Original Article

Functional differentiation of the dorsal striatum: a coordinate-based neuroimaging meta-analysis

Qian Zheng[1]^, Xiaojuan Ba[1], Qiang Wang[1], Junying Cheng[2], Jiaofen Nan[1], Taigang He[3,4]

[1]College of Software Engineering, Zhengzhou University of Light Industry, Zhengzhou, China; [2]Department of Magnetic Resonance, The First Affiliated Hospital of Zhengzhou University, Zhengzhou, China; [3]Biomedical Research Unit, Royal Brompton Hospital and Imperial College London, London, UK; [4]Cardiovascular Sciences Research Centre, St George's, University of London, London, UK

Contributions: (I) Conception and design: Q Zheng, J Nan; (II) Administrative support: Q Zheng, J Nan; (III) Provision of study materials or patients: J Cheng; (IV) Collection and assembly of data: X Ba, Q Wang; (V) Data analysis and interpretation: X Ba; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Jiaofen Nan. College of Software Engineering, Zhengzhou University of Light Industry, 136 Kexue Avenue, High-tech Zone, Zhengzhou 450002, China. Email: nanjiaofen@163.com; Taigang He. Cardiovascular Sciences Research Centre, St George's, University of London, Cranmer Terrace, London SW17 0RE, UK. Email: t.he@sgul.ac.uk.

Background: The dorsal striatum, a nucleus in the basal ganglia, plays a key role in the execution of cognitive functions in the human brain. Recent studies have focused on how the dorsal striatum participates in a single cognitive function, whereas the specific roles of the caudate and putamen in performing multiple cognitive functions remain unclear. In this paper we conducted a meta-analysis of the relevant neuroimaging literature to understand the roles of subregions of the dorsal striatum in performing different functions.

Methods: PubMed, Web of Science, and BrainMap Functional Database were searched to find original functional magnetic resonance imaging (fMRI) studies conducted on healthy adults under reward, memory, emotion, and decision-making tasks, and relevant screening criteria were formulated. Single task activation, contrast activation, and conjunction activation analyses were performed using the activation likelihood estimation (ALE) method for the coordinate-based meta-analysis to evaluate the differences and linkages.

Results: In all, 112 studies were included in this meta-analysis. Analysis revealed that, of the 4 single activation tasks, reward, memory, and emotion tasks all activated the putamen more, whereas decision-making tasks activated the caudate body. Contrast analysis showed that the caudate body played an important role in the 2 cooperative activation tasks, but conjunction activation results found that more peaks appeared in the caudate head.

Discussion: Different subregions of the caudate and putamen assume different roles in processing complex cognitive behaviors. Functional division of the dorsal striatum identified specific roles of 15 different subregions, reflecting differences and connections between the different subregions in performing different cognitive behaviors.

Keywords: Activation likelihood estimation (ALE); dorsal striatum; functional differentiation; functional magnetic resonance imaging (fMRI); meta-analysis

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^ ORCID: 0000-0001-7984-625X.

Introduction

During the brain's processing of reward information and negative emotions, dopamine release increases in the dorsal and ventral striatum (1,2). The hippocampus in the brain is the key hub of episodic memory, but the insula and dorsal striatum are also related to other forms of memory (3). Similarly, a growing amount of evidence from neuroimaging and neuropsychological studies shows that there are direct and indirect ways to control decision-making behavior in the striatum, and the brain's choices based on current expected return or actions related to decision making are closely related to the dorsal striatum (4-6). At first, these functions seem unrelated, but the commonality among them all is the dorsal striatum. The striatum is a nucleus in the basal ganglia, and the dorsal striatum, consisting of the caudate and putamen, is the gateway to the basal ganglia. The dorsal striatum receives convergent excitatory afferents from the cortex and thalamus and forms the origins of the direct and indirect pathways that are important in the cortex-basal ganglia-thalamus-cortical circuit (7). The dopaminergic neurons in this circuit are distributed throughout the striatum, which is of great significance to neurological diseases involving abnormal basal ganglia and dopaminergic function, such as Parkinson's disease and dystonia (8,9). From this viewpoint, it is particularly important to functionally localize the caudate and putamen in the dorsal striatum and explore their differences and connections.

There has been a considerable increase in the number of meta-analyses in neuroimaging field in recent years (10), but studies integrating multiple different activation tasks in the same region to show their coherence remain rare. To better understand the roles of subregions of the dorsal striatum in performing different functions, this study aimed to explore functional partitioning in the caudate and putamen using a meta-analysis of the existing literature. Recent meta-analyses on brain studies have produced substantial findings. For example, using a coordinate-based meta-analysis, Arioli *et al.* found that the lateral temporal areas and the amygdala are involved in processing social and emotional concepts (11). In 2021, Mas-Herrero *et al.* used a meta-analysis to integrate brain involvement in music and food responses to identify reward circuits involved in the brain response (12). In the same year, Sorella *et al.* used a meta-analysis to investigate whether or not anger perception and anger experience rely on similar or different neural mechanisms in the human brain (13). Inspired by these studies, the present study used the activation likelihood estimation (ALE) method to determine commonly activated brain regions by collecting data from multiple studies and used spatial coordinates under reward, emotion, memory, and decision-making tasks (14,15) to discern the functional division of the dorsal striatum.

The idea behind the ALE method is that coordinates reported in the included studies are considered likelihood distributions, which are modeled by a 3-dimensional Gaussian function (16) and from which an ALE value can be calculated for each voxel to estimate the activation probability of each voxel for the task identified throughout the study. Finally, in order to distinguish the real convergence of focus from random clustering, an ALE null-distribution is formed by thousands of iterations of whole-brain coordinates (17). Coordinate-based meta-analyses are not limited by experimental design, task, the number of subjects, or methods of data analysis, and they can maximize the consistency of location information between studies and minimize the subjectivity of analytical methods (18).

In recent years, many researchers have used different methods to map the relationship between the structure and function of the human brain (i.e., a brain atlas) (19). Inspired by the creation of the brain atlas, we used the ALE algorithm to integrate different studies on the striatum in the human brain to create a functional division in this region, with each subregion created by this division being involved in different activation tasks (20). This study had two main aims: (I) to identify the subregions in the striatum of healthy adults involved in processing reward, emotion, memory, and decision-making tasks; and (II) to analyze similarities and differences in the subregions that assume different functions in response to the 4 activation tasks. These activation tasks were chosen because these cognitive functions are widely used by humans and are the most studied in the neuroimaging literature, ensuring there are sufficient activation foci for the meta-analysis. We present the following article in accordance with the PRISMA reporting checklist (available at https://qims.amegroups.com/article/view/10.21037/qims-22-133/rc).

Methods

In this study, the functional division of the dorsal striatum was achieved through a literature search, retrieval, screening, and data extraction; ALE analysis of single activation tasks; and ALE conjunction and contrast analyses

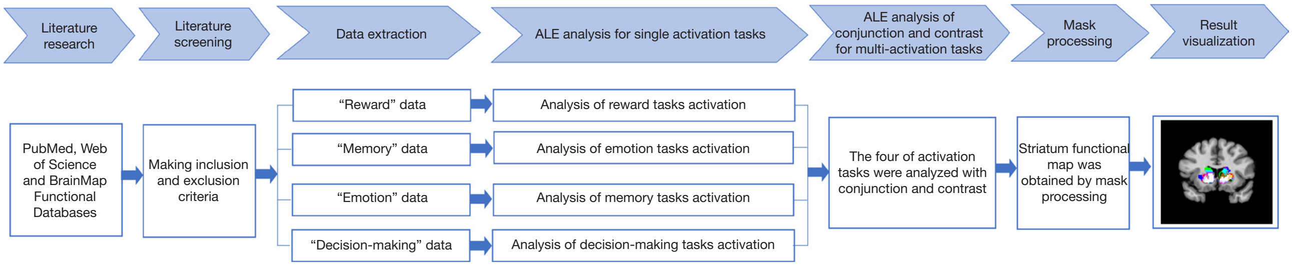

Figure 1 Methodological flowchart for this study. ALE, activation likelihood estimation.

of multiple activation tasks. Cumulatively, this approach was able to show that different regions assume different functional roles (see *Figure 1*).

Data collection

Literature search

A systematic literature search was performed to identify relevant articles in PubMed, Web of Science, and the BrainMap Functional Database (21-23). The BrainMap Functional Database, accessed using Sleuth V3.0.4 (http://www.brainmap.org/sleuth/), contains data of functional and structural neuroimaging experiments based on Talairach coordinates (24) or Montreal Neurological Institute (MNI) space (25), and is widely used for meta-analyses of human brain structure and function research in healthy and diseased individuals.

Specific keyword searches were performed to retrieve literature relating to the reward, memory, emotion, and decision-making paradigms. For the reward paradigm, the PubMed and Web of Science databases were searched using the following keywords: "dorsal striatum" OR "striatum" AND "reward" AND "functional magnetic resonance imaging (fMRI)" NOT "animal". This search identified 2,970 nonoverlapping studies. In the BrainMap Functional Database, "reward" and "fMRI" were the 2 keywords used, with the experimental environment set to "normal mapping"; this identified another 12 nonoverlapping studies.

For the memory paradigm, the PubMed and Web of Science databases were searched using the keywords "dorsal striatum" OR "striatum" AND "memory" AND "fMRI" NOT "animal", with 1484 nonoverlapping studies identified. The BrainMap Functional Database was searched using the keywords "memory" and "fMRI", with the experimental environment set to "normal mapping"; this identified another 22 non-overlapping studies.

For the emotion paradigm, the PubMed and Web of Science databases were searched using the keywords "dorsal striatum" OR "striatum" AND "emotion" AND "fMRI" NOT "animal", identifying 1,604 nonoverlapping studies. The BrainMap Functional Database was searched using the keywords "emotion" and "fMRI", with the experimental environment set to "normal mapping", identifying another 36 nonoverlapping studies.

For the decision-making paradigm, the PubMed and Web of Science databases were searched using the keywords "dorsal striatum" OR "striatum" AND ("decision" OR "decision-making") AND "fMRI" NOT "animal", with 1,681 nonoverlapping studies identified. Using the search terms ("decision" OR "decision-making") and "fMRI" in the BrainMap Functional Database, with the experimental environment set to "normal mapping", another 3 nonoverlapping studies were identified.

Thus, a total of 7,812 nonoverlapping studies were identified in this study.

Inclusion and exclusion criteria

Before selecting articles for inclusion in a meta-analysis, comprehensive inclusion criteria must be determined and rigorously applied to minimize bias. In the present study, all studies included were magnetic resonance imaging studies performed in healthy adults aged 14–79 years. The titles, abstracts, and full text of all articles were screened for eligibility (*Figure 2*). Case reports, pharmacological trials, trials involving clinical populations, neuroimaging studies on children or on patients with certain neurological diseases, and review articles were excluded. Studies were considered eligible for inclusion in the analysis if they met the following criteria: published after 2000; activation reported in standardized 3-dimensional space (Talairach or MNI), with the activation area being the dorsal striatum (caudate, putamen); use of fMRI; the activation task resulting in instantaneous activation; and the activation type

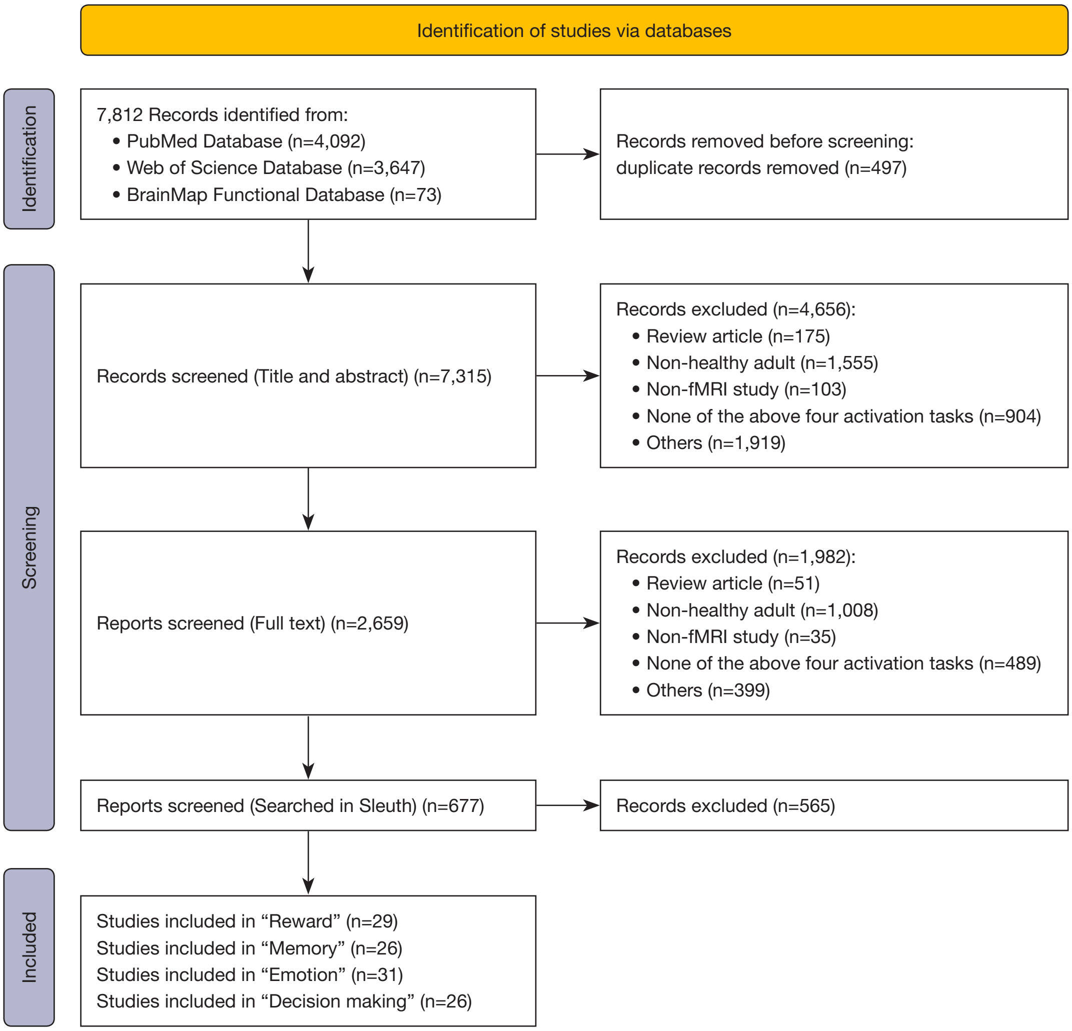

Figure 2 Flowchart showing study inclusion in the meta-analysis. fMRI, functional magnetic resonance imaging.

reported by the researchers being "reward", "memory", "emotion", and "decision making". The application of these criteria yielded 29 reward studies (548 subjects, 74 trials), 26 memory studies (463 subjects, 50 trials), 31 emotion studies (658 subjects, 52 trials), and 26 decision-making studies (518 subjects, 50 trials), for a total of 112 studies (Table S1) that were used in the meta-analysis.

Data extraction

Data were independently extracted from all included studies by Ba and Wang and included basic information (e.g., article title, author/s, and publication date), participant information (e.g., number of participants, age/mean age, and male:female ratio), experimental materials (e.g., scanned fMRI data) and stimulation methods (e.g., objects, pictures, videos, language, music), study methods (e.g., whether the data coordinates reported are in MNI or Talairach space), and the results (e.g., literature research activation paradigm, as well as activation area).

Data analysis

ALE analysis for single activation tasks

The specific process of ALE analysis for single activation tasks using GingerALE V3.0.2 (http://www.brainmap.org/ale/) software was as follows:

(I) Data organization: the coordinates in all studies included in this analysis were exported to plain text (.txt) files using Sleuth software.

(II) Transformation: all coordinates were transformed

Table 1 Activation results under the reward task

Cluster No.	MNI peak coordinate			ALE value	Brain region
	x	y	z		
1	12	12	–4	0.085461	Right cerebrum, sublobar, caudate, gray matter, caudate head
1	14	–2	12	0.0298301	Right cerebrum, sublobar, caudate, gray matter, caudate body
1	–10	2	12	0.026592	Left cerebrum, sublobar, caudate, gray matter, caudate body
1	–26	4	4	0.0243451	Left cerebrum, sublobar, lentiform nucleus, gray matter, putamen

MNI, Montreal Neurological Institute; ALE, activation likelihood estimation.

into coordinates in common MNI space.

(III) Parameter setting: uncorrected P value thresholds were used to yield reasonable results, with a threshold of P<0.01 and the minimum cluster size set to a volume of 600 mm^3.

Mask processing: the object of this study is the dorsal striatum, so the masks of the caudate and the putamen generated by the anatomical automatic labeling (AAL) atlas (19) were used for processing.

Viewing results: Mango (http://www.rii.uthscsa.edu/mango/mango.html) software was used to view the results of the meta-analysis, and the Colin atlas (26) was used with consideration to the statistical coordinate data in MNI space.

ALE analysis of conjunction and contrast for multiple activation tasks

To test for significant differences in the results of analyses of the four single activation tasks, GingerALE software also provides conjunction and contrast meta-analyses. ALE analysis results for the four activation tasks were merged into a single data set before the conjunction and contrast meta-analyses, which resulted in six data sets in total. ALE analysis was performed on the merged data set, and then conjunction and contrast analyses were performed using the ALE threshold images of the merged data set. Conjunction analysis includes any two kinds of conjunction results (e.g., A conjunction B), whereas contrast analysis includes any two kinds of mutual comparisons (e.g., A-B and B-A). As in ALE analysis for single activation tasks, the parameters for contrast and conjunction analyses were a threshold of P<0.01, with 5,000 P value permutations, and a minimum cluster size of 600 mm^3.

Functional differentiation of the striatum

Using the specified parameters in the ALE analysis, activation results for single tasks in the whole brain were obtained; the striatum mask in the AAL brain template was used to process the ALE results to obtain 4 functional partitions of the striatum for reward, memory, emotion, and decision-making tasks. Activation areas in the mask were labeled as follows: 1 for reward, 2 for memory, 4 for emotion, and 8 for decision making. Areas of coactivation were also labeled: 3 for reward and memory; 5 for reward and emotion; 6 for memory and emotion; 7 for reward, memory, and emotion; 9 for reward and decision making; 10 for memory and decision making; 11 for reward, memory, and decision making; 12 for emotion and decision making; 13 for reward, emotion, and decision making; 14 for memory, emotion, and decision making; and 15 for reward, memory, emotion, and decision making. Thus, 15 different functional zones were marked in the striatum area.

Results

Analysis of single activation tasks

Reward

We analyzed activation information in the dorsal striatum under different reward tasks, including 26 monetary rewards, 1 each for food rewards, language and social-type rewards, temperature and taste rewards, and personal preference rewards. The skewed distribution of studies toward monetary reward tasks might have caused inclination in the results. However, these studies showed significant consistency in the caudate and putamen, with a total of 12 clusters activated with the coordinates of the largest cluster located from (–36, –26, –26) to (40, 32, 26) in MNI space and a center coordinate of (2, 7, –5) (see Table S2). The analysis showed significant activation in the caudate on the right side of the brain, whereas activation on the left side was mainly in the caudate body and putamen (*Table 1*; *Figure 3*).

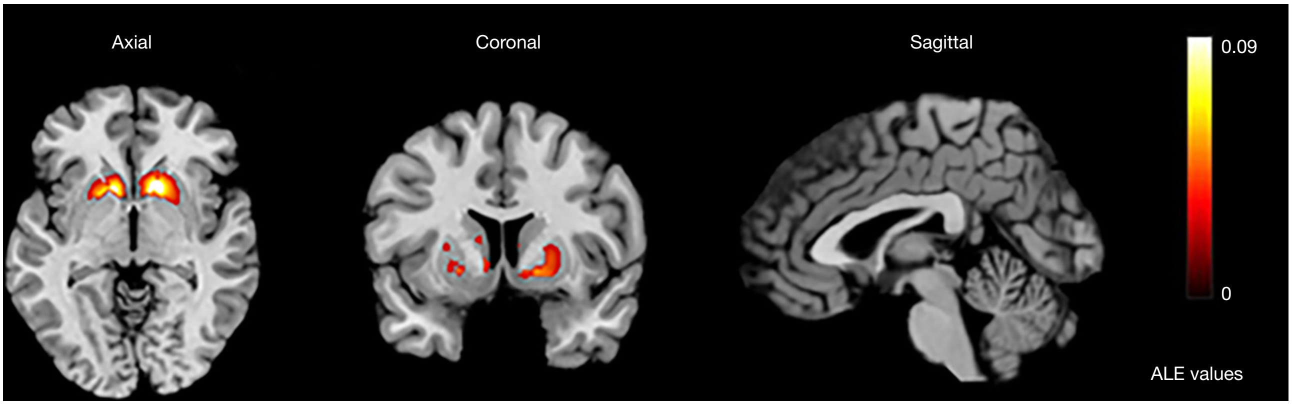

Figure 3 The largest activation cluster for the reward task centered at (2,7,–5) in Montreal Neurological Institute space. ALE, activation likelihood estimation.

Table 2 Activation results under the memory task

Cluster No.	MNI peak coordinate			ALE value	Brain region
	x	y	z		
1	10	12	–10	0.0303841	Right cerebrum, sublobar, caudate, gray matter, caudate head
1	12	8	–2	0.026199	Right cerebrum, sublobar, caudate, gray matter, caudate head
1	20	8	0	0.024628	Right cerebrum, sublobar, lentiform nucleus, gray matter, putamen
1	22	4	16	0.0220977	Right cerebrum, sublobar, caudate, gray matter, caudate body
1	28	–2	8	0.019593	Right cerebrum, sublobar, lentiform nucleus, gray matter, putamen
1	30	–8	–10	0.016469	Right cerebrum, sublobar, lentiform nucleus, gray matter, putamen
1	16	12	16	0.0133372	Right cerebrum, sublobar, caudate, gray matter, caudate body
2	–20	6	0	0.0332396	Left cerebrum, sublobar, lentiform nucleus, gray matter, putamen
2	–14	0	12	0.0249166	Left cerebrum, sublobar, caudate, gray matter, caudate body
2	–20	12	–12	0.0186555	Left cerebrum, sublobar, lentiform nucleus, gray matter, putamen

MNI, Montreal Neurological Institute; ALE, activation likelihood estimation.

Memory

There were 26 relevant articles included in the activation study of memory tasks, including 9 working memory, 2 vocabulary memory, 3 emotional memory, and 1 each of episodic and working memory, episodic memory, semantic memory, declarative memory, reward memory, vocabulary and perceptual memory, selective memory, source memory, learning memory, confirmatory memory, precise and distorted memory, and spatial location memory. The results of the whole-brain analysis showed that the memory task activated 12 clusters (Table S3). Activation peaks were found in the dorsal striatum in the 2 larger clusters and were more significant on the right side of the brain. The largest cluster center was located at (21,4,–4) in MNI space (*Table 2*; *Figure 4*).

Emotion

In all, 31 studies studying activation by emotional tasks were included. All selected studies contained emotions such as pleasure, neutrality, sadness, disgust, fear, and pain, and the main ways to stimulate these emotions were pictures, movies, music, smells, facial expressions, and vocabulary. ALE analysis indicated that 8 clusters were activated by the emotion tasks (Table S4). The largest activation cluster was located from (–36, –34, –24) to (36, 32, 22) in MNI space, with the center coordinate at (2, 2, –1). There were

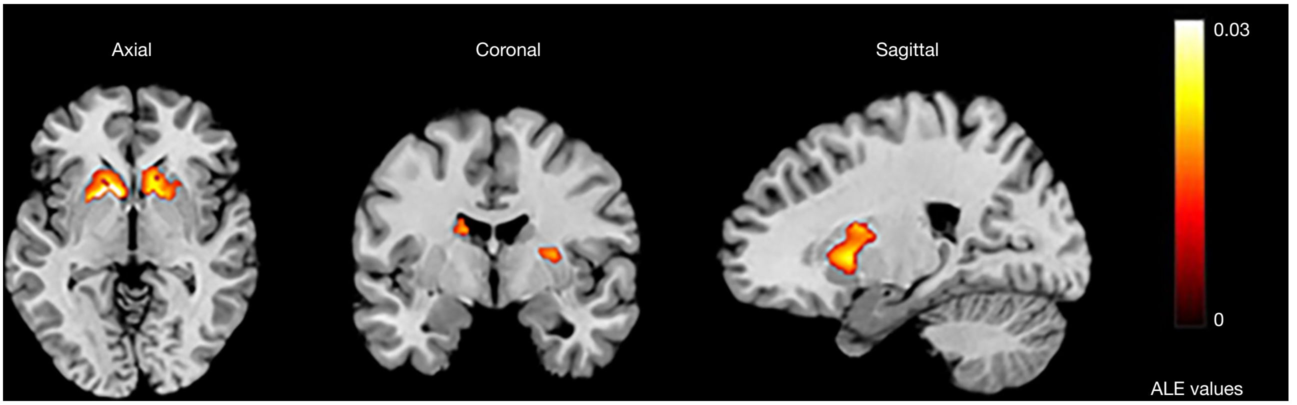

Figure 4 The largest activation cluster for the memory task centered at (21,4,–4) in Montreal Neurological Institute space. ALE, activation likelihood estimation.

Table 3 Activation results under the emotion task

Cluster No.	MNI peak coordinate			ALE value	Brain region
	x	y	z		
1	10	8	2	0.044895	Right cerebrum, sublobar, caudate, gray matter, caudate body
1	–10	8	6	0.034102	Left cerebrum, sublobar, caudate, gray matter, caudate body
1	14	6	16	0.034102	Left cerebrum, sublobar, caudate, gray matter, caudate body
1	–10	16	2	0.030288	Left cerebrum, sublobar, caudate, gray matter, caudate body
1	22	8	0	0.024583	Right cerebrum, sublobar, lentiform nucleus, gray matter, putamen
1	–20	10	–10	0.019019	Left cerebrum, sublobar, lentiform nucleus, gray matter, putamen
1	–24	–2	6	0.01578	Left cerebrum, sublobar, lentiform nucleus, gray matter, putamen
6	–32	–22	2	0.018084	Left cerebrum, sublobar, lentiform nucleus, gray matter, putamen

MNI, Montreal Neurological Institute; ALE, activation likelihood estimation.

22 peaks found in the largest activation clusters, but there was no obvious activation peak in the cluster in the caudate head region (*Table 3*; *Figure 5*).

Decision making

Decision making involves choosing between different solutions. The ALE algorithm analyzed 4 intertemporal, 3 rewarding, 7 risky, 9 economic, 1 preference, 2 action, and 1 exploratory decision-making studies, showing that 18 clusters were activated in the brain. The largest activated cluster was located from (–2, –14, –20) to (34, 28, 26) in MNI space with central coordinates of (14, 8, 2) and 7 peaks (Table S5). The peaks in the largest clusters tended to converge in the right brain rather than in the left brain. Compared with other functions, decision-making tasks activated both sides of the brain more evenly (*Table 4*; *Figure 6*).

Contrast analysis

Data in *Tables 1-4* indicate that the caudate head and caudate body in the striatum are most activated by decision making, whereas the caudate body is more activated by emotion tasks. To understand differences in activation areas between different tasks, contrast analysis of the 4 activation tasks was performed; the results of whole-brain contrast analysis are presented in Table S6. Contrast analysis of any 2 tasks showed that, in the dorsal striatum, the activation peak was greater in the putamen than that in other tasks, with this being mainly apparent from the reward and decision-

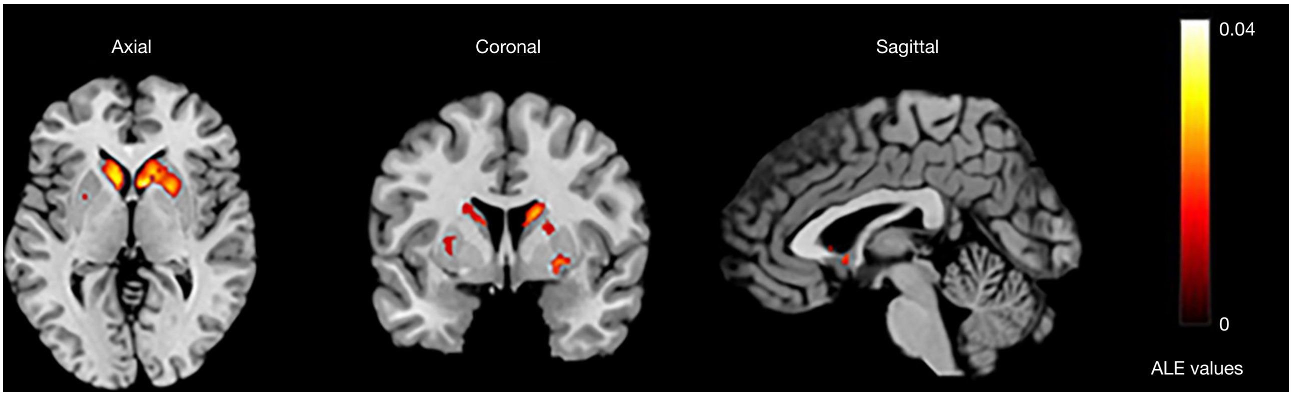

Figure 5 The largest activation cluster for the emotion task centered at (2,2,–1) in Montreal Neurological Institute space. ALE, activation likelihood estimation.

Table 4 Activation results under the decision-making task

Cluster No.	MNI peak coordinate			ALE value	Brain region
	x	y	z		
1	12	14	–6	0.039232	Right cerebrum, sublobar, caudate, gray matter, caudate head
1	18	10	12	0.028605	Right cerebrum, sublobar, caudate, gray matter, caudate body
1	18	6	–14	0.028543	Right cerebrum, sublobar, lentiform nucleus, gray matter, putamen
1	30	–8	8	0.023354	Right cerebrum, sublobar, lentiform nucleus, gray matter, putamen
1	8	–2	20	0.021768	Right cerebrum, sublobar, caudate, gray matter, caudate body
2	–10	8	–6	0.039481	Left cerebrum, sublobar, caudate, gray matter, caudate head
2	–10	12	4	0.03066	Left cerebrum, sublobar, caudate, gray matter, caudate body
2	–26	10	–2	0.017975	Left cerebrum, sublobar, lentiform nucleus, gray matter, putamen
2	–26	4	8	0.015567	Left cerebrum, sublobar, lentiform nucleus, gray matter, putamen
5	32	–20	–10	0.021232	Right cerebrum, sublobar, lentiform nucleus, gray matter, putamen
6	28	16	–2	0.020071	Right cerebrum, sublobar, lentiform nucleus, gray matter, putamen
14	–20	–6	14	0.018954	Left cerebrum, sublobar, lentiform nucleus, gray matter, putamen

MNI, Montreal Neurological Institute; ALE, activation likelihood estimation.

making tasks. In the contrast analysis of other tasks, no significant difference was found in the dorsal striatum. The refined contrast analysis results are presented in *Table 5* and *Figure 7*.

Conjunction analysis

The results of calculating the conjunction of any 2 of the 4 types of activation tasks studied are provided in Table S7; the results for the striatum region are presented in *Table 6* and show that the caudate and the putamen have significant agreement in all conjunction analyses. Similarly, the 4 functional paradigms coactivated the core regions of the caudate and putamen, as well as the remaining regions, were also coactivated by different tasks, indicating that the caudate and putamen are involved in functional integration between different functional categories.

After the conjunction of any 3 of the 4 types of activation tasks, the striatum was divided into 15 functional subregions, with each functional subregion responsible for different cognitive control. Among the functional subregions, the region located in MNI space from (–10, 10, –4)

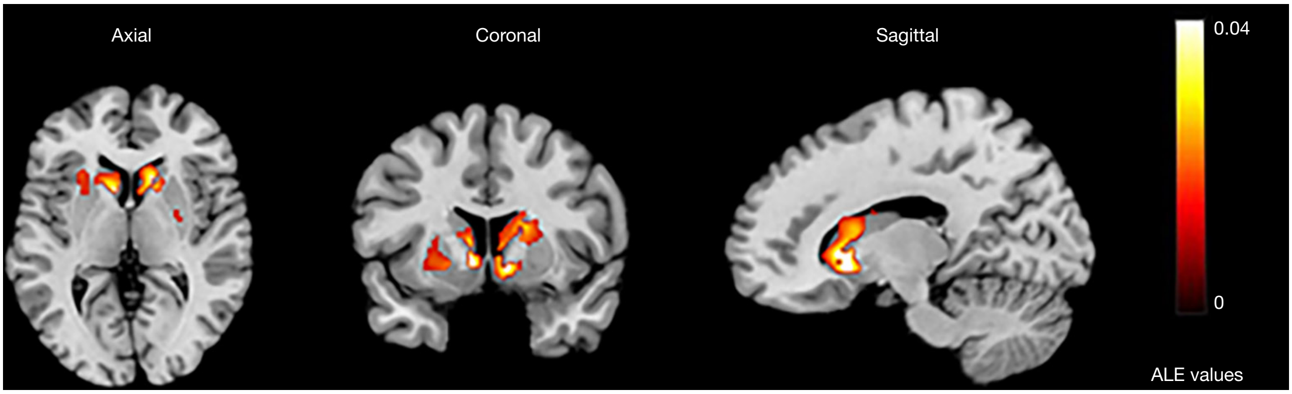

Figure 6 The largest activation cluster for the decision-making task centered at (14,8,2) in Montreal Neurological Institute space. ALE, activation likelihood estimation.

Table 5 Contrast analysis of multiple single-activation tasks

Contrast	Cluster No.	Activation cluster volume (mm^3)	MNI peak coordinate			P value	z score	Brain region
			x	y	z			
Reward > memory	1	2,112	19.4	9.7	–4.9	0.0164	0	Right cerebrum, sublobar, lentiform nucleus, gray matter, putamen
Memory > reward	–	–	–	–	–	–	–	None
Reward > emotion	2	2,912	–16	10	–2	0.0004	3.352795	Left cerebrum, sublobar, lentiform nucleus, gray matter, putamen
Emotion > reward	–	–	–	–	–	–	–	None
Reward > decision making	–	–	–	–	–	–	–	None
Decision making > reward	1	7,52	31	–19	–7	0.004	2.65207	Right cerebrum, sublobar, lentiform nucleus, gray matter, putamen
Memory > emotion	–	–	–	–	–	–	–	None
Emotion > memory	–	–	–	–	–	–	–	None
Memory > decision making	–	–	–	–	–	–	–	None
Decision making > memory	–	–	–	–	–	–	–	None
Decision making > emotion	–	–	–	–	–	–	–	None
Emotion > decision making	–	–	–	–	–	–	–	None

MNI, Montreal Neurological Institute.

to (15, 10, 2) is jointly activated by reward, memory, emotion, and decision-making functions, with a center coordinate of (–1, 14, –2); this region is part of the caudate head and caudate body.

Figure 8 shows all the conjunction results from 3 different views (axial, coronal, sagittal), and *Figure 9* shows the 15 different functional subregions that the dorsal striatum was divided into in the coronal plane. The final mask results for the 15 functional subregions are available online (https://github.com/Isbmm/15-subregions-mask).

Discussion

The results of the present study indicate that, based on a large-scale coordinate meta-analysis of published fMRI studies, there is functional differentiation in the dorsal

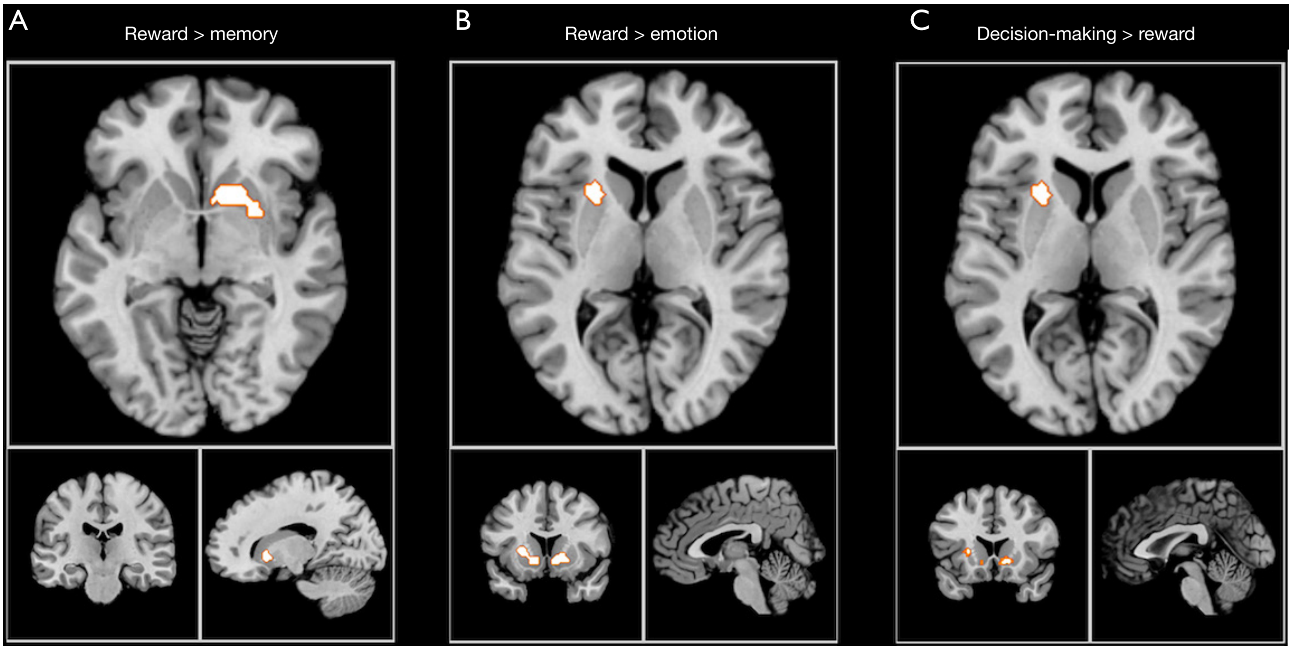

Figure 7 Contrast analysis results for (A) reward and memory, (B) reward and emotion, and (C) decision making and reward.

striatum. Using a coordinate-based meta-analysis method we could differentiate the dorsal striatum into four functional areas, which are defined by reward, memory, emotion, and decision-making functions. The activation peaks of reward and memory function were mainly distributed in the caudate, whereas the activation peaks of emotion and decision-making tasks were evenly distributed in the caudate and putamen. In addition to this functional differentiation, the functional categories were subjected to contrast and conjunction analyses to explore the differences and connections between different functional categories. From these analyses, there were obvious differences in the putamen region. However, the result of conjunction activation of any two functions was located in the caudate and putamen, with no significant difference.

Reward is an important motivator for all species and many external factors, such as contextual environment, cognitive value, and reward conditions, can influence individual responses in the face of reward (27). Unidirectional connections from the cortex to the matrix of the corpus striatum initiate the cortex-basal ganglia-thalamus-cortical loop, where the striatum has complementary roles in shaping corticostriatal plasticity to record or anticipate reward (28). Meanwhile, the striatum, as a receptor for cortical and dopamine projections during reward processing, is located at the center of the functional loop that affects the motor and cognitive aspects of behavior (29,30). One study found that when the human brain is rewarded with money, the activation of the right caudate head decreases with decreasing response (31). Similarly, other research showed that during the expectation of primary (32) or secondary rewards (33), the blood oxygen level–dependent response of the dorsal striatum increases. The present study confirms these results in revealing that the dorsal striatum is involved in reward processing. As shown in a comparative study between healthy people and patients with major depressive disorder, decreased reward activation occurs in the caudate, putamen, thalamus, anterior cingulate cortex, and insula (34).

Memory function involves the brain integrating structured information and remembering complex multidimensional information through temporal or spatial associations (35). Evidence from humans and other animals suggests that there are multiple memory systems defined by different neural substrates and functional needs. The memory systems of the hippocampus, amygdala, and dorsal striatum have different roles in memory tasks. Of these brain regions, the dorsal striatum is more important in memory tasks that need to strengthen stimulus response correlation (36). Animal studies have found that the dorsal striatum is important for the gradual, feedback-guided learning that results in habit memory, and an elegant double

Table 6 Conjunction analysis of multiple single activation tasks

Conjunction	Cluster No.	Activation cluster volume (mm³)	MNI peak coordinate			ALE value	Brain region
			x	y	z		
Reward_conj_memory	1	11,048	–18	8	0	0.03261438	Left cerebrum, sublobar, lentiform nucleus, gray matter, putamen
	1		–24	4	4	0.023548719	Left cerebrum, sublobar, lentiform nucleus, gray matter, putamen
	1		–12	0	12	0.022341166	Left cerebrum, sublobar, caudate, gray matter, caudate body
	1		–20	12	–12	0.018655526	Left cerebrum, sublobar, lentiform nucleus, gray matter, putamen
	2	10,240	10	12	–10	0.030384148	Right cerebrum, sublobar, caudate, gray matter, caudate head
	2		12	8	–2	0.026198952	Right cerebrum, sublobar, caudate, gray matter, caudate head
	2		20	8	0	0.024628002	Right cerebrum, sublobar, lentiform nucleus, gray matter, putamen
	2		28	0	6	0.017268842	Right cerebrum, sublobar, lentiform nucleus, gray matter, putamen
	2		18	4	16	0.014271136	Right cerebrum, sublobar, caudate, gray matter, caudate body
	2		18	8	16	0.013320627	Right cerebrum, sublobar, caudate, gray matter, caudate body
Reward_conj_emotion	1	25,440	10	8	2	0.044894863	Right cerebrum, sublobar, caudate, gray matter, caudate body
	1		–10	8	6	0.034102	Left cerebrum, sublobar, caudate, gray matter, caudate body
	1		26	0	–12	0.0292304	Right cerebrum, sublobar, lentiform nucleus, gray matter, putamen
	1		22	8	0	0.0245828	Right cerebrum, sublobar, lentiform nucleus, gray matter, putamen
	1		–20	10	–10	0.0190189	Left cerebrum, sublobar, lentiform nucleus, gray matter, putamen
	1		–24	-2	6	0.0157796	Left cerebrum, sublobar, lentiform nucleus, gray matter, putamen
Reward_conj_decision making	1	10,592	–10	12	4	0.0306597	Left cerebrum, sublobar, caudate, gray matter, caudate body
	1		–26	10	–4	0.0174626	Left cerebrum, sublobar, lentiform nucleus, gray matter, putamen
	1		–26	4	8	0.0155668	Left cerebrum, sublobar, lentiform nucleus, gray matter, putamen
	2	9,512	12	14	–6	0.0392321	Right cerebrum, sublobar, caudate, gray matter, caudate head
	2		20	8	–14	0.0215258	Right cerebrum, sublobar, lentiform nucleus, gray matter, putamen
	2		14	6	14	0.0144495	Right cerebrum, sublobar, caudate, gray matter, caudate body
	2		28	-2	6	0.0132864	Right cerebrum, sublobar, lentiform nucleus, gray matter, putamen

Table 6 (*continued*)

Table 6 (*continued*)

Conjunction	Cluster No.	Activation cluster volume (mm³)	MNI peak coordinate			ALE value	Brain region
			x	y	z		
	3	536	26	14	–2	0.0150849	Right cerebrum, sublobar, lentiform nucleus, gray matter, putamen
	9	16	28	12	–2	0.011703827	Right cerebrum, sublobar, lentiform nucleus, gray matter, putamen
Memory_ conj_ emotion	1	8,568	–10	10	0	0.026224438	Left cerebrum, sublobar, caudate, gray matter, caudate head
	1		–18	10	–8	0.0178558	Left cerebrum, sublobar, lentiform nucleus, gray matter, putamen
	1		–24	-2	6	0.0157796	Left cerebrum, sublobar, lentiform nucleus, gray matter, putamen
	2	5,280	12	8	–2	0.026199	Right cerebrum, sublobar, caudate, gray matter, caudate head
	2		20	8	0	0.0233723	Right cerebrum, sublobar, lentiform nucleus, gray matter, putamen
	2		12	16	–4	0.0219033	Right cerebrum, sublobar, caudate, gray matter, caudate head
Memory_ conj_ decision making	1	6,400	–26	10	–2	0.0174461	Left cerebrum, sublobar, lentiform nucleus, gray matter, putamen
	1		–26	4	8	0.0155668	Left cerebrum, sublobar, lentiform nucleus, gray matter, putamen
	2	6,368	10	12	–10	0.0303841	Right cerebrum, sublobar, caudate, gray matter, caudate head
	2		12	8	–2	0.026199	Right cerebrum, sublobar, caudate, gray matter, caudate head
	2		28	–4	8	0.0168263	Right cerebrum, sublobar, lentiform nucleus, gray matter, putamen
	2		20	6	6	0.0165626	Right cerebrum, sublobar, lentiform nucleus, gray matter, putamen
	3	720	26	16	–2	0.0161739	Right cerebrum, sublobar, lentiform nucleus, gray matter, putamen
Emotion_ conj_ decision making	1	8,096	–8	10	4	0.030274037	Left cerebrum, sublobar, caudate, gray matter, caudate body
	1		–18	10	–8	0.0185376	Left cerebrum, sublobar, lentiform nucleus, gray matter, putamen
	2	6,264	10	8	0	0.0324197	Right cerebrum, sublobar, caudate, gray matter, caudate head
	2		18	8	14	0.0243084	Right cerebrum, sublobar, caudate, gray matter, caudate body
	2		14	10	12	0.0241357	Right cerebrum, sublobar, caudate, gray matter, caudate body
	4	312	26	14	–2	0.0150849	Right cerebrum, sublobar, lentiform nucleus, gray matter, putamen
	10	24	–26	2	6	0.0113494	Left cerebrum, sublobar, lentiform nucleus, gray matter, putamen
	11	16	–26	0	8	0.0115825	Left cerebrum, sublobar, lentiform nucleus, gray matter, putamen

MNI, Montreal Neurological Institute; ALE, activation likelihood estimation; conj, conjunction.

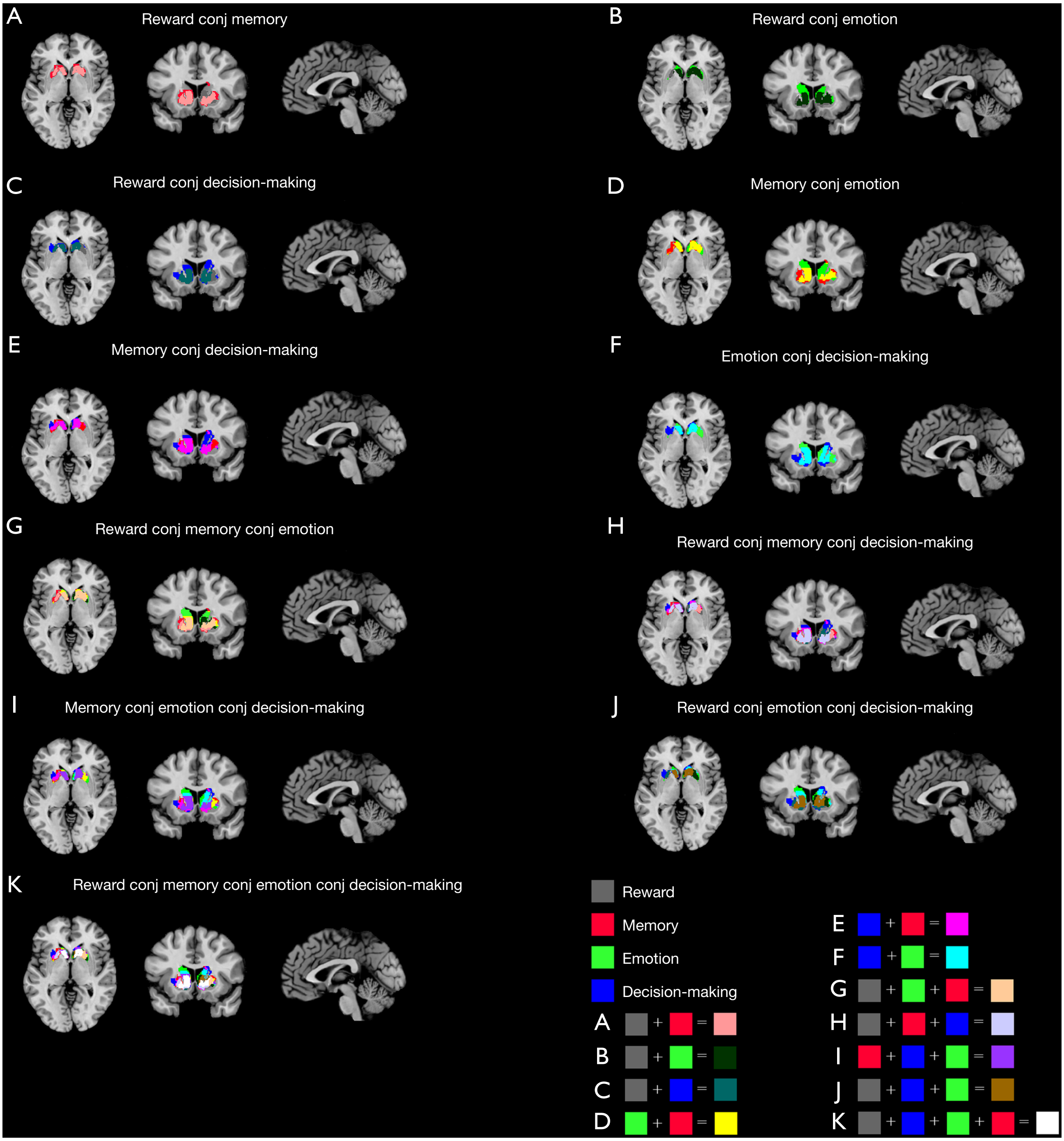

Figure 8 Conjunction activation results of the dorsal striatum under 4 single activation tasks at (–1,14,–2) in Montreal Neurological Institute space. (A-F) Conjunction result of 2 tasks; (G-J) conjunction result of 3 tasks. (K) Final functional differentiation result.

dissociation was demonstrated in rats after the creation of fornix and caudate lesions in two tasks that appeared to measure declarative memory and habit memory (37). A similar contrast between declarative memory and habit memory was later demonstrated for amnesic patients and patients with Parkinson' disease (38,39). Although different memory systems are separated, there is still synergistic activation between them. The putamen is mainly associated

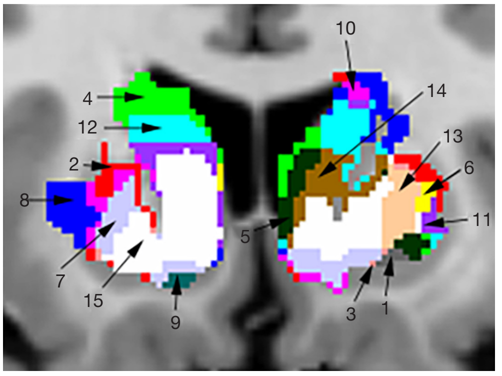

Figure 9 Enlarged view of the dorsal striatum divided into 15 functional subregions.

with the hippocampus in memory tasks, linking the overall events involved in memory (40).

Emotions influence attention, decision making, memory, physiological responses, and social interactions, and the ability to successfully regulate emotions is associated with many important psychological, social, and physical health outcomes (41,42). In the process of emotion perception and regulation, the amygdala and ventromedial prefrontal cortex play a central role in negative emotions, whereas regions such as the striatum and insula cortex play a certain role in the regulation of other emotions (43). The results of the present study are consistent with the findings of related studies on the role of dopamine in human processing of negative emotions. Dynamic molecular imaging technology has been used to explore dopamine release in the striatum during emotion processing, especially in the caudate and putamen (2). However, the present study included not only multiple negative emotion-processing studies, but also studies on positive, neutral, disgust, fear, and other emotions. The results of the present study were not significantly different from those of previous single-imaging studies in the dorsal striatum. Difficulty in emotion regulation is considered to be the core mechanism of mood and anxiety disorders (44). In patients with depression, increases in depression severity are related to the functional connection between the dorsal caudate and the right dorsolateral prefrontal cortex (45).

Decision making is the ability to make an appropriate choice between different action plans, which requires an ability to combine estimates of causal relationships between actions and their consequences or results with their value or utility. Although there is extensive literature linking cognitive functions specific to the prefrontal cortex (46), other studies suggest that these functions depend on reward-related circuitry linking prefrontal, premotor, and sensorimotor cortices with the striatum (47-49). Most evidence suggests that direct and indirect striatal pathways control behavior in an opposing manner (50,51). In one study, significant activation was found in the caudate, putamen, globus pallidus, thalamus, midbrain, and cingulate gyrus in tasks involving economic decision making behind responses to monetary rewards (52). For other types of decision-making processes, such as risk decision making, the putamen, hippocampus, parahippocampal gyrus, and lingual gyrus, but not the caudate, are positively correlated with behavioral preference. The relevant decision-making studies included in the present analysis were primarily focused on risk and economic decision making, and the results showed significant activation in the putamen region.

Contrast analysis was used to examine the significance of differences in the convergence between any two groups of different foci for the four independent tasks. The results showed differences in the processing of different functional information between the caudate and putamen. For example, measurements of anatomical and functional connections in humans, nonhuman primates, and mice have shown that there is a clear link between the caudate and the frontal lobe region responsible for "executive" function (53). The biggest difference between the caudate and putamen in the performance of cognitive function is that the caudate promotes behavior by stimulating correct action schema and selecting appropriate subgoals based on an evaluation of action outcomes, whereas the cognitive function of the putamen is more limited to stimulus response, habit, or learning. The results showed significant differences in the putamen. Different parts of the striatum receive inputs from different cortical regions and project their outputs to the cortex through the thalamus. Meanwhile, the anterior putamen is connected to related areas in the cortex, and the posterior putamen is connected to the primary motor cortex and supplementary motor areas (54). The putamen seems to be the area for the coordination and cross-functional integration of independent functional channels, directing a coordinated behavioral display and modification in response to external and internal stimuli (55). Physiologically, volume changes in the putamen are associated with different neurological and psychiatric disorders, such as bipolar disorder and attention deficit hyperactivity disorder (56,57).

In the context of the functional differentiation of the striatum described above, achieving functional integration is a more critical issue (i.e., conjunction analysis that shows the similarity of the two data sets). Conjunction analysis revealed the overlap of all categories in the caudate and putamen. This overlap may reflect a shared role in information processing between functional systems. This shared role may reflect the multimodal integration between different task categories: on the one hand, with information being transferred between different functional systems; and on the other, with all task categories sharing a common basic functional role (58). Analysis of a large number of different functional categories in this study showed that most of the final conjunction results of all functions converge in the caudate head and putamen. From this point of view, the core of the conjunction outcome converges in subregions in the caudate and putamen. Although the present study only focused on the caudate and putamen, it is important to understand the anatomical structure of the frontostriatal circuit and related disease processes. Studies have shown that the human caudate is interconnected with the prefrontal cortex, inferior and middle temporal gyrus, frontal eye fields, cerebellum, and thalamus; the putamen is interconnected with the prefrontal cortex, primary motor area, primary somatosensory cortex, supplementary motor area, premotor area, cerebellum, and thalamus (59). It can be predicted that the functional partitions into which we have divided the striatum may have important implications for future research on related psychiatric disorders caused by striatal circuit disorders.

Analysis of the functional loss of patients with striatal abnormalities could be used to indirectly validate our functional differentiation. One study confirmed that depression can be safely and effectively treated through repetitive transcranial stimulation therapy (60). This method improves the integrity of frontostriatal connections by inducing striatal dopamine release onto the dorsolateral prefrontal cortex in depressed patients. In another study, transplantation of human embryonic mesencephalic tissue bilaterally into the caudate and putamen led to significant symptomatic relief in patients with Parkinson disease and reduced dependence on levodopa (61). Computed tomography findings in a patient with segmental axial dystonia revealed 3 small areas of encephalomalacia, 1 involving the head of the caudate. In another report, treatment with trihexyphenidyl resulted in significant improvements in dystonia and scoliosis (62). Huntington disease (HD) is characterized by striatal atrophy that starts before the onset of motor symptoms, and treatment with laquinimod results in reduced volume loss in the caudate and other brain regions in patients with early HD (63).

Although the present study provides an idea for the division of the dorsal striatum into different functional areas, we acknowledge several limitations that need to be addressed in future studies. First, because the nucleus accumbens cannot be accurately located in the common brain atlas, the role of the ventral striatum (including the nucleus accumbens) in the functional paradigms we studied was not considered. Second, like many other neuroimaging meta-analysis algorithms, the coordinate-based ALE meta-analysis provides only a measure of reported peak coordinate convergence and not the magnitude of peak activation effects. The coordinate-based meta-analysis requires that each activation cluster exceed the significance threshold set in each study, and does not weight the activation statistics (64). Third, there are considerable differences in stimulus methods, experimental methods, and scanning parameters among neuroimaging studies included in meta-analyses. Although the possible effects of these factors was minimized in the present study during the literature screening process, it is possible that these systematic differences could have led to some discrepancies. Fourth, the striatum is not only involved in reward, memory, emotion, and decision-making paradigms. This area has a greater degree of activation under stimulation tasks such as smell, hearing, language, and learning. Future meta-analyses should include a wider range of stimulus modalities and tasks. Finally, not all studies include voxel-based activation coordinates that would allow them to be included in ALE analysis.

Conclusions

Using a large-scale meta-analysis, this study has revealed the functional differentiation and integration of the caudate and putamen in the human dorsal striatum. The 15 different subregions identified are involved in the processing of different functions. The observed functional differentiation and integration of the dorsal striatum may constitute the link between these different functional systems and the transmission of information between them. We conducted a comprehensive summary and evaluation of the relevant brain cognitive neuroimaging literature. The ensuing results may benefit future research on depression, Parkinson's disease, schizophrenia, and other diseases.

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Footnote

Reporting Checklist: The authors have completed the PRISMA reporting checklist. Available at https://qims.amegroups.com/article/view/10.21037/qims-22-133/rc

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Table S1 Information of 112 studies included in this study

Number	Study	Task	Modality	N [female]	Age (SD/mean)	Tesla (T)
Reward						
1	Grabenhorst *et al.* [2010]	Thermal and taste reward	fMRI	14 [5]	Mean =24	3
2	Ramnani *et al.* [2003]	Monetary reward	fMRI	8 [0]	–	3
3	Spreckelmeyer *et al.* [2009]	Monetary and social reward	fMRI	32 [16]	20–53 (mean =28.9)	1.5
4	Abler *et al.* [2006]	Monetary reward	fMRI	11 [0]	22–36	3
5	Camara *et al.* [2009]	Monetary reward	fMRI	17 [10]	2.6/21.6	3
6	Cox *et al.* [2005]	Monetary reward	fMRI	22 [10]	18–30	3
7	Elliott *et al.* [2008]	Monetary reward	fMRI	12 [0]	Mean =30.3	1.5
8	Knutson *et al.* [2005]	Monetary reward	fMRI	14 [8]	Mean =22	1.5
9	Knutson *et al.* [2001]	Monetary reward	fMRI	8 [4]	Mean =31	1.5
10	Knutson *et al.* [2003]	Monetary reward	fMRI	12 [6]	Mean =31	1.5
11	Knutson *et al.* [2008]	Monetary reward	fMRI	15 [0]	2.12/20.73	1.5
12	Knutson *et al.* [2001]	Monetary reward	fMRI	9 [7]	–	1.5
13	Elliott *et al.* [2004]	Monetary reward	fMRI	12 [6]	Mean =23.6	1.5
14	Elliott *et al.* [2003]	Monetary reward	fMRI	12 [6]	Mean =23.6	1.5
15	Bjork *et al.* [2007]	Monetary reward	fMRI	20 [10]	6.4/34.1	3
16	Valentin *et al.* [2009]	Juice and monetary reward	fMRI	17 [5]	19–40 (1.7/25)	3
17	Smith *et al.* [2010]	Monetary reward	fMRI	23 [0]	18–28 (mean =21.8)	3
18	Dreher *et al.* [2006]	Monetary reward	fMRI	31 [15]	5.7/27.6	3
19	Izuma *et al.* [2008]	Monetary reward	fMRI	19 [10]	Mean =21.6	3
20	Kirsch *et al.* [2003]	Language and monetary reward	fMRI	27 [4]	Mean =23.36	1.5
21	Linke *et al.* [2010]	Monetary reward	fMRI	33 [16]	19–32 (2.92/22.6)	3
22	Liu *et al.* [2007]	Monetary reward	fMRI	15 [9]	18–45 (mean =26)	3
23	Nieuwenhuis *et al.* [2005]	Monetary reward	fMRI	14 [6]	22–31 (mean =25.4)	1.5
24	Yacubian *et al.* [2006]	Monetary reward	fMRI	42 [0]	5.5/27.3	3
25	Zink *et al.* [2004]	Monetary reward	fMRI	16 [6]	18–32	3
26	Wrase *et al.* [2007]	Monetary reward	fMRI	14 [0]	10.3/39.9	1.5
27	Ernst *et al.* [2004]	Monetary reward	fMRI	17 [0]	20–40	3
28	Rilling *et al.* [2004]	Monetary reward	fMRI	19 [11]	7.8/21.8	3
29	Koeneke *et al.* [2008]	Personal preference reward	fMRI	19 [19]	2.63/24.05	3
Memory						
1	Foerde *et al.* [2006]	Declarative memory	fMRI	14 [9]	18–45 (6.53/25.71)	3
2	Bedwell *et al.* [2005]	Working memory	fMRI	14 [6]	22–40 (5.8/29.2)	1.5
3	Cabeza *et al.* [2002]	Episodic and working memory	fMRI	20 [7]	3.68/22.6	–
4	Lie *et al.* [2006]	Working memory	fMRI	12 [2]	19–36 (5/24)	1.5
5	Fliessbach *et al.* [2006]	Vocabulary memory	fMRI	21 [12]	19–43 (6.2/27.4)	1.5
6	Adcock *et al.* [2006]	Reward memory	fMRI	12 [3]	18–35	3
7	Sailer *et al.* [2007]	Working memory	fMRI	38 [38]	21.4–40.6 (mean =26.4)	3
8	Assaf *et al.* [2006]	Semantic memory	fMRI	18 [7]	21–73 (15/40.8)	3
9	Daselaar *et al.* [2006]	Vocabulary memory	fMRI	14 [6]	2.4/21.4	4
10	Sommer *et al.* [2008]	Emotional memory	fMRI	17 [17]	Mean =27.4	3
11	Ritchey *et al.* [2008]	Emotional memory	fMRI	13 [7]	3.4/22.6	4
12	Gruber *et al.* [2003]	Working memory	fMRI	13 [5]	3.5/24.9	3
13	Prince *et al.* [2005]	Vocabulary and perceptual memory	fMRI	16 [5]	1.7/19.8	4
14	Altamura *et al.* [2007]	Working memory	fMRI	18 [7]	Mean =27.4	3
15	Nee *et al.* [2009]	Selective memory	fMRI	18 [8]	18–25	3
16	Cairo *et al.* [2004]	Working memory	fMRI	18 [10]	18–35 (mean =27.5)	1.5
17	Addis *et al.* [2007]	Episodic memory	fMRI	16 [9]	18–33 (mean =23)	3
18	Postle *et al.* [2007]	Working memory	fMRI	12 [7]	4.2/22.8	3
19	Peters *et al.* [2007]	Source memory	fMRI	15 [7]	20–35 (mean =25)	1.5
20	Clapp *et al.* [2010]	Working memory	fMRI	22 [9]	18–32 (mean=24.57)	3
21	Dennis *et al.* [2011]	Learning memory	fMRI	12 [4]	18–30 (3.5/22.2)	4
22	Gutchess *et al.* [2012]	Confirmatory memory	fMRI	16 [8]	19–33 (4.57/24.13)	1.5
23	Kensinger *et al.* [2005]	Precise and distorted memory	fMRI	16 [8]	18–30	1.5
24	Marvel *et al.* [2012]	Working memory	fMRI	16 [8]	14–18	3
25	Mickley *et al.* [2009]	Emotional memory	fMRI	19 [8]	18–35	1.5
26	de Rover *et al.* [2008]	Spatial location memory	fMRI	20 [10]	19–33 (4/25)	1.5
Emotion						
1	Wehrum *et al.* [2013]	Emotional pictures	fMRI	100 [50]	Mean =25	1.5
2	Roth *et al.* [2014]	Shame and pride emotions	fMRI	25	18–50 (mean =34)	3
3	Kotz *et al.* [2003]	Semantic emotions	fMRI	12 [8]	22–29 (mean =24)	3
4	Meseguer *et al.* [2007]	Positive and negative pictures	fMRI	14	Mean =28.8	3
5	Baumgartner *et al.* [2006]	Fear and sadness emotions	fMRI	9 [9]	21–30 (2.9/24.7)	3
6	Goldin *et al.* [2008]	Neutral and negative movies	fMRI	17 [17]	3.5/22.7	3
7	Hutcherson *et al.* [2008]	Happiness and sorrow movies	fMRI	28 [28]	18–21	3
8	Walter *et al.* [2008]	Neutral, pleasurable and sexual pictures	fMRI	21 [10]	21–36 (mean =24.8)	1.5
9	Britton *et al.* [2006]	Disgusted, happy, sad pictures and movies	fMRI	12 [6]	19–29 (mean =23.6)	3
10	Fitzgerald *et al.* [2004]	Aversion emotions	fMRI	12 [5]	22–53 (mean =31.2)	1.5
11	Trost *et al.* [2012]	Positive and negative music	fMRI	15 [7]	Mean =28.8	3
12	Phillips *et al.* [2004]	Fear and disgust facial pictures	fMRI	8 [0]	25–36 (mean =32)	1.5
13	Mueller *et al.* [2015]	Pleasant and unpleasant music	fMRI	23 [13]	2.9/25.9	3
14	Butler *et al.* [2007]	Fear emotions	fMRI	42 [16]	Mean =28	3
15	Schiller *et al.* [2008]	Fear emotions	fMRI	17 [8]	18–31	3
16	Trost *et al.* [2014]	Pleasant music	fMRI	20 [13]	7.5/25.8	3
17	Herwig *et al.* [2007]	Positive, negative and neutral pictures	fMRI	16 [10]	23–36	1.5
18	Bogert *et al.* [2016]	Pleasant,fear and sadness music	fMRI	56 [34]	20–53 (mean =28.2)	3
19	Brattico *et al.* [2011]	Pleasant and sadness music	fMRI	15 [6]	2.9/23.9	3
20	Lutz *et al.* [2014]	Negative pictures	fMRI	49 [32]	20–57 (7.96/29.98)	3
21	Mobbs *et al.* [2007]	Fear emotions	fMRI	14	Mean =26	–
22	Grimm *et al.* [2006]	Emotional pictures	fMRI	29 [21]	20–27	1.5
23	Osaka *et al.* [2004]	Pain emotions	fMRI	20 [11]	20–27	1.5
24	Rolls *et al.* [2003]	Pleasant and unpleasant smells	fMRI	11 [6]	–	3
25	Wagner *et al.* [2011]	Shame and sorrow emotions	fMRI	18 [18]	25–30 (mean =27.5)	3
26	Maddock *et al.* [2003]	Emotional vocabulary	fMRI	8 [6]	24–45	1.5
27	Morris *et al.* [2004]	Fear and disgust facial pictures	fMRI	12	–	2
28	Morris *et al.* [2001]	Fear facial pictures	fMRI	6 [2]	Mean =29.3	2
29	Lee *et al.* [2008]	Emotional facial pictures	fMRI	14 [7]	Mean =23.8	–
30	de Gelder *et al.* [2004]	Pleasant and fear emotions	fMRI	7 [3]	–	3
31	Viinikainen *et al.* [2010]	Emotional pictures	fMRI	17 [9]	21–26 (mean =23)	3
Decision-making						
1	Robertson *et al.* [2015]	Rewarding decision-making	fMRI	16 [8]	19–27 (mean =23)	3
2	Xu *et al.* [2009]	Intertemporal decision-making	fMRI	20 [10]	22–29 (mean =25)	3
3	Ernst *et al.* [2004]	Economic decision-making	fMRI	17 [7]	Mean =24	3
4	Hsu *et al.* [2005]	Risky decision-making	fMRI	16 [3]	Mean =24	–
5	Kuhnen *et al.* [2005]	Risky decision-making	fMRI	19 [10]	24–39 (mean =27)	1.5
6	Matthews *et al.* [2004]	Risky decision-making	fMRI	12 [5]	20–56 (mean =34)	1.5
7	Peters *et al.* [2009]	Intertemporal and risky decision-making	fMRI	22 [14]	Mean =26.3	3
8	Weber *et al.* [2008]	Intertemporal decision-making	fMRI	23 [11]	19–36 (mean =23)	3
9	Schonberg *et al.* [2007]	Rewarding decision-making	fMRI	29 [15]	22–39 (mean =27.4)	3
10	Engelmann *et al.* [2009]	Risky decision-making	fMRI	10 [3]	–	3
11	Knutson *et al.* [2007]	Economic decision-making	fMRI	26 [12]	18–26	1.5
12	Knutson *et al.* [2008]	Economic decision-making	fMRI	24 [12]	–	1.5
13	Glascher *et al.* [2009]	Rewarding decision-making	fMRI	20 [9]	4.7/22.3	3
14	Guitart-Masip *et al.* [2010]	Economic decision-making	fMRI	21 [12]	Mean =22.2	3
15	Kim *et al.* [2007]	Preference decision-making	fMRI	25 [12]	18–45 (mean =26.67)	3
16	Wunderlich *et al.* [2009]	Action decision-making	fMRI	23 [10]	18–29	3
17	Daw *et al.* [2006]	Exploratory decision-making	fMRI	14	–	1.5
18	Bickel *et al.* [2009]	Intertemporal decision-making	fMRI	30 [21]	20–67 (mean =47.1)	3
19	Hare *et al.* [2010]	Economic decision-making	fMRI	22 [22]	19–38 (mean =24.7)	3
20	Engelmann *et al.* [2009]	Economic decision-making	fMRI	24 [15]	5.3/23	3
21	Hampton *et al.* [2006]	Economic decision-making	fMRI	16 [8]	–	3
22	Han *et al.* [2010]	Economic decision-making	fMRI	20 [11]	20–33 (mean =24)	3
23	Venkatraman *et al.* [2009]	Risky decision-making	fMRI	23 [13]	18–31 (mean =24)	4
24	Milea *et al.* [2007]	Action decision-making	fMRI	12 [5]	21–30	–
25	Mitchell *et al.* [2009]	Economic decision-making	fMRI	19 [10]	21–50 (8.6/26.9)	1.5
26	Hsu *et al.* [2009]	Risky decision-making	fMRI	21 [11]	7.5/29.6	3

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Table S2 Activation results under reward task

Cluster #	Volume mm^3	MNI peak coordinate			ALE value	P	Z	Brain region
		x	y	z				
1	51,624	12	12	–4	0.085461	1.71E–28	11.011578	Right Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Head
1		–12	10	–4	0.0740147	1.42E–23	9.939302	Left Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
1		4	–16	10	0.0343764	4.34E–09	5.7546177	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
1		14	–2	12	0.0298301	1.06E–07	5.188899	Right Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Body
1		26	0	–14	0.0294915	1.33E–07	5.1454453	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
1		34	26	–6	0.0288801	2.02E–07	5.0669394	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
1		–10	2	12	0.026592	9.38E–07	4.766418	Left Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Body
1		6	0	4	0.0253368	2.13E–06	4.598657	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
1		–26	4	4	0.0243451	4.02E–06	4.4640765	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter. Putamen
1		–30	20	2	0.0240799	4.78E–06	4.4269295	Left Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
1		0	–6	8	0.023421	7.27E–06	4.335625	Inter-Hemispheric.Sub-lobar.Extra-Nuclear.White Matter.*
1		–12	–4	16	0.0217216	2.11E–05	4.0952435	Left Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
1		34	22	4	0.020883	3.54E–05	3.9734282	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
1		30	–8	–22	0.0155539	7.94E–04	3.1580386	Right Cerebrum.Limbic Lobe.Parahippocampal Gyrus.Gray Matter.Amygdala
1		18	–12	–2	0.0144169	0.0014909	2.9696052	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
2	4,632	2	2	48	0.0287465	2.21E–07	5.050114	Left Cerebrum.Limbic Lobe.Cingulate Gyrus.*.*
2		–6	6	46	0.0178268	2.18E–04	3.5172672	Left Cerebrum.Limbic Lobe.Cingulate Gyrus.White Matter.*
2		–12	–6	54	0.0133941	0.0026139	2.792648	Left Cerebrum.Frontal Lobe.Medial Frontal Gyrus.Gray Matter. Brodmann area 6
3	3,928	2	48	–8	0.0376731	3.94E–10	6.1474676	Right Cerebrum.Limbic Lobe.Anterior Cingulate.Gray Matter.*
4	3,456	4	30	32	0.0231753	8.46E–06	4.302167	Right Cerebrum.Frontal Lobe.Cingulate Gyrus.*.*
4		4	18	36	0.0153826	8.74E–04	3.1301777	Right Cerebrum.Frontal Lobe.Cingulate Gyrus.*.*
4		6	40	38	0.0150978	0.0010214	3.0839334	Right Cerebrum.Frontal Lobe.Medial Frontal Gyrus.Gray Matter.Brodmann area 8
5	1,920	–2	–20	–14	0.0159901	6.21E–04	3.2292047	Left Brainstem.Midbrain.*.*.*
5		4	–22	–14	0.0154599	8.35E–04	3.143327	Right Brainstem.Midbrain.*.*.*
6	1,176	–20	36	–18	0.0210937	3.11E–05	4.0040236	Left Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.*
6		–18	42	–18	0.0201426	5.56E–05	3.8646536	Left Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.*
7	1,072	–38	–14	52	0.0222716	1.50E–05	4.1739006	Left Cerebrum.Frontal Lobe.Precentral Gyrus.Gray Matter. Brodmann area 4
8	1,024	4	–50	18	0.0234273	7.22E–06	4.3370113	Right Cerebrum.Limbic Lobe.Posterior Cingulate.Gray Matter. Brodmann area 30
9	792	–28	–52	48	0.0157431	7.14E–04	3.1889234	Left Cerebrum.Parietal Lobe.Sub-Gyral.White Matter.*
9		–22	–60	44	0.0146669	0.0012986	3.0117826	Left Cerebrum.Parietal Lobe.Precuneus.White Matter.*
10	704	44	36	28	0.0175766	2.52E–04	3.4789119	Right Cerebrum.Frontal Lobe.Middle Frontal Gyrus.Gray Matter.Brodmann area 9
10		34	30	26	0.0154724	8.31E–04	3.1449628	Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.*
11	688	–30	–62	–36	0.014736	0.0012494	3.0234776	Left Cerebellum.Posterior Lobe.Cerebellar Tonsil.Gray Matter.*
11		–38	–58	–38	0.0133323	0.0026997	2.7821836	Left Cerebellum.Posterior Lobe.Cerebellar Tonsil.Gray Matter.*
12	600	12	–88	10	0.0178997	2.09E–04	3.5279536	Right Cerebrum.Occipital Lobe.Cuneus.Gray Matter.Brodmann area 17

Cluster #, cluster number; volume mm^3, activation cluster volume, the unit is mm^3; (x,y,z), peak coordinate in Montreal Neurological Institute (MNI) space; ALE value, activation likelihood estimation value; P, P value; Z, Z score.

Table S3 Activation results under memory task

Cluster #	Volume mm^3	MNI peak coordinate			ALE value	P	Z	Brain region
		x	y	z				
1	19,696	36	28	−6	0.0346477	7.359E−09	5.6648717	Right Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.Gray Matter. Brodmann area 47
1		12	8	−10	0.0321852	4.137E−08	5.361077	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Lateral Globus Pallidus
1		10	12	−10	0.0303841	1.43E−07	5.132505	Right Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Head
1		12	8	−2	0.026199	2.274E−06	4.584654	Right Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Head
1		22	−28	−12	0.0248245	5.484E−06	4.397167	Right Cerebrum.Limbic Lobe.Parahippocampal Gyrus.Gray Matter. Brodmann area 28
1		20	8	0	0.024628	6.186E−06	4.370945	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
1		12	−14	−2	0.0225273	2.273E−05	4.0777845	Right Cerebrum.Sub-lobar.Thalamus.Gray Matter.*
1		22	4	16	0.0220977	2.954E−05	4.016457	Right Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Body
1		10	−2	4	0.0212079	5.06E−05	3.8877203	Right Cerebrum.Sub-lobar.Thalamus.Gray Matter.*
1		30	−34	−4	0.0198872	0.000111	3.692633	Right Cerebrum.Temporal Lobe.Sub-Gyral.Gray Matter. Hippocampus
1		28	−2	8	0.0195932	0.0001323	3.6476202	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
1		30	−14	−22	0.0169799	0.0005829	3.247131	Right Cerebrum.Limbic Lobe.Parahippocampal Gyrus.Gray Matter. Hippocampus
1		30	−8	−10	0.0164687	0.0007711	3.166611	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
1		22	−14	−14	0.0161856	0.0008985	3.1218672	Right Cerebrum.Limbic Lobe.Parahippocampal Gyrus.Gray Matter. Brodmann area 28
1		6	−16	−12	0.0136479	0.0034944	2.697378	Right Brainstem.Midbrain.*.Gray Matter.Red Nucleus
1		16	12	16	0.0133372	0.0041112	2.6428006	Right Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Body
1		44	22	−16	0.0132961	0.0041971	2.6357903	Right Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.Gray Matter. Brodmann area 47
2	13,792	−12	10	−4	0.0332791	1.936E−08	5.4966035	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Lateral Globus Pallidus
2		−20	6	0	0.0332396	1.991E−08	5.4916663	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
2		−14	0	12	0.0249166	5.148E−06	4.4108567	Left Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Body
2		−12	−14	4	0.0238121	1.033E−05	4.2576284	Left Cerebrum.Sub-lobar.Thalamus.Gray Matter.Ventral Lateral Nucleus
2		−20	12	−12	0.0186555	0.0002267	3.5068247	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
2		−4	−22	10	0.0120641	0.0078351	2.416508	Left Cerebrum.Sub-lobar.Thalamus.Gray Matter.*
3	4,992	−36	30	−4	0.0225006	2.315E−05	4.0735273	Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.Gray Matter. Brodmann area 47
3		−30	30	−6	0.0208772	6.167E−05	3.839387	Left Cerebrum.Sub-lobar.Insula.Gray Matter.Brodmann area 13
3		−42	14	26	0.0206692	6.991E−05	3.8085005	Left Cerebrum.Frontal Lobe.Middle Frontal Gyrus.Gray Matter. Brodmann area 9
3		−42	20	24	0.0179666	0.0003356	3.4010508	Left Cerebrum.Frontal Lobe.Middle Frontal Gyrus.Gray Matter. Brodmann area 9
3		−44	26	0	0.0171199	0.0005396	3.2690353	Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.Gray Matter. Brodmann area 13
3		−44	28	12	0.0159589	0.0010181	3.0848901	Left Cerebrum.Frontal Lobe.Middle Frontal Gyrus.Gray Matter. Brodmann area 46
3		−50	2	30	0.0149641	0.0017449	2.9209316	Left Cerebrum.Frontal Lobe.Precentral Gyrus.Gray Matter. Brodmann area 6
3		−28	26	−12	0.014949	0.0017543	2.919261	Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.Gray Matter. Brodmann area 47
4	3,784	4	20	44	0.0276106	9.075E−07	4.773026	Right Cerebrum.Frontal Lobe.Medial Frontal Gyrus.Gray Matter. Brodmann area 6
4		−4	32	30	0.0175436	0.0004272	3.3345222	Left Cerebrum.Limbic Lobe.Cingulate Gyrus.Gray Matter.Brodmann area 32
4		−4	10	48	0.0150184	0.0016897	2.9309373	Left Cerebrum.Limbic Lobe.Cingulate Gyrus.Gray Matter.Brodmann area 24
5	2,152	36	44	22	0.0302709	1.54E−07	5.118461	Right Cerebrum.Frontal Lobe.Middle Frontal Gyrus.Gray Matter. Brodmann area 9
6	1,984	−20	−68	52	0.0201126	9.747E−05	3.7254817	Left Cerebrum.Parietal Lobe.Precuneus.Gray Matter.Brodmann area 7
6		−14	−68	54	0.0190361	0.0001822	3.5645986	Left Cerebrum.Parietal Lobe.Precuneus.Gray Matter.Brodmann area 7
6		−28	−64	44	0.0161373	0.0009234	3.1138344	Left Cerebrum.Parietal Lobe.Precuneus.Gray Matter.Brodmann area 7
7	1,928	−38	−62	−14	0.0255771	3.385E−06	4.5007915	Left Cerebrum.Temporal Lobe.Fusiform Gyrus.Gray Matter. Brodmann area 37
7		−48	−62	−6	0.0141913	0.0026317	2.790459	Left Cerebrum.Occipital Lobe.Middle Occipital Gyrus.Gray Matter. Brodmann area 19
8	1,440	−44	−6	50	0.02297	1.736E−05	4.140015	Left Cerebrum.Frontal Lobe.Precentral Gyrus.Gray Matter. Brodmann area 6
8		−42	−6	46	0.0222392	2.713E−05	4.0364676	Left Cerebrum.Frontal Lobe.Precentral Gyrus.Gray Matter. Brodmann area 6
9	1,432	−24	−32	−14	0.0195352	0.0001363	3.640105	Left Cerebrum.Limbic Lobe.Parahippocampal Gyrus.Gray Matter. Brodmann area 36
9		−18	−34	−6	0.0147822	0.0019226	2.89059	Left Cerebrum.Limbic Lobe.Parahippocampal Gyrus.Gray Matter. Brodmann area 30
10	1,360	−32	−92	10	0.0180858	0.0003137	3.4195154	Left Cerebrum.Occipital Lobe.Middle Occipital Gyrus.Gray Matter. Brodmann area 18
10		−24	−92	2	0.01565	0.0012037	3.0347435	Left Cerebrum.Occipital Lobe.Lingual Gyrus.Gray Matter.Brodmann area 17
11	1,144	34	−50	46	0.0260262	2.537E−06	4.561713	Right Cerebrum.Parietal Lobe.Superior Parietal Lobule.Gray Matter. Brodmann area 7
12	1,072	−34	−36	44	0.0223375	2.553E−05	4.05073	Left Cerebrum.Parietal Lobe.Inferior Parietal Lobule.Gray Matter. Brodmann area 40
12		−44	−38	40	0.013633	0.0035311	2.693895	Left Cerebrum.Parietal Lobe.Supramarginal Gyrus.Gray Matter. Brodmann area 40
13	1,072	24	0	52	0.0193286	0.000154	3.608463	Right Cerebrum.Frontal Lobe.Sub-Gyral.Gray Matter.Brodmann area 6
13		22	10	52	0.0158397	0.0010863	3.06555	Right Cerebrum.Frontal Lobe.Medial Frontal Gyrus.Gray Matter. Brodmann area 6
14	928	6	26	18	0.0214633	4.353E−05	3.9240777	Right Cerebrum.Limbic Lobe.Anterior Cingulate.Gray Matter. Brodmann area 33
15	872	34	−60	−16	0.0180079	0.0003282	3.407202	Right Cerebellum.Posterior Lobe.Declive.Gray Matter.*
15		36	−52	−24	0.014892	0.0018117	2.90922	Right Cerebellum.Anterior Lobe.Culmen.Gray Matter.*
15		28	−66	−18	0.0144245	0.0023294	2.8297305	Right Cerebellum.Posterior Lobe.Declive.Gray Matter.*
16	768	−22	−6	−16	0.0197451	0.0001205	3.6716435	Left Cerebrum.Limbic Lobe.Parahippocampal Gyrus.Gray Matter. Amygdala

Cluster #, cluster number; volume mm^3, activation cluster volume, the unit is mm^3; (x,y,z), peak coordinate in Montreal Neurological Institute (MNI) space; ALE value, activation likelihood estimation value; P, P value; Z, Z score.

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Table S4 Activation results under emotion task

Cluster #	Volume mm^3	MNI peak coordinate			ALE value	P	Z	Brain region
		x	y	z				
1	42,504	10	8	2	0.0448949	1.8E−13	7.2701097	Right Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Body
1		26	−4	−12	0.035032	4.799E−10	6.116064	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Lateral Globus Pallidus
1		−10	8	6	0.034102	9.782E−10	6.001476	Left Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Body
1		14	6	16	0.0331516	2.012E−09	5.8832917	Right Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Body
1		−10	16	2	0.0302879	1.696E−08	5.5199833	Left Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Body
1		−10	−8	8	0.0282734	7.382E−08	5.2555203	Left Cerebrum.Sub-lobar.Thalamus.Gray Matter.*
1		22	8	0	0.0245828	1E−06	4.7533875	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter. Putamen
1		−16	−4	−14	0.0211195	1.042E−05	4.255781	Left Cerebrum.Limbic Lobe.Parahippocampal Gyrus.Gray Matter.Brodmann area 28
1		−20	10	−10	0.0190189	4.109E−05	3.937971	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter. Putamen
1		6	−18	8	0.0182323	6.796E−05	3.8154821	Right Cerebrum.Sub-lobar.Thalamus.Gray Matter.Medial Dorsal Nucleus
1		0	−22	−12	0.0175786	0.0001023	3.713352	Left Brainstem.Midbrain.*.Gray Matter.Red Nucleus
1		−4	−6	−12	0.0174903	0.0001082	3.6990952	Left Cerebrum.Sub-lobar.*.Gray Matter.Hypothalamus
1		26	−18	−14	0.0171715	0.000132	3.648196	Right Cerebrum.Limbic Lobe.Parahippocampal Gyrus.Gray Matter.Brodmann area 28
1		−4	−30	0	0.0166669	0.0001798	3.5680382	Left Cerebrum.Sub-lobar.Thalamus.Gray Matter.Pulvinar
1		24	−16	−18	0.0165296	0.000196	3.5453465	Right Cerebrum.Limbic Lobe.Parahippocampal Gyrus.Gray Matter.Brodmann area 28
1		−6	−14	−12	0.0161499	0.0002476	3.4833329	Left Brainstem.Midbrain.*.Gray Matter.Substania Nigra
1		−24	−2	6	0.0157796	0.0003104	3.4223192	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter. Putamen
1		−20	−4	8	0.0156096	0.0003443	3.3940725	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Lateral Globus Pallidus
1		−26	−20	−14	0.0148648	0.0005428	3.2673557	Left Cerebrum.Limbic Lobe.Parahippocampal Gyrus.Gray Matter.Brodmann area 28
1		32	−16	−16	0.014764	0.0005768	3.2501183	Right Cerebrum.Limbic Lobe.Parahippocampal Gyrus.Gray Matter.Hippocampus
1		−2	28	−4	0.0137733	0.0010426	3.0778277	Left Cerebrum.Limbic Lobe.Anterior Cingulate.Gray Matter. Brodmann area 24
1		26	−20	−2	0.0101298	0.0079931	2.4092295	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Lateral Globus Pallidus
2	8,360	50	16	−2	0.0200954	2.04E−05	4.102855	Right Cerebrum.Sub-lobar.Insula.Gray Matter.Brodmann area 13
2		52	−2	−6	0.0185306	5.619E−05	3.8621595	Right Cerebrum.Temporal Lobe.Superior Temporal Gyrus.Gray Matter.Brodmann area 22
2		34	28	8	0.0178396	8.69E−05	3.7543502	Right Cerebrum.Sub-lobar.Insula.Gray Matter.Brodmann area 13
2		42	28	−4	0.0175085	0.0001068	3.7022624	Right Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.Gray Matter. Brodmann area 47
2		46	20	24	0.015907	0.0002868	3.4438024	Right Cerebrum.Frontal Lobe.Middle Frontal Gyrus.Gray Matter. Brodmann area 9
2		52	2	−14	0.0146352	0.00062	3.2295084	Right Cerebrum.Temporal Lobe.Superior Temporal Gyrus.Gray Matter.Brodmann area 38
2		40	22	12	0.0130165	0.0016189	2.9442036	Right Cerebrum.Sub-lobar.Insula.Gray Matter.Brodmann area 13
2		54	−16	−2	0.012803	0.0018383	2.9046464	Right Cerebrum.Temporal Lobe.Superior Temporal Gyrus.Gray Matter.Brodmann area 22
3	4,424	−56	16	2	0.0205063	1.559E−05	4.164668	Left Cerebrum.Frontal Lobe.Precentral Gyrus.Gray Matter. Brodmann area 44
3		−50	−8	−6	0.0166346	0.0001843	3.5615766	Left Cerebrum.Temporal Lobe.Superior Temporal Gyrus.Gray Matter.Brodmann area 22
3		−46	8	0	0.0163116	0.0002245	3.5095282	Left Cerebrum.Sub-lobar.Insula.Gray Matter.Brodmann area 13
3		−52	−2	−8	0.0156207	0.0003422	3.3957415	Left Cerebrum.Temporal Lobe.Superior Temporal Gyrus.Gray Matter.Brodmann area 22
4	2,224	−34	24	−6	0.022786	3.4E−06	4.49986	Left Cerebrum.Sub-lobar.Insula.Gray Matter.Brodmann area 13
4		−32	26	8	0.0160245	0.0002682	3.4619243	Left Cerebrum.Sub-lobar.Insula.Gray Matter.Brodmann area 13
5	1,640	−2	20	44	0.0164209	0.0002098	3.5274465	Left Cerebrum.Frontal Lobe.Medial Frontal Gyrus.Gray Matter. Brodmann area 6
5		−4	14	56	0.0147994	0.000563	3.2570124	Left Cerebrum.Frontal Lobe.Superior Frontal Gyrus.Gray Matter. Brodmann area 6
5		−4	8	56	0.0142286	0.0007929	3.158501	Left Cerebrum.Frontal Lobe.Medial Frontal Gyrus.Gray Matter. Brodmann area 6
5		−6	24	38	0.0106074	0.0061921	2.501006	Left Cerebrum.Limbic Lobe.Cingulate Gyrus.Gray Matter. Brodmann area 32
6	808	−32	−22	2	0.0180839	7.472E−05	3.792009	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter. Putamen
7	664	−56	−16	2	0.018828	4.641E−05	3.90864	Left Cerebrum.Temporal Lobe.Superior Temporal Gyrus.Gray Matter.Brodmann area 22
8	624	−6	−50	28	0.0156103	0.0003443	3.3940725	Left Cerebrum.Limbic Lobe.Posterior Cingulate.Gray Matter. Brodmann area 31

Cluster #, cluster number; volume mm^3, activation cluster volume, the unit is mm^3; (x,y,z), peak coordinate in Montreal Neurological Institute (MNI) space; ALE value, activation likelihood estimation value; P, P value; Z, Z score.

Table S5 Activation results under decision-making task

Cluster #	Volume mm^3	MNI peak coordinate			ALE value	P	Z	Brain region
		x	y	z				
1	14,168	12	14	−6	0.0392321	9.86E−11	6.3636894	Right Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Head
1		18	10	12	0.028605	2.26E−07	5.0455303	Right Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Body
1		18	6	−14	0.028543	2.37E−07	5.036299	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
1		30	−8	8	0.0233539	7.46E−06	4.329827	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
1		8	−2	20	0.021768	2.04E−05	4.102916	Right Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Body
1		12	−10	12	0.016424	0.0005015	3.2896922	Right Cerebrum.Sub-lobar.Thalamus.Gray Matter.Ventral Lateral Nucleus
1		0	−6	8	0.0150655	0.0010807	3.0671124	Left Cerebrum.Sub-lobar.Thalamus.Gray Matter.*
2	11,848	−10	8	−6	0.0394813	8.13E−11	6.393137	Left Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Head
2		−10	12	4	0.0306597	5.43E−08	5.311859	Left Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Body
2		−26	10	−2	0.017975	0.0002047	3.5339632	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
2		−28	20	2	0.0159147	0.0006711	3.206795	Left Cerebrum.Sub-lobar.Claustrum.Gray Matter.*
2		−26	4	8	0.0155668	0.0008137	3.1509433	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
2		−28	20	−10	0.0145764	0.0014255	2.9833715	Left Cerebrum.Sub-lobar.Insula.Gray Matter.Brodmann area 13
2		−6	12	20	0.0139725	0.0020006	2.8780596	Left Cerebrum.Limbic Lobe.Anterior Cingulate.Gray Matter.Brodmann area 33
2		−6	26	−10	0.0109938	0.0093659	2.3508272	Left Cerebrum.Limbic Lobe.Anterior Cingulate.Gray Matter.Brodmann area 24
3	3,488	−4	36	26	0.0226283	1.18E−05	4.2273636	Left Cerebrum.Limbic Lobe.Cingulate Gyrus.Gray Matter.Brodmann area 32
3		16	32	24	0.0206593	4.09E−05	3.9392648	Right Cerebrum.Limbic Lobe.Anterior Cingulate.Gray Matter.Brodmann area 32
3		0	44	24	0.0170497	0.0003501	3.3895383	Left Cerebrum.Frontal Lobe.Medial Frontal Gyrus.Gray Matter. Brodmann area 9
3		4	34	22	0.0170266	0.0003541	3.386404	Right Cerebrum.Limbic Lobe.Cingulate Gyrus.Gray Matter.Brodmann area 32
4	2,240	0	−32	30	0.0261569	1.19E−06	4.7175856	Left Cerebrum.Limbic Lobe.Cingulate Gyrus.Gray Matter.Brodmann area 23
4		−2	−44	34	0.0154031	0.0008961	3.1226792	Left Cerebrum.Limbic Lobe.Cingulate Gyrus.Gray Matter.Brodmann area 31
4		8	−42	42	0.0134744	0.0026257	2.7911947	Right Cerebrum.Limbic Lobe.Cingulate Gyrus.Gray Matter.Brodmann area 31
5	1,904	32	−20	−10	0.0212323	2.86E−05	4.0236793	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
6	1,704	28	16	−2	0.0200708	5.88E−05	3.8511639	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
6		26	38	−16	0.0185867	0.0001432	3.6273649	Right Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.Gray Matter. Brodmann area 47
6		34	24	−10	0.0145393	0.0014576	2.9765377	Right Cerebrum.Sub-lobar.Insula.Gray Matter.Brodmann area 47
7	1,632	−4	60	−16	0.0209235	3.48E−05	3.9778523	Left Cerebrum.Frontal Lobe.Medial Frontal Gyrus.Gray Matter. Brodmann area 10
7		−12	62	−6	0.0153921	0.0009012	3.1210124	Left Cerebrum.Frontal Lobe.Medial Frontal Gyrus.Gray Matter. Brodmann area 10
7		−2	56	−8	0.0151601	0.0010267	3.0823984	Left Cerebrum.Frontal Lobe.Medial Frontal Gyrus.Gray Matter. Brodmann area 10
8	1,176	−48	40	−2	0.0169345	0.0003749	3.3706992	Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.Gray Matter. Brodmann area 45
8		−48	28	−8	0.0150775	0.0010746	3.0688024	Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.Gray Matter. Brodmann area 47
8		−42	32	−10	0.0137771	0.0022188	2.8452492	Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.Gray Matter. Brodmann area 47
9	1,096	−36	−72	−24	0.0182747	0.0001728	3.5784497	Left Cerebellum.Posterior Lobe.Uvula.Gray Matter.*
9		−42	−72	−34	0.0158564	0.0006904	3.198629	Left Cerebellum.Posterior Lobe.Pyramis.Gray Matter.*
10	976	−20	−28	2	0.0193882	8.89E−05	3.748774	Left Cerebrum.Sub-lobar.Thalamus.Gray Matter.Pulvinar
11	920	48	46	16	0.0191046	0.0001057	3.7049413	Right Cerebrum.Frontal Lobe.Middle Frontal Gyrus.Gray Matter. Brodmann area 46
12	856	56	−58	−12	0.0190601	0.0001083	3.6988568	Right Cerebrum.Temporal Lobe.Inferior Temporal Gyrus.Gray Matter. Brodmann area 20
12		58	−48	−14	0.0159384	0.0006598	3.211692	Right Cerebrum.Temporal Lobe.Inferior Temporal Gyrus.Gray Matter. Brodmann area 20
13	808	14	−76	50	0.0167846	0.0004084	3.3470144	Right Cerebrum.Parietal Lobe.Precuneus.Gray Matter.Brodmann area 7
14	776	−20	−6	14	0.0189544	0.0001156	3.6821847	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
15	712	4	−46	6	0.0174376	0.0002798	3.4504805	Right Cerebellum.Anterior Lobe.Culmen.Gray Matter.*
16	664	−16	−24	38	0.0191346	0.0001038	3.7094822	Left Cerebrum.Limbic Lobe.Cingulate Gyrus.Gray Matter.Brodmann area 31
17	624	−46	2	24	0.017823	0.0002246	3.5093415	Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.Gray Matter. Brodmann area 9
18	616	−28	−66	48	0.0156755	0.0007645	3.1691036	Left Cerebrum.Parietal Lobe.Superior Parietal Lobule.Gray Matter. Brodmann area 7
18		−18	−64	44	0.0149879	0.0011308	3.0535464	Left Cerebrum.Parietal Lobe.Precuneus.Gray Matter.Brodmann area 7

Cluster #, cluster number; volume mm^3, activation cluster volume, the unit is mm^3; (x,y,z), peak coordinate in Montreal Neurological Institute (MNI) space; ALE value, activation likelihood estimation value; P, P value; Z, Z score.

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Table S6 Contrast analysis of multiple single activation task

Cluster #	Volume mm^3	MNI peak coordinate			P	Z	Brain region
		x	y	z			
Contrast: reward > memory							
1	2,112	19.4	9.7	−4.9	0.0164	0	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
2	840	7.3	48	−5.3	0	3.7190173	Right Cerebrum.Limbic Lobe.Anterior Cingulate.Gray Matter.*
Contrast: memory > reward							
1	1,864	22.4	−28.9	−11.1	0	3.7190173	*.*.*.*.*
1		36	−36	−5	0.0002	3.5400841	Right Cerebrum.Temporal Lobe.Sub-Gyral.White Matter.*
1		25	−26	−15	0.0034	2.7064834	Right Cerebrum.Limbic Lobe.Parahippocampal Gyrus.Gray Matter.Brodmann area 35
2	1,472	39	43	16	0.0004	3.352795	Right Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.*
2		38	42	20	0.0008	3.1559067	Right Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.*
2		30	44	24	0.0012	3.0356722	Right Cerebrum.Frontal Lobe.Superior Frontal Gyrus.White Matter.*
3	1,432	−21.3	−29.7	−11.2	0.0002	3.5400841	Left Cerebrum.Limbic Lobe.Parahippocampal Gyrus.*.*
3		−25.2	−32.6	−12.2	0.0002	3.5400841	Left Cerebrum.Limbic Lobe.Parahippocampal Gyrus.White Matter.*
4	1,072	−46	−64	−8	0.0002	3.5400841	Left Cerebrum.Occipital Lobe.Sub-Gyral.White Matter.*
4		−46.7	−65.3	−4	0.0006	3.2388802	Left Cerebrum.Occipital Lobe.Middle Occipital Gyrus.White Matter.*
4		−38	−63	−22	0.001	3.0902321	Left Cerebellum.Posterior Lobe.Declive.Gray Matter.*
4		−34	−66	−14	0.0014	2.9888823	Left Cerebellum.Posterior Lobe.Declive.Gray Matter.*
Contrast: reward > emotion							
1	3,240	14.1	11.2	−9.2	0	3.7190173	Right Cerebrum.Sub-lobar.*.Gray Matter.*
2	2,912	−15.8	9.5	−5.4	0.001	3.0902321	Left Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
2		−16	10	−2	0.0004	3.352795	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
3	1,928	8.4	47.7	−8.1	0	3.7190173	Right Cerebrum.Limbic Lobe.Anterior Cingulate.White Matter.*
3		−0.4	52.1	−7	0.0002	3.5400841	Left Cerebrum.Limbic Lobe.Anterior Cingulate.*.*
4	1,000	−1	−9	50	0.0016	2.9478426	Left Cerebrum.Frontal Lobe.Paracentral Lobule.Gray Matter.Brodmann area 31
4		3	−4	48	0.0018	2.9112377	Left Cerebrum.Limbic Lobe.Cingulate Gyrus.*.*
4		−2	6	48	0.003	2.7477813	Left Cerebrum.Limbic Lobe.Cingulate Gyrus.Gray Matter.Brodmann area 24
Contrast: emotion > reward							
1	1,128	48	1	−14	0	3.7190173	Right Cerebrum.Temporal Lobe.Sub-Gyral.White Matter.*
1		48	5	0	0.0008	3.1559067	Right Cerebrum.Sub-lobar.Insula.Gray Matter.Brodmann area 13
1		50	10	−4	0.001	3.0902321	Right Cerebrum.Sub-lobar.Insula.Gray Matter.Brodmann area 13
1		52	−4	−12	0.0042	2.6355543	Right Cerebrum.Temporal Lobe.Superior Temporal Gyrus.Gray Matter.Brodmann area 22
2	752	−25.2	−20.4	−12	0	3.7190173	Left Cerebrum.Temporal Lobe.Sub-Gyral.White Matter.*
2		−34	−18	−16	0.0002	3.5400841	Left Cerebrum.Limbic Lobe.Parahippocampal Gyrus.Gray Matter.Hippocampus
2		−30	−20	−13	0.0004	3.352795	Left Cerebrum.Sub-lobar.Lateral Ventricle.Cerebro-Spinal Fluid.*
Contrast: reward > decision-making							
1	1,616	19.4	9.9	−5.3	0	3.7190173	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Lateral Globus Pallidus
2	920	8	46	−6	0	3.7190173	Right Cerebrum.Limbic Lobe.Anterior Cingulate.Gray Matter.Brodmann area 32
Contrast: decision-making > reward							
1	752	31	−19	−7	0.004	2.6520698	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
1		28	−24	−4	0.0028	2.7703273	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
1		22	−24	−12	0.003	2.7477813	*.*.*.*.*
1		26.7	−28	−8.7	0.0034	2.7064834	Right Cerebrum.Limbic Lobe.Parahippocampal Gyrus.White Matter.*
1		26	−22	−12	0.004	2.6520698	Right Cerebrum.Limbic Lobe.Sub-Gyral.White Matter.*
Contrast: memory > emotion							
1	1,504	35	38	20	0	3.7190173	Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.*
1		39.3	44	22	0.001	3.0902321	Right Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.*
2	808	8	13	−16	0.0016	2.9478426	Right Cerebrum.Limbic Lobe.Anterior Cingulate.Gray Matter.Brodmann area 25
2		12	12	−15	0.0026	2.794376	Right Cerebrum.Sub-lobar.*.Gray Matter.*
2		12	10	−10	0.0028	2.7703273	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
3	704	−39.3	−61.3	−21.3	0.002	2.8781617	Left Cerebellum.Posterior Lobe.Declive.Gray Matter.*
3		−36	−60	−10	0.0064	2.489286	Left Cerebrum.Occipital Lobe.Fusiform Gyrus.White Matter.*
3		−32	−60	−12	0.0082	2.39989	Left Cerebellum.Posterior Lobe.Declive.Gray Matter.*
4	608	35	−49	40	0.001	3.0902321	Right Cerebrum.Parietal Lobe.Sub-Gyral.White Matter.*
Contrast: memory > decision-making							
1	904	38.7	26.7	0	0.0002	3.5400841	Right Cerebrum.Sub-lobar.Insula.Gray Matter.Brodmann area 13
1		34	34	−4	0.0006	3.2388802	Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.*
1		32	30	0	0.0008	3.1559067	Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.*
2	856	−26	−33.3	−17.3	0.0046	2.6045313	Left Cerebrum.Limbic Lobe.Parahippocampal Gyrus.Gray Matter.Brodmann area 36
2		−26	−36	−11	0.0004	3.352795	Left Cerebrum.Limbic Lobe.Parahippocampal Gyrus.White Matter.*
2		−28	−30	−12	0.001	3.0902321	Left Cerebrum.Limbic Lobe.Parahippocampal Gyrus.White Matter.*
3	808	2	24	38	0.0002	3.5400841	Inter-Hemispheric.*.*.*.*
4	776	−42	27	2	0	3.7190173	Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.Gray Matter.Brodmann area 13
4		−36	30	0	0.0014	2.9888823	Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.*
4		−30	35	−5	1	0	Left Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.*
Contrast: decision-making > emotion							
1	984	−6	34	22	0.0024	2.820158	Left Cerebrum.Limbic Lobe.Anterior Cingulate.Gray Matter.Brodmann area 32
1		−4	38	26	0.0026	2.794376	Left Cerebrum.Limbic Lobe.Cingulate Gyrus.Gray Matter.Brodmann area 32
1		0	34	26	0.003	2.7477813	Left Cerebrum.Limbic Lobe.Cingulate Gyrus.*.*
2	728	13.3	9.3	−13.3	0.0004	3.352795	Right Cerebrum.Sub-lobar.*.Gray Matter.*
Contrast: emotion > decision-making							
1	1,320	26.6	−4.2	−17.4	0	3.7190173	Right Cerebrum.Limbic Lobe.Parahippocampal Gyrus.Gray Matter.Amygdala
2	1,088	−45	−6	−5	0.0002	3.5400841	Left Cerebrum.Sub-lobar.Insula.Gray Matter.Brodmann area 13
2		−46	−10	−6	0.0004	3.352795	Left Cerebrum.Sub-lobar.Insula.*.*
2		−50	2	−8	0.0006	3.2388802	Left Cerebrum.Temporal Lobe.Superior Temporal Gyrus.Gray Matter.Brodmann area 22
2		−46	6	−4	0.0028	2.7703273	Left Cerebrum.Sub-lobar.Insula.Gray Matter.Brodmann area 13
2		−50	10	−2	0.0036	2.6874495	Left Cerebrum.Sub-lobar.Insula.*.*
2		−46	12	−2	0.0046	2.6045313	Left Cerebrum.Sub-lobar.Insula.Gray Matter.Brodmann area 13

Cluster #, cluster number; volume mm^3, activation cluster volume, the unit is mm^3; (x,y,z), peak coordinate in Montreal Neurological Institute (MNI) space; ALE value, activation likelihood estimation value; P, P value; Z, Z score.

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Table S7 Conjunction analysis of multiple single activation task

Cluster #	Volume mm^3	MNI peak coordinate			ALE value	Brain region
		x	y	z		
Conjunction: reward_ conj _memory						
1	11,048	–12	10	–4	0.033279087	Left Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
1		–18	8	0	0.03261438	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
1		–24	4	4	0.023548719	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
1		–12	0	12	0.022341166	Left Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Body
1		–20	12	–12	0.018655526	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
1		–14	–8	–4	0.014634266	Left Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
1		–8	–14	6	0.014228115	Left Cerebrum.Sub-lobar.Thalamus.Gray Matter.Medial Dorsal Nucleus
2	10,240	12	8	–10	0.032185193	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
2		10	12	–10	0.030384148	Right Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Head
2		34	26	–6	0.028880097	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
2		12	8	–2	0.026198952	Right Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Head
2		20	8	0	0.024628002	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
2		8	–2	4	0.01934089	Right Cerebrum.Sub-lobar.Thalamus.Gray Matter.Anterior Nucleus
2		28	0	6	0.017268842	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
2		18	–2	8	0.016190035	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
2		18	4	16	0.014271136	Right Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Body
2		18	8	16	0.013320627	Right Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Body
3	472	–2	30	30	0.015150301	Left Cerebrum.Limbic Lobe.Cingulate Gyrus.Gray Matter.Brodmann area 32
3		2	30	38	0.013589921	Inter–Hemispheric.*.*.*.*
4	208	4	18	40	0.014469479	Right Cerebrum.Limbic Lobe.Cingulate Gyrus.*.*
5	184	–22	–2	–16	0.014614396	Left Cerebrum.Limbic Lobe.Parahippocampal Gyrus.White Matter.*
6	184	28	–6	–12	0.014626038	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
7	168	8	–16	4	0.015321739	Right Cerebrum.Sub-lobar.Thalamus.Gray Matter.Medial Dorsal Nucleus
8	168	–4	8	48	0.014732766	Left Cerebrum.Limbic Lobe.Cingulate Gyrus.Gray Matter.Brodmann area 24
9	136	16	–14	0	0.013778226	Right Cerebrum.Sub-lobar.Thalamus.Gray Matter.*
10	64	30	–10	–22	0.013231937	Right Cerebrum.Sub-lobar.Lateral Ventricle.Cerebro-Spinal Fluid.*
11	64	–42	–10	52	0.01248834	Left Cerebrum.Frontal Lobe.Precentral Gyrus.Gray Matter.Brodmann area 4
12	16	6	26	24	0.011216096	Right Cerebrum.Limbic Lobe.Cingulate Gyrus.*.*
13	8	26	–8	–14	0.011271476	Right Cerebrum.Sub-lobar.*.Gray Matter.Amygdala
14	8	22	–8	–12	0.011193498	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
15	8	18	–8	–4	0.011304774	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
16	8	–4	–20	8	0.011540647	Left Cerebrum.Sub-lobar.Thalamus.Gray Matter.Medial Dorsal Nucleus
17	8	–26	–60	42	0.011511424	Left Cerebrum.Parietal Lobe.Precuneus.White Matter.*
Conjunction: reward_ conj _emotion						
1	25,440	10	8	2	0.044894863	Right Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Body
1		–10	8	6	0.034101978	Left Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Body
1		26	0	–12	0.02923035	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
1		22	8	0	0.02458282	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
1		14	2	16	0.024015015	Right Cerebrum.Sub-lobar.Lateral Ventricle.Cerebro-Spinal Fluid.*
1		–18	–2	–12	0.020652795	Left Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
1		–20	10	–10	0.01901887	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
1		6	–18	8	0.01823227	Right Cerebrum.Sub-lobar.Thalamus.Gray Matter.Medial Dorsal Nucleus
1		–24	–2	6	0.015779603	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
1		–6	–10	8	0.015747154	Left Cerebrum.Sub-lobar.Thalamus.Gray Matter.Medial Dorsal Nucleus
1		–12	–8	14	0.01422217	Left Cerebrum.Sub-lobar.Thalamus.Gray Matter.*
1		–10	–4	12	0.013886281	Left Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
1		14	–10	12	0.010785186	Right Cerebrum.Sub-lobar.Thalamus.Gray Matter.Ventral Lateral Nucleus
2	888	–4	–18	–14	0.015541157	Left Brainstem.Midbrain.*.*.*
2		–4	–28	–4	0.011649065	Left Brainstem.Midbrain.*.*.*
3	888	34	26	6	0.01605417	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
3		38	26	–4	0.01575051	Right Cerebrum.Sub-lobar.Insula.Gray Matter.*
4	216	–32	22	–2	0.015833732	Left Cerebrum.Sub-lobar.Insula.White Matter.*
5	168	–4	10	54	0.013073181	Left Cerebrum.Frontal Lobe.Medial Frontal Gyrus.Gray Matter.Brodmann area 6
5		–2	4	56	0.012588951	Left Cerebrum.Frontal Lobe.Medial Frontal Gyrus.Gray Matter.Brodmann area 6
6	88	14	–14	0	0.011461202	Right Cerebrum.Sub-lobar.Thalamus.Gray Matter.*
7	24	–2	2	56	0.011407402	Left Cerebrum.Frontal Lobe.Medial Frontal Gyrus.Gray Matter.Brodmann area 6
8	16	–4	12	54	0.011988824	Left Cerebrum.Frontal Lobe.Medial Frontal Gyrus.Gray Matter.Brodmann area 6
9	8	32	18	–4	0.009780914	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
10	8	–32	20	6	0.009819939	Left Cerebrum.Sub-lobar.Insula.White Matter.*
11	8	–30	22	6	0.01103627	Left Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
Conjunction: reward_ conj _decision-making						
1	10,592	–10	8	–6	0.039481327	Left Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
1		–10	12	4	0.0306597	Left Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Body
1		–26	10	–4	0.017462585	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
1		–28	20	2	0.015914729	Left Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
1		–26	4	8	0.015566818	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
1		–24	18	–12	0.011963048	Left Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
2	9,512	12	14	–6	0.039232075	Right Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Head
2		20	8	–14	0.021525828	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
2		10	–2	18	0.017395828	Right Cerebrum.Sub-lobar.Lateral Ventricle.Cerebro-Spinal Fluid.*
2		12	–8	12	0.015094435	Right Cerebrum.Sub-lobar.Thalamus.Gray Matter.*
2		0	–6	8	0.015065536	Inter–Hemispheric.Sub-lobar.Extra-Nuclear.White Matter.*
2		14	6	14	0.014449487	Right Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Body
2		10	–12	10	0.013836882	Right Cerebrum.Sub-lobar.Thalamus.Gray Matter.Medial Dorsal Nucleus
2		28	–2	6	0.013286449	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
3	536	26	14	–2	0.015084863	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
3		34	24	–10	0.014539308	Right Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.*
3		32	20	–4	0.013471166	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
4	376	–18	–4	16	0.016731545	Left Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
5	160	–2	54	–8	0.014449894	Left Cerebrum.Frontal Lobe.Medial Frontal Gyrus.Gray Matter.*
5		–2	52	–14	0.012478291	Left Cerebrum.Frontal Lobe.Medial Frontal Gyrus.*.*
6	72	–20	–62	46	0.012929494	Left Cerebrum.Parietal Lobe.Precuneus.White Matter.*
7	56	8	36	24	0.012220076	Right Cerebrum.Limbic Lobe.Cingulate Gyrus.White Matter.*
8	24	–2	32	28	0.01310776	Left Cerebrum.Limbic Lobe.Cingulate Gyrus.Gray Matter.Brodmann area 32
9	16	28	12	–2	0.011703827	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
10	16	–4	30	28	0.011982411	Left Cerebrum.Limbic Lobe.Cingulate Gyrus.White Matter.*
11	16	0	34	28	0.012060597	Left Cerebrum.Limbic Lobe.Cingulate Gyrus.Gray Matter.Brodmann area 32
12	8	–40	–62	–36	0.010981381	Left Cerebellum.Posterior Lobe.Cerebellar Tonsil.Gray Matter.*
13	8	34	16	–2	0.011025434	Right Cerebrum.Sub-lobar.Claustrum.Gray Matter.*
14	8	20	2	10	0.010941391	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
15	8	4	–50	12	0.01090003	Right Cerebrum.Limbic Lobe.Posterior Cingulate.*.*
16	8	–2	30	26	0.011127329	Left Cerebrum.Limbic Lobe.Cingulate Gyrus.Gray Matter.Brodmann area 32
17	8	0	32	26	0.011606091	Left Cerebrum.Limbic Lobe.Cingulate Gyrus.*.*
18	8	2	34	26	0.012015814	Inter–Hemispheric.*.*.*.*
Conjunction: memory_ conj _emotion						
1	8,568	–10	10	0	0.026224438	Left Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Head
1		–14	2	10	0.022134723	Left Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
1		–12	–10	6	0.02141949	Left Cerebrum.Sub-lobar.Thalamus.Gray Matter.Ventral Lateral Nucleus
1		–18	10	–8	0.017855821	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
1		–10	–4	10	0.017498232	Left Cerebrum.Sub-lobar.Thalamus.Gray Matter.*
1		–24	–2	6	0.015779603	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
2	5,280	12	8	–2	0.026198952	Right Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Head
2		20	8	0	0.023372296	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
2		12	16	–4	0.021903273	Right Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Head
2		20	6	16	0.018750329	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
2		16	12	16	0.013337228	Right Cerebrum.Sub-lobar.Lateral Ventricle.Cerebro-Spinal Fluid.*
3	992	40	28	–4	0.016910002	Right Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.Gray Matter.Brodmann area 47
3		34	26	4	0.014510156	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
4	936	28	–8	–10	0.016445965	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Lateral Globus Pallidus
4		30	–16	–18	0.013984475	Right Cerebrum.Limbic Lobe.Parahippocampal Gyrus.Gray Matter.Hippocampus
4		24	–14	–16	0.013682182	Right Cerebrum.Limbic Lobe.Parahippocampal Gyrus.White Matter.*
5	640	8	–16	4	0.014939671	Right Cerebrum.Sub-lobar.Thalamus.Gray Matter.Medial Dorsal Nucleus
6	448	–20	–4	–16	0.016334414	Left Cerebrum.Limbic Lobe.Parahippocampal Gyrus.Gray Matter.Amygdala
7	416	–2	20	44	0.016420934	Left Cerebrum.Frontal Lobe.Medial Frontal Gyrus.Gray Matter.Brodmann area 6
8	360	–36	26	–4	0.017461129	Left Cerebrum.Sub-lobar.Insula.Gray Matter.*
9	16	–38	24	8	0.011313089	Left Cerebrum.Sub-lobar.Insula.White Matter.*
10	8	–40	26	4	0.009834221	Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.Gray Matter.Brodmann area 13
Conjunction: memory_ conj _decision-making						
1	6,400	–12	10	–4	0.033279087	Left Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
1		–26	10	–2	0.01744608	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
1		–26	4	8	0.015566818	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
1		–10	2	10	0.014426751	Left Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
2	6,368	10	12	–10	0.030384148	Right Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Head
2		12	8	–2	0.026198952	Right Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Head
2		20	6	14	0.017457647	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
2		28	–4	8	0.016826339	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
2		20	6	6	0.016562644	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
2		16	12	16	0.013337228	Right Cerebrum.Sub-lobar.Lateral Ventricle.Cerebro-Spinal Fluid.*
2		16	–4	–2	0.012518587	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
3	720	30	18	–2	0.016932553	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
3		26	16	–2	0.016173916	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
3		34	24	–10	0.014539308	Right Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.*
4	344	–16	–6	16	0.015760321	Left Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
5	240	–4	34	30	0.016284596	Left Cerebrum.Limbic Lobe.Cingulate Gyrus.Gray Matter.Brodmann area 32
6	176	–26	–66	46	0.013775799	Left Cerebrum.Parietal Lobe.Precuneus.White Matter.*
7	160	26	–26	–12	0.016076565	Right Cerebrum.Limbic Lobe.Parahippocampal Gyrus.White Matter.*
8	80	–20	–6	–14	0.012019973	Left Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
9	24	44	44	22	0.011751012	Right Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.*
10	16	–14	–4	–4	0.011666442	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Medial Globus Pallidus
11	16	–8	0	8	0.011855342	Left Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
12	16	10	30	22	0.011002142	Right Cerebrum.Limbic Lobe.Anterior Cingulate.*.*
13	16	–50	2	26	0.012505072	Left Cerebrum.Frontal Lobe.Precentral Gyrus.White Matter.*
14	16	–48	2	28	0.012040478	Left Cerebrum.Frontal Lobe.Precentral Gyrus.White Matter.*
15	8	–28	24	–10	0.011261929	Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.*
16	8	–8	0	4	0.011642123	Left Cerebrum.Sub-lobar.Thalamus.Gray Matter.*
17	8	12	–6	10	0.011517352	Right Cerebrum.Sub-lobar.Thalamus.Gray Matter.*
18	8	14	–6	12	0.011674695	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
19	8	42	42	22	0.011022133	Right Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.*
20	8	–20	–66	48	0.011021092	Left Cerebrum.Parietal Lobe.Precuneus.White Matter.*
Conjunction: emotion_ conj _decision-making						
1	8,096	–8	10	4	0.030274037	Left Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Body
1		–18	10	–8	0.018537577	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
1		–14	–2	–10	0.015358497	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Medial Globus Pallidus
2	6,264	10	8	0	0.03241965	Right Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Head
2		18	8	14	0.024308382	Right Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Body
2		14	10	12	0.024135718	Right Cerebrum.Sub-lobar.Caudate.Gray Matter.Caudate Body
2		12	2	20	0.012891931	Right Cerebrum.Sub-lobar.Lateral Ventricle.Cerebro-Spinal Fluid.*
3	312	28	–20	–12	0.013671659	Right Cerebrum.Temporal Lobe.Sub-Gyral.White Matter.*
3		32	–18	–14	0.013416298	Right Cerebrum.Sub-lobar.Lateral Ventricle.Cerebro-Spinal Fluid.*
4	312	26	14	–2	0.015084863	Right Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
5	288	–18	–6	12	0.013971033	Left Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
6	280	20	2	–16	0.015108815	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
7	280	10	–12	12	0.012939177	Right Cerebrum.Sub-lobar.Thalamus.Gray Matter.Medial Dorsal Nucleus
8	32	–30	20	–8	0.011299767	Left Cerebrum.Sub-lobar.Claustrum.Gray Matter.*
9	24	–6	28	–10	0.010880676	Left Cerebrum.Limbic Lobe.Anterior Cingulate.White Matter.*
10	24	–26	2	6	0.011349389	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
11	16	–26	0	8	0.011582507	Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
12	8	36	24	–8	0.010567112	Right Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
13	8	–28	22	–2	0.010431197	Left Cerebrum.Sub-lobar.Claustrum.Gray Matter.*
14	8	–30	22	0	0.010302743	Left Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.*
15	8	–2	–6	6	0.010503497	Left Cerebrum.Sub-lobar.Thalamus.Gray Matter.*

Cluster #, cluster number; volume mm^3, activation cluster volume, the unit is mm^3; (x,y,z), peak coordinate in Montreal Neurological Institute (MNI) space; ALE value, activation likelihood estimation value; P, P value; Z, Z score.

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