed greater reward value. Specifically, it has been suggested that the positive feelings associated with social contact become more and more important as we age, and that its anticipation becomes a primary driving force of motivated behavior (Carstensen and Turk-Charles, 1994; Carstensen, 1995; Kryla-Lighthall and Mather, 2008). Indeed, although the number of social contacts decreases over the lifetime, social closeness with intimate friends and family increases (Carstensen, 1992). A questionnaire study by Ojha and Pramanick (2009) confirms that social belongingness becomes a more important need as age increases. Also in line with this assumption, Fredrickson and Carstensen (1990) reported that older people place more importance in whether a social encounter is emotionally meaningful than if it has potential for future contact or helps to gain information. Young people, on the other hand, find all three criteria equally important. Based on these findings, it can be assumed that with increasing age, positive social stimuli become more salient than in young age. These differences in reward valuation should be associated with different levels of anticipatory arousal during the anticipation of the respective rewards (Knutson and Greer, 2008), and manifest themselves in differential activation patterns of the NAcc in response to reward-predicting cues (Spreckelmeyer et al., 2009). We tested this assumption by comparing young and older adults that performed both a social incentive delay task and a monetary incentive delay task. We hypothesized that reward type would modulate anticipatory neural activation in different directions in young and older individuals, with young subjects favoring money over social reward and older adults showing the opposite pattern.

**EXPERIMENTAL PROCEDURES**

**Subjects**

Fifty-two right-handed healthy volunteers participated in the study. Four participants were excluded owing to structural anomalies or excessive head movement during scanning. Thus, data from 24 older (12 men; mean age = 66.2 years, range = 60–78 years) and 24 younger participants (12 men: mean age = 23.4 years, range = 20–28 years) were included in the analysis. None of the subjects had a history of neurological or psychiatric disorder or were taking psycho-pharmacologically active medication. Furthermore, the subgroup of older participants underwent a dementia screening to exclude cognitive impairments. Subjects were recruited through newspaper advertisements and bulletin-board announcements (e.g. at bridge clubs).

The study was approved by the Ethics Committee of the Medical Faculty of the RWTH Aachen University. Subjects gave written informed consent according to the Declaration of Helsinki (Declaration, 1991) and were paid an allowance for participation in the study.

**Stimuli and task**

The experiment consisted of two conditions (Figure 1): a ‘monetary incentive delay’ (MID) task as introduced by Knutson et al. (2000), and a ‘social incentive delay’ (SID) task (Spreckelmeyer et al., 2009). Four MID and SID blocks were presented interleaved with the order of conditions counterbalanced across participants. At the beginning of each block, participants were informed which condition (MID or SID) would follow.

In both conditions, each trial started with the presentation of a cue for 250 ms that signaled potential reward (20 Cents, 1 Euro, or 3 Euros in the MID, three types of happy facial expressions with increasing intensity level in the SID) or a neutral control outcome. After a delay period (jittered between 2250–2750 ms), a target button had to be pushed within a set time window to receive reward. The time window was adapted for individual reaction time that had been assessed prior to the experiment (187–352 ms). Success was acknowledged by presenting the picture of a wallet containing the respective amount of money (MID), or a smiling face (SID) (each 1500–1650 ms). The control outcome consisted of an empty wallet in the MID condition, and a graphically dysmorphed face image (in which all facial features were eliminated) in the SID condition. Each condition consisted of 88 trials, yielding a total of 176 trials. For a more detailed description of the paradigms, see Spreckelmeyer et al. (2009) or Rademacher et al. (2010).

Prior to entering the scanner, participants performed a practice session composed of 44 trials per condition to familiarize them with the experiment. Participants were informed that their performance had no influence on the allowance paid for participation.
Age effects on reward anticipation

Behavioral measures

Reaction times and hit rates were assessed for all conditions and tested for differences in separate analyses of variance (ANOVA) with within-subject factors ‘type of reward’ (monetary, social) as well as ‘level of reward’ (control, low, medium, high) and between-subject factor ‘age group’.

Furthermore, to rule out group-specific personality differences, participants completed German versions of the revised Temperament and Character Inventory (TCI) (Cloninger et al., 1993), the behavioral inhibition system/behavioral activation system scales (BIS/BAS) (Carver and White, 1994), and the Cambridge Behaviour Scale (Baron-Cohen and Wheelwright, 2004). Group differences were assessed using unpaired *t*-tests.

fMRI setting

Stimuli presentations and recording of reaction times were performed using the software Presentation (Neurobehavioral Systems, Inc., San Francisco, CA). Participants indicated their response by pressing the button of a fiber-optic custom-made response box with the index finger of their right hand.

Image acquisition

Scanning was performed on a 1.5T whole body scanner (Philips Medical Systems, Achieva, Best, Netherlands) using standard gradients and a standard quadrature head coil. Participants lay in a supine position, and their head movement was limited by foam padding within the head coil. To ensure optimal visual acuity, participants were offered fMRI-compatible glasses that could be fixed to the video goggles. For each participant, a series of 840 Echo Planar Imaging (EPI) scans, lasting ~28 min, were acquired. Stimuli were presented in an event-related fashion.

Functional scans were aligned parallel to the anterior commissure - posterior commissure (AC/PC) line and fully covered the striatum (Supplementary Figure S1). The fMRI recording, including five initial dummy scans, had the following parameters: number of slices (NS): 22; slice thickness (ST): 3.8 mm; interslice gap (IG): 0 mm; matrix size (MS): 64 × 64; field of view (FOV): 240 × 240 mm; repetition time (TR): 2 s; echo time (TE): 50 ms; flip angle (FA): 90°. For anatomical localization, we acquired high resolution images with a T1-weighted 3D Fast Field Echo (FFE) sequence (repetition time (TR) = 25 ms; echo time (TE) = 4.59 ms; number of slices (NS) = 170 (sagittal); slice thickness (ST) = 2 mm; interslice gap (IG) = 1 mm; field of view (FOV) = 256 × 256 mm; voxel size = 1 × 1 × 2 mm).

Image analysis

The data were preprocessed and analyzed using the Statistical Parametric Mapping software package (SPM5) (http://www.fil.ion.ucl.ac.uk), implemented in MATLAB 7.10.0 (Mathworks Inc., Sherborn, MA, USA). The first five volumes from each participant were discarded from data analysis because of the non-equilibrium state of magnetization.

All remaining images were realigned to the mean image to correct for head movement, coregistered with the anatomical 3D image, and spatially normalized to the standard template of the Montreal Neurological Institute (MNI, Canada) using the unified segmentation approach (Ashburner and Friston, 2005). Subsequently, the normalized data were smoothed with a resliced voxel size 3 × 3 × 3 mm with an 8 mm full width at half maximum (FWHM) isotropic Gaussian kernel to allow for statistical inference using the Gaussian Random Field theory. Finally, a high-pass filter was applied to remove baseline drifts owing to cardiorespiratory and other cyclical influences. An event-related statistical analysis was performed in a two-level mixed-effects procedure. At the subject level, a fixed-effects General Linear Model (GLM) was specified for each participant. Changes in blood oxygen level-dependent (BOLD) signal during reward anticipation were modeled at the onset of each trial (i.e. the presentation of the cue) as delta function convolved with a hemodynamic response function (HRF). Both conditions (MID and SID) with their four levels of potential reward magnitude were modeled as separate regressors. In addition to these eight regressors of interest, the six rigid-body movement parameters determined from realignment were included in the GLM as covariates of no interest. Regression coefficients for all regressors were estimated using the restricted maximum likelihood procedure as implemented in SPM5.

For group inferences, an analysis of variances was computed with within-subject factors ‘reward type’ (monetary, social) and ‘reward level’ (control, low, medium, high), and between-subject factor ‘age group’. Whole-brain analyses were thresholded at *P* < 0.05, family-wise error corrected (FWE) for multiple comparisons. In addition, region of interest (ROI) analyses were performed for the right and left NAcc (at an FWE-corrected level of *P* < 0.05), using anatomically defined masks of the NAcc (WFU Pick-Atlas version 2.4; Wake Forest University, Winston-Salem, NC, USA; http://fmrri.wfubmc.edu/soft-ware/PickAtlas). In case of interaction effects, follow-up analyses were performed on mean parameter estimates from the ROI extracted vs baseline.

RESULTS

Behavioral data

Hit rates

The ANOVA on hit rates in the eight outcome categories (Figure 2) revealed a significant main effect of ‘age group’ [*F*(1, 46) = 11.87, *P* = 0.001, *η*2 = 0.21], reflecting higher hit rates for older compared with younger participants [17.66 (s.d. = 3.59) vs 14.25 (s.d. = 4.68)]. A significant main effect of ‘reward level’ [*F*(2, 13), 97.81] = 14.74, *P* < 0.001, *η*2 = 0.24, Greenhouse–Geisser corrected] reflected higher hit rates for all reward levels compared to the control condition and a higher hit rate for the highest compared with the lowest reward level,
Reward type was also found to interact with reward level reflecting higher hit rates in the MID than in the SID task (16.41 vs 15.5). However, ‘reward type’ and ‘reward level’ were also found to interact (F(3, 138) = 15.53, P = 0.009, η² = 0.08), showing that hit rates were significantly higher in the MID than the SID task in rewarded trials (P < 0.05) but not in control trials.

Reaction times
The ANOVA on reaction times for the eight outcome categories also revealed a main effect of reward level (F(2.36, 108.45) = 4.43, P = 0.01, η² = 0.09, Greenhouse–Geisser corrected): reaction times were significantly faster for the highest reward level compared with the three other levels (P < 0.05). No significant group effect was found.

Personality assessment
Age group was not found to differ on any personality dimension (all P > 0.05, Supplementary Table S1).

fMRI-data
Whole-brain analysis
Testing for a main effect of reward level at whole-brain level (P < 0.05, FWE corrected), independent of reward type or age group, revealed a pattern of activation that included parts of the striatum, the thalamus, and the anterior cingulate (Table 1, Figure 3). Testing for other main effects (reward type or age group) or interactions did not yield any clusters of activation that survived the correction level of P < 0.05 (FWE).

Region of interest analyses
Testing for an effect of age on neural activation in our a priori defined ROI of the NAcc revealed no main effect of age. However, we found an interaction of reward type and age group in the right NAcc (peak z-score 2.57 at x = 9, y = 5, z = –7). Parameter estimates extracted from the right NAcc ROI suggest a disordinal interaction pattern with opposite effect directions in older vs younger participants depending on reward type (Figure 4).

DISCUSSION
The aim of the present study was to explore whether age effects on the neural correlates of reward anticipation can be modulated by offering different types of reward. Specifically, we wanted to test the possibility that neural responsivity to cues of potential reward is differentially activated in young and older individuals depending on whether the expected reward is social or monetary in nature.

Confirming prior studies examining reward anticipation (i.e. Knutson et al., 2001a; Ernst et al., 2004), anticipation of both reward types activated the ventral striatum, thalamus, and anterior cingulate cortex in younger and older subjects. No main effect of age group was observed at whole-brain level or in our a priori-defined ROI of the NAcc. However, and in line with our hypothesis, ROI analysis yielded an interaction of reward type and age group in the right NAcc. Although young participants seemed more responsive to cues of monetary than social reward, older participants showed the opposite pattern. This finding suggests that older adults may demonstrate similar, or even increased, sensitivity for certain kinds of reward. A similar suggestion has been made by Jimura et al. (2011) who compared delay discounting of monetary and liquid rewards (i.e. favorite drinks) in younger and older adults. Although younger subjects discounted monetary rewards more steeply than older participants, no significant difference was detected for liquid rewards. Together, the data speak against a general decrease of sensitivity to rewards with increasing age. Rather, they suggest that sensitivity toward rewards is differently modulated in young and older adults depending on reward type.

NAcc activation to different types of reward has been found to be reflective of subjective preference (to the extent that it is predictive of consumers’ choice in a shopping task) (Knutson et al., 2007). We therefore suggest that the observed age-dependent differences in NAcc activation patterns during anticipation of social vs monetary reward in our sample are reflective of age-related differences in subjective preference. Enhanced NAcc activation to cues of social reward in older participants can be interpreted as reflecting age-related changes in incentive salience attributed to this type of reward. This interpretation would be consistent with the account that positive social stimuli become more salient with old age as a consequence of a shift in psychological needs (Carstensen and Turk-Charles, 1994; Carstensen,
In a questionnaire study that examined the effect of age on the priority of life needs, Ojha and Pramanick (2009) found that in older subjects (61–80 years old), belongingness and love are primary, while young (21–40 years) or middle aged (41–60 years) persons rate physiological or esteem needs as more important. Similarly, younger and older participants in our sample may have differed in the motivational value attributed to monetary and social reward.

Table 1  Main effect of reward level ($P < 0.05$, FWE)

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<th>Brain regions</th>
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<td>L anterior cingulate cortex</td>
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<td>L ventral striatum</td>
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Of note, we did not find an overall decrease in NAcc activation in older participants during reward anticipation. This result is consistent with the findings by Samanez-Larkin et al. (2007) who—using a similar task—did not find evidence for diminished neural response to reward predictive cues in older adults. However, our data are less consistent with studies reporting diminished neural responses of older participants in the ventral striatum and anterior cingulate cortex during reward anticipation (Dreher et al., 2008; Schott et al., 2007). As outlined in the introduction, this disparity in findings might be explained by differences in task complexity. For example, it is possible that the cognitive tasks applied by e.g. Schott et al. (2007) or Dreher et al. (2008) were perceived as more difficult. Thus, together with the findings by Samanez-Larkin et al. (2007) our data speak against the assumption of a general decline of reward sensitivity and basic motivational function in the aging brain.

Although Samanez-Larkin et al. (2007) found no difference between younger and older adults in neural responses to monetary rewards, our ROI analysis yielded age differences in parameter estimates. A possible explanation for these contradictory findings could be the varied sets of offered rewards. In the study by Samanez-Larkin et al. (2007) only monetary rewards were used, whereas the present study additionally offered social stimuli. It is known from research on decision-making...
making that the attractiveness of one option strongly depends on the presence or absence of alternatives (Tversky and Simonson, 1993). Context effects can even influence the rewarding value of presence or absence of alternatives (Koekeke et al., 2008). Thus, the inclusion of social reward as additional reward type in the current study may have influenced the individual value attributed to the offered monetary rewards.

Several limitations of the present study need to be addressed. First, a general problem of fMRI studies comparing age groups is that aging involves many changes in morphology and hemodynamics that might affect the BOLD signal. In a group comparison of young and older adults, it cannot be ruled out that a finding of diminished activity in older participants is actually owing to such changes. However, in the present study, we did not find evidence for a significant main effect of age group. Instead, we observed a significant interaction effect. As neurovascular age differences should influence all experimental conditions equally, it is unlikely it would cause differential condition effects within age groups (Samanez-Larkin and D’Esposito, 2008). Therefore, we would argue that the finding of differential responses to social and monetary rewards in the present study can be interpreted as age-related changes in reward processing occurring independent of mere physiological aging effects.

Second, unfortunately, in the present study, no self-reports on the importance of money and social rewards were collected, and the present data do not provide information about the reasons that could underlie different valuations (for example, a more stable financial situation in the older subsample). As the present study is cross-sectional, it is also not clear whether differences between the age groups are a result of individual aging processes or whether they represent a cohort effect. Longitudinal approaches would be needed to answer this question. However, research showed that older adults’ preference for emotionally meaningful social partners as described within the SST framework disappears when participants are asked to imagine an expansive future (Fung et al., 1999). Hence, such preferences are rather due to perceived limitations on time than to age, per se, suggesting that they are not product of a cohort effect.

Third, the current sample size is not sufficient to consider sex as an additional group factor. In a previous study on the anticipation of monetary and social reward, sex differences in brain activation patterns were found in young subjects (Spreckelmeyer et al., 2009). In future research, it would be interesting to examine whether increasing age and the associated changes of motivational salience of potential incentives as suggested by the SST (Carstensen, 2006) are modulated by sex.

Fourth, social rewards differ from monetary rewards in that personality dispositions influence how powerful particular social rewards work as incentives (Buss, 1983). In the current study, social stimuli consisted of still pictures of smiling faces. Pictures of smiling faces have been found to be associated with positive feelings and to motivate approach. In the current study, they are also likely to signal social approval. It cannot be ruled out that young and old people differ in their interpretation of the face stimuli and that additional moderators, e.g. loneliness, moderated their valuation. Hence, the possibility needs to be taken into account that the observed effects are driven by differences in motives (e.g. affiliation motive vs. achievement motive) between old and young adults.

To conclude, the present study provides new insights into the effects of aging on reward processing by including social reward as a second reward type in addition to money. Although dopaminergic neurotransmission is known to be reduced with increasing age, no significant main effect was found when neural correlates of reward anticipation were compared for young and older subjects. Instead, an ROI analysis of the NAcc revealed enhanced neural response to cues of social reward in older participants compared with young subjects. Our finding represents preliminary evidence that older individuals may show increased neural responses to reward-predicting cues. Together, our data extend previous work on reward processing in the aging brain to the realms of social reward processing, and brings attention to the impact of age-related changes in psychological needs on motivated behavior.

**SUPPLEMENTARY DATA**

Supplementary data are available at SCAN online.

**REFERENCES**


