1 **Willingness to Pay in the Human Brain: A fMRI Activation**
2 **Likelihood Estimation Meta-analysis**
3 Xiaoqiang Yao ^{1,2}, Zhigang Huang ¹, Yiwen Wang ^{1,2} * et al.
4 ¹ School of Economics and Management, Fuzhou University, Fuzhou 350108, China
5 ² Institute of Psychological and Cognitive Sciences, Fuzhou University, Fuzhou 350108,
6 China
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22 * Corresponding author: Prof. Y.W. Wang.
23 *Address:* Institute of Psychological and Cognitive Sciences, Fuzhou University, 2
24 Wulong River North Avenue, University Town, Fuzhou, Fujian
25 *E-mail address:* wangeven@126.com (Y.W. Wang)
26 *Phone number:* 0591-22863565
27

Abstract

The neural substrate of willingness to pay (WTP) ultimately supports human economic exchange activities and plays a crucial role in daily life. This paper aimed to identify the neural basis of WTP for food and nonfood, as well as the brain regions related to real and hypothetical WTP choices. We found the human brain centers of WTP by performing an activation likelihood estimation (ALE) meta-analysis (27 experiments, 796 subjects) on the existing neuroimaging studies. The conjunction analysis revealed that WTP for food and nonfood engaged a common cluster in the paracingulate and cingulate gyrus, revealing a common reward circuit in the brain. The frontal medial cortex and paracingulate gyrus were particularly activated by WTP for nonfood. Furthermore, the left caudate, left thalamus, angular gyrus and supramarginal gyrus (subregions of inferior parietal lobule) were more convergently activated by hypothetical WTP choice. Our findings support the idea that a common currency representation in the brain and reward-specific neural basis. Results also provide evidence of neural representations of the hypothetical bias.

Keywords: Willingness to pay; Subjective value; Meta-analysis; Activation likelihood estimation; functional magnetic resonance imaging

1.Introduction

Consumers' willingness to pay (WTP) plays a crucial role in daily life and is the cornerstone of marketing strategy such as developing competitive strategies, conducting to value audits, and designing optimal pricing for new product (Anderson, Jain, & Chintagunta, 1992). From an economic view, WTP denotes the maximum price a consumer calculated willing to pay for a given quantifies of a good (Schmidt & Bijmolt, 2020; Wertenbroch & Skiera, 2002). A WTP value reflects the consumer's subjective value of the quantify of the good (Wertenbroch & Skiera, 2002). With the development of neuroimaging techniques and intersection of multiple disciplines, how the brain performs value computation has attracted the attention of scientist from decision and consumer neuroscience (Chib, Rangel, Shimojo, & O'Doherty, 2009; Clithero, Carter, & Huettel, 2009; De Martino, Kumaran, Holt, & Dolan, 2009; Hare, O'doherty, Camerer, Schultz, & Rangel, 2008; Plassmann, O'doherty, & Rangel, 2007).

What are our brain responses when we are making economic decisions? These studies revealed that activity in several areas including the medial orbitofrontal cortex (mOFC), anterior cingulate cortex (ACC), ventromedial prefrontal cortex (vmPFC),

1 and inferior frontal gyrus (IFG), among others were correlated with economic decision-
 2 making (Chib et al., 2009; De Martino et al., 2009; Hare et al., 2008; Kennerley, Walton,
 3 Behrens, Buckley, & Rushworth, 2006; Padoa-Schioppa & Assad, 2006; Padoa-
 4 Schioppa & Conen, 2017; Wallis, 2007). Plassmann et al. (2007) firstly, investigated
 5 the neural representation of WTP in everyday economic transactions. They found that
 6 mOFC, ACC, and dorsolateral prefrontal cortex (DLPFC) were correlated with WTP.
 7 Likewise, Grueschow, Polania, Hare, and Ruff (2015) examined the neural representing
 8 of WTP for movie by using Becker-DeGroot-Marschak(BDM) auction (Becker,
 9 DeGroot, & Marschak, 1964) and they found that significant activity in the mPFC, the
 10 posterior cingulate cortex (PCC), and the parietal lobule among others during WTP
 11 decisions. However, the above studies have identified multiple brain regions associated
 12 with WTP computation, it is not clear how consistent and specific these findings are. In
 13 other words, whether there are specific brain regions associated with the computation
 14 of WTP, and the specificity of brain activity for different types of rewards and in distinct
 15 WTP measure contexts.

16 Previous studies on the neural mechanism of WTP have used different reward stimuli,
 17 which can be broadly classified as primary (i.e., food, sex) and secondary rewards (i.e.,
 18 money, power). Primary rewards have innate value and are essential for human survival
 19 and reproduction, whereas secondary rewards are not directly related to survival
 20 (Sescousse, Caldú, Segura, & Dreher, 2013). Several studies have found that a
 21 phylogenetically and ontogenically older region posterior lateral OFC processes
 22 primary rewards for specificity, whereas a phylogenetically recent structure anterior
 23 lateral OFC processes secondary rewards for specificity (Sescousse et al., 2013;
 24 Sescousse, Redouté, & Dreher, 2010). There is also a common set of brain areas
 25 associated with processing primary and secondary rewards, including the ventral
 26 striatum, the anterior cingulate cortex, the anterior insula and among others (Sescousse
 27 et al., 2013; Sescousse et al., 2010). For example, Chib et al. (2009) found the vmPFC
 28 was correlated with subject's WTP for all classes of items (money, trinkets and snacks).
 29 Other studies have also investigated the neural basis of WTP for non-primary rewards,
 30 such as movie and books. Grueschow et al. (2015) examined the neural representing of
 31 WTP for movie by using BDM auction and found that significant activity in the medial
 32 prefrontal cortex (mPFC), the posterior cingulate cortex (PCC), and the parietal lobule
 33 among others during WTP decisions. Likewise, Waskow et al. (2016) revealed that
 34 neural activity in the OFC, mPFC, and the ACC during decision-making correlates with
 35 individual's WTP for music. Therefore, when performing WTP calculations for
 36 different reward types, are there common and different neural representations?

1 Another factor that affects the neural basis of WTP may be the measure context.
2 There are various methods of measuring WTP in existing market research. According
3 to the measure context, the methods of measuring WTP can be divided into hypothetical
4 and real measuring of WTP (Miller, Hofstetter, Krohmer, & Zhang, 2011). Specifically,
5 the BDM auction is the most widely used measures of WTP under real context (Becker
6 et al., 1964). In the BDM procedure, participants first state their bids for each item, and
7 then at the end of procedure, one bids will be randomly selected. If participants' bid is
8 less than the price of a randomly item, the participant does not buy the item, if
9 participants' bid is equal to or more than the price of a randomly item, the participant
10 must buy the item for the randomly item price. The open questioning is one of the most
11 used measure of WTP under hypothetical context, in which a participant stated their
12 bids for each item. Real choice may usually be precise, direct, have greater stakes, and
13 tend to be emotional, while hypothetical choices, without any consequences, may be
14 quick and unconscious, and require fewer cognitive resources (Kang, Rangel, Camus,
15 & Camerer, 2011).

16 Moreover, previous research has found a hypothetical bias between real and
17 hypothetical WTP, that is, participants overstate their WTP for the goods under
18 hypothetical conditions compared to in real WTP context (Schmidt & Bijmolt, 2020).
19 They revealed that the hypothetical WTP is typically overestimated by almost 21%
20 when compared to the real WTP for consumer goods (Schmidt & Bijmolt, 2020).
21 Meanwhile, researchers also tested the neural representation mechanism of this
22 hypothetical bias (Kang & Camerer, 2013; Kang et al., 2011). Kang et al. (2011)
23 revealed that activity in OFC and ventral striatum (VS) correlated with the WTP for
24 consumer products in both types of real and hypothetical decision. In addition, they
25 found that the mOFC, ACC, caudate and inferior frontal gyrus were more responsive to
26 decision value in real than hypothetical WTP. Conversely, Kang and Camerer (2013)
27 found that more deactivation in the striatum and mOFC in real WTP for aversive foods,
28 compared with hypothetical trials. Overall, whether there are brain regions activity
29 specificity and consistency for real and hypothetical WTP have not been addressed.
30 Answering these questions is important for understanding the neural basis of the WTP.

31 To address the above issues, we supposed a quantitative meta-analysis of these
32 studies by using different reward type and contexts of measuring WTP may be able to
33 answer these questions above. Therefore, the aim of this study was to (1) examine the
34 neural representation of WTP for different rewards, (2) to investigate the common and
35 distinct of brain network of WTP for different rewards, and (3) to identify the
36 consistency and specificity of WTP measures context neural basic in the brain. To

1 achieve these aims, we conducted meta-analyses with activation likelihood estimation
2 (ALE) method by comparing the WTP for food and nonfood reward as well as real and
3 hypothetical WTP choices.

4

5 **2. Materials and methods**

6 *2.1. literature search and selection*

7 A systematic literature search was performed in Web of Science and PubMed
8 databases to identify relevant studies (up to the August, 2020). The following key words
9 were used for the search: “willingness to pay”, and “Becker-DeGroot-Marshak”, in
10 combination(“And”) with “fMRI”. In addition to Web of science and PubMed search,
11 several other sources were explored, including (a) work cited in review paper (Peters &
12 Büchel, 2010); (b) cited articles in meta-analyses (Bartra, McGuire, & Kable, 2013;
13 Levy & Glimcher, 2012); and (c) relevant reference lists of the initial search pre-
14 selected articles.

15 The inclusion criteria for articles were as follows: (1) fMRI was used as the main
16 methodology; (2) study that included at least one group of healthy participants were
17 including; (3) fMRI results were derived from whole-brain analysis; (4) activations
18 coordinates (foci) were presented in a standardized stereotaxic space (Talairach or
19 Montreal Neurological Institute, MNI); (5) articles were published in peer-review
20 journals; and (6) articles were written in English. (6) for each experiment per subject
21 group, only one most strongly reflects the WTP process contrast’s coordinate data was
22 extracted.

23 A total 25 studies (27 experiments) were included in following meta-analyses: 17 of
24 these studies (19 experiments) focused on WTP for food reward, 11 of these studies (11
25 experiments) on WTP for nonfood reward (three studies contributed to both categories).
26 On the other hand, according to the context of measurement WTP, it can be divided into
27 hypothetical and real WTP. A real measure of WTP such as BDM auction, and a
28 hypothetical measure such as open questioning (Miller et al., 2011). In this, there are
29 22 articles (24 experiments) that use the BDM method to measure real WTP, and 4
30 articles (4 experiments) that use the hypothetical method to measure WTP (one study
31 contributed to both categories). Figure. 1 showed a Preferred Reporting Items for
32 Systematic and Meta-Analyses (PRISMA) flowcharts depicts the steps taken to
33 identification and identify eligible studies. Table 1 presents the details of all included
34 studies. The present meta-analyses study was preregistered on the Open Science
35 Framework (<https://osf.io/6fbwr>).

Fig.1. PRISMA flowchart of identification and identify eligible studies; fMRI, functional magnetic resonance imaging; WTP, willingness to pay.

1

2

Table 1
 Overview of studies included for the meta-analysis.

Article	Subjects(male)	Mean age	Methodology	Stimuli	Contrast included	Space	soft
Chib et al. (2009) S1	19(15M)	23	fMRI	Money/food/trinkets	Brain regions encode the WTP	MNI	SPM8
Chib et al. (2009) S2	13(11M)	NA	fMRI	snacks	Activations for bid choices	MNI	SPM8
Contreras-Rodriguez et al. (2020)	75(NA)	25-40	fMRI	Foods	Functional > standard food trials	MNI	SPM
Enax et al. (2015a)	33(NA)	NA	fMRI	Food products	Correlation with WTP	MNI	SPM8
Enax et al. (2015b)	25(11M)	23.3	fMRI	Food products	Correlates of WTP	MNI	SPM8
Gospic et al. (2014)	38(NA)	NA	fMRI	Charity picture	proposals > non-proposals	MNI	SPM8
Grueschow et al. (2015)	26(13M)	20-28	fMRI	DVD	Correlation with purchasing decisions	MNI	SPM8
Hare et al. (2010)	22(0M)	24.7	fMRI	Charitable organizations	Correlated with donation during free trials	MNI	SPM5
Hare et al. (2008)	16(9M)	24.1	fMRI	Foods	Activity in th goal values	MNI	SPM5
Plassmann et al. (2007)	19(16M)	25.45	fMRI	Foods	Correlates of WTP in free trials	MNI	SPM5
Plassmann et al. (2010) S1	19(15M)	23.7	fMRI	Neutral and aversive foods	Free bid > force-bid trials	MNI	SPM5

Plassmann et al. (2010) S2	20(15M)	23-25	fMRI	Aversive and appetitive foods	Correlation with free-bid trials	MNI	SPM5
Lawn et al. (2020)	38(29M)	NA	fMRI	Cigarettes	Purchase vs Not Purchase	MNI	SPM12
Linder et al. (2010)	30(15M)	26.03	fMRI	Foods	Correlated with WTP	MNI	SPM5
Mackey et al. (2016)	19(9M)	31.5	fMRI	Aversive and appetitive foods	WTP task-related regions	MNI	AFNI
De Martino et al. (2009)	18(10M)	NA	fMRI	Lottery tickets	Correlated with WTP	MNI	SPM2
Medic et al. (2014)	47(23M)	23.8	fMRI	Snack items	Correlated with subjective value	MNI	SPM8
Motoki et al. (2019)	27(21M)	20.37	fMRI	Book	WTP during the purchasing task	MNI	SPM8
Rihm et al. (2019)	32(32M)	26.13	fMRI	Snack foods and trinket	Brain regions activation for all goods	MNI	SPM12
Tang et al. (2014)	29(NA)	NA	fMRI	Food	Correlated with participants bid	MNI	SPM8
Verdejo-Román. et al. (2017)	76(NA)	NA	fMRI	Food	Activations during WTP	MNI	SPM8
Waskow et al. (2016)	25(13)	35.08	fMRI	Music album	Correlated with the prices paid	MNI	SPM8
Weber et al. (2007)	16(10M)	24.85	fMRI	MP3 songs	Buying > Selling	MNI	SPM2
Huijsmans et al. (2019)	47(20M)	23.5	fMRI	Supermarket products	Abundance > scarcity	MNI	SPM12
Winston et al. (2014)	21(8M)	24.0	fMRI	Pain shocks	Correlation with bids	MNI	SPM8

Zangemeister et al. (2019)	22(NA)	NA	fMRI	Flavored liquid	Correlated with WTP	MNI	SPM8
Kang et al. (2011)	24(24M)	20.9	fMRI	Consumer products	Correlate with stimulus value	MNI	SPM5

Note: S1=study1; S2=study2; NA=Not available; fMRI=Functional magnetic resonance imaging; WTP= willingness to pay; MNI=Montreal Neurological Institute.

2.2. Activation likelihood estimation (ALE) method

2.2.1. Activation likelihood estimation analyses

We performed the activation likelihood estimation (ALE) algorithm for coordinate-based meta-analysis (Eickhoff et al., 2009; Laird, Eickhoff, et al., 2009; Laird, Lancaster, & Fox, 2009; Turkeltaub, Eden, Jones, & Zeffiro, 2002), which aims to identify converging areas of reported coordinates across different experiments, empirically determining whether this clustering is higher than expected by chance (Eickhoff, Bzdok, Laird, Kurth, & Fox, 2012; Turkeltaub et al., 2012). The ALE algorithm to treat each focus reported on function neuroimaging studies as the center of a 3D Gaussian probability distribution and then calculates the maximum of each focus within an experiment, creating modeled activation maps. This ALE map is determined against the null hypothesis by using permutation tests (Eickhoff et al., 2012). For all analyses, the threshold for significance using a cluster-level family-wise error (cFWE) correction at $p < 0.05$ with a cluster defining threshold of $p < 0.001$ and 5,000 permutations (Eickhoff et al., 2012). To perform ALE meta-analysis, we used Ginger ALE v.3.0.2. (<http://www.brainmap.org/ale/>) with MNI coordinates.

2.2.2. Conjunction and contrast analyses

To test neural basis that is common or distinct to WTP for food and nonfood rewards, and measure WTP under different context (hypothetical and real measure of WTP), we further performed conjunction (i.e., WTP for food and nonfood rewards; hypothetical and real WTP) and contrast analyses based on the ALE results (i.e., WTP for food reward > WTP for nonfood reward; hypothetical WTP > real WTP).

For conjunction analysis, we implemented by using the conservative minimum statistic (Nichols, Brett, Andersson, Wager, & Poline, 2005) to identify regions consistently recruited across conditions. For the contrast analysis, we firstly conducted separate ALE analyses for each condition and computing the voxel-wise difference between the ensuring ALE maps (Eickhoff et al., 2011). Afterwards, all experiments were pooled and randomly divided into two groups of same size as that in the two original sets of experiments, reflecting the contrasted ALE analyses (Langner, Leiberg, Hoffstaedter, & Eickhoff, 2018). The ALE scores of these two randomly assembled groups were calculated, and the difference between these ALE scores were recorded for each voxel of the brain. Repeating this process 25,000 times then yielded the null-distribution of differences in ALE values between the two conditions. The true difference in the ALE values was then tested against this voxel-wise null-distribution of label-exchangeability, and threshold at a probability of $p > 95\%$ for true differences.

2.2.3. Data visualization

We used probabilistic cytoarchitectonic maps of human brain to label our resulting coordinates to anatomical structures, as implemented in SPM Anatomy Toolbox v.3 (Eickhoff, Heim, Zilles, & Amunts, 2006; Eickhoff et al., 2007; Eickhoff et al., 2005). For visualization purposes, BrainNet Viewer (Xia, Wang, & He, 2013) was implemented.

3. Results

3.1 WTP for food and nonfood ALE meta-analyses

3.1.1 WTP for food

The results of ALE meta-analysis of WTP for food are presented in Table 2 and displayed visually in Fig.2A. The ALE analysis revealed that the regions with significant activity in WTP for food were the paracingulate gyrus, cingulate gyrus, frontal medial cortex, frontal orbital cortex, insular cortex, frontal pole, frontal operculum cortex and inferior frontal gyrus.

Table 2

ALE meta-analyses result of WTP for food and nonfood.

Cluster no	Macroanatomical location	MNI coordinate			Z score	Volume(mm^3)
		x	y	z		
WTP for food						
1	Paracingulate Gyrus/Cingulate Gyrus	-2	42	-6	6.43	2952
	Cingulate Gyrus	2	36	4	3.67	
	Frontal Medial Cortex/Subcallosal Cortex	-4	32	-18	3.48	
2	Frontal Orbital Cortex/Frontal Pole	30	28	-10	5.12	1760
	Insular Cortex/Frontal Orbital Cortex	30	22	-6	4.70	
3	Insular Cortex/Frontal Operculum Cortex	-36	22	0	4.27	1192
	Insular Cortex/ Frontal Orbital Cortex	-34	14	-10	3.90	
4	Frontal Pole/Inferior Frontal Gyrus	44	42	12	6.28	1056
WTP for nonfood						
1	Paracingulate Gyrus/Cingulate Gyrus	-2	42	-6	6.29	2560
	Frontal Medial Cortex/Frontal Pole	-6	50	-14	3.63	
	Frontal Pole/ Frontal Medial Cortex	-4	56	-8	3.51	

Note: MNI=Montreal Neurological Institute. All peaks were assigned to the most probable brain area by using the SPM Anatomy toolbox V3.

Fig.2. ALE results of WTP for food (A) and nonfood(B).

2.1.2 WTP for nonfood

Results from ALE meta-analysis suggested that the regions with significant convergence activity in WTP for nonfood were the paracingulate gyrus, cingulate gyrus, frontal medial cortex, frontal pole, and frontal medial cortex (Table 2 and Figure 2B).

2.1.3 Conjunction and contrast analyses of food and nonfood WTP

The results of conjunction and contrast with food and nonfood WTP are presented in Table 3 and displayed visually in Fig.3. The conjunction analysis revealed that a common area was activated in the paracingulate gyrus and cingulate gyrus for both food and nonfood WTP (Fig.3A). The contrast analysis revealed that the frontal medial cortex and paracingulate gyrus were stronger activity in nonfood WTP (Fig.3B). However, the contrast analysis showed that no clusters was found for food WTP than nonfood WTP.

1 **Table3**

2 Contrast and conjunction analyses of food and nonfood WTP.

Cluster no	Macroanatomical location	MNI coordinate			Z score	Volume(mm^3)
		x	y	z		
Food WTP ∩ nonfood WTP						
1	Paracingulate Gyrus/ Cingulate Gyrus	-2	42	-6		1824
WTP for Food >nonfood						
No clusters found						
Nonfood WTP >Food WTP						
1	Frontal Medial Cortex/ Paracingulate Gyrus	-6	50	-16	2.61	208

3 *Note*: MNI=Montreal Neurological Institute. All peaks were assigned to the most probable brain area by using the

4 SPM Anatomy toolbox V3.

5

6 **Fig.3.** Results of the ALE conjunction (A) and contrast (B) analyses of food and

7 nonfood WTP.

2.2 Real and hypothetical WTP choice ALE meta-analyses

2.2.1 Real WTP choice

The regions with significant activations in real WTP choice are shown in Table 4 and Fig 4 A. Significant cross-study convergence activity during real WTP choice were observed in the bilateral cingulate gyrus, paracingulate gyrus, frontal pole, inferior frontal gyrus, insular cortex, frontal operculum cortex and frontal orbital cortex.

Table4

ALE meta-analyses result of real WTP and hypothetical WTP choice.

Cluster no	Macroanatomical location	MNI coordinate			Z score	Volume(mm^3)
		x	y	z		
Real WTP choice						
1	Paracingulate Gyrus/Cingulate Gyrus	-4	40	-6	6.83	3760
	Cingulate Gyrus	2	36	4	3.84	
2	Frontal Pole/Inferior Frontal Gyrus	44	42	12	6.37	1096
3	Frontal Orbital Cortex/Insular Cortex	28	26	-8	4.21	1016
4	Insular Cortex / Frontal Operculum Cortex	-36	22	0	4.33	936
	Insular Cortex/ Frontal Orbital Cortex	-30	14	-8	3.59	
Hypothetical WTP choice						
1	Left Caudate/Left Accumbens	-6	4	-2	5.13	528
2	Angular Gyrus/Supramarginal Gyrus	62	-46	26	4.60	496

Note : MNI=Montreal Neurological Institute. All peaks were assigned to the most probable brain area by using the SPM Anatomy toolbox V3.

Fig.4. ALE results of real WTP (A) and hypothetical WTP choice (B).

2.2.2 Hypothetical WTP choice

The regions with significant activations in hypothetical WTP choice are shown in Table 4 and Fig. 4B. The brain areas of significant cross-study activity were observed in the left caudate, left accumbens, angular gyrus (AG) and supramarginal gyrus (SMG), both AG and SMG are subregions of inferior parietal lobule (IPL) and overlap with temporoparietal junction (TPJ).

2.2.3 Conjunction and contrast analyses of real and hypothetical WTP choices

The results of contrast and conjunction of real and hypothetical WTP choices are illustrated in Table 5 and Fig.5. The results of conjunction analysis showed that no clusters found. The contrast analysis revealed that the left caudate, left thalamus, angular gyrus, and supermarginal gyrus (subregions of IPL) were stronger activity in hypothetical WTP choice (Fig.5). However, the contrast analysis showed that no cluster found for real WTP than hypothetical WTP.

Table5

Contrast and conjunction analyses of real and hypothetical WTP choice.

Cluster no	Macroanatomical location	MNI coordinate			Z score	Volume(mm^3)
		x	y	z		
Hypothetical WTP choice > Real WTP choice						
1	Left Caudate/Left Thalamus	-6	3.3	-1.5	2.18	560
2	Angular Gyrus /Supermarginal Gyrus	61	-46	26	2.12	490
Real WTP choice > Hypothetical WTP choice						
No clusters found						
hypothetical WTP choice ∩ Real WTP choice						
No clusters found						

Note : MNI=Montreal Neurological Institute. All peaks were assigned to the most probable brain area by using the SPM Anatomy toolbox V3.

Fig.5. The results of the contrast analysis between the real and hypothetical WTP choice.

4. Discussion

In the present study we investigate the neural representation of WTP, as well as the specificity and consistency of brain activity across different types of reward and WTP measurement contexts. The results indicate there is a neural circuit consisting of the paracingulate gyrus, cingulate gyrus, frontal medial cortex, frontal orbital cortex, insular cortex, frontal pole, inferior frontal gyrus and among others significant activation during WTP for food and nonfood. ALE results demonstrated that the paracingulate and cingulate gyrus link to both food and nonfood reward WTP

1 processing, reflecting a common neural representation of WTP. In contrast, the WTP
2 for nonfood were more engaged in the frontal medial cortex and paracingulate gyrus.
3 Moreover, real WTP choice engaged a neural network consisting of the paracingulate
4 gyrus, cingulate gyrus, frontal pole, inferior frontal gyrus, frontal orbital cortex, and
5 insular cortex. In addition, the hypothetical WTP choice specific responses were further
6 observed in the left caudate, left thalamus, angular gyrus and supramarginal gyrus
7 (subregions of IPL).

8 To be more specific, we first investigated the neural basis of WTP computation for
9 different rewards, and identified the common and distinct brain regions of WTP for
10 different rewards. Results showed that frontal medial cortex, frontal pole and cingulate
11 gyrus and paracingulate gyrus were associated with WTP computation for both food
12 and nonfood rewards. This result is similar to several previous studies on the neural
13 mechanisms of decision value in response to different rewards (Chib et al., 2009; Kang
14 et al., 2011; Rihm et al., 2019). These findings support the idea that a set of regions in
15 the brain process of reward computation in an indiscriminate manner. This results also
16 in line with the common currency hypothesis that frontal medial cortex encodes
17 different types of decision values. Previous studies have highlighted the role of ACC in
18 cognitive processes, including cost-benefit decision-making, motivation, and action-
19 reward (Holroyd & Yeung, 2012; Rushworth, Noonan, Boorman, Walton, & Behrens,
20 2011; Shenhav, Botvinick, & Cohen, 2013). In addition, our results revealed that
21 nonprimary reward specific activations in the frontal medial cortex and paracingulate
22 gyrus. A similar result was found in a previous neuroimaging meta-analysis of primary
23 and secondary rewards. Specially, Sescousse et al. (2013) found that anterior lateral
24 OFC was more associated with processing secondary rewards and the OFC of the
25 posterior lateral was more associated with processing primary rewards. The results of
26 the current study may also support the idea that non-primary rewards processing is in
27 the anterior lateral frontal lobe compared to primary reward. Lastly, inconsistent with
28 the two previous meta-analyses (Bartra et al., 2013; Sescousse et al., 2013), VS was not
29 found to be activated in the food and nonfood reward WTP calculations in the current
30 study. Previous study reported that VS encode prediction errors (Hare et al., 2008). One
31 possible explanation is that the absence of VS activation is due to the absence of
32 feedback from WTP decisions in the studies included in the current meta-analysis, and
33 therefore would not have included prediction errors and correct responses to WTP
34 decision outcomes.

35 We also examined the neural representations of both real and hypothetical WTP
36 choice. Our contrast analysis suggested that hypothetical WTP choice specific

1 responses in the left caudate, left thalamus, angular gyrus and supramarginal gyrus
2 (subregions of IPL). This result is consistent with multiple previous studies of WTP for
3 goods measured using hypothetical methods (Contreras-Rodriguez et al., 2020; Kang
4 et al., 2011; Verdejo-Román, Fornito, Soriano-Mas, Vilar-López, & Verdejo-García,
5 2017). Verdejo-Román et al. (2017) found that compared with plain food processing of
6 highly palatable food was associated with greater activation of supramarginal gyrus.
7 Another study by Contreras-Rodriguez et al. (2020) revealed that angular gyrus
8 increased activation during WTP for functional food compared with standard food.
9 Lastly, Kang et al. (2011) found stronger activation in processing for hypothetical than
10 real WTP choice in left caudate. This result is similar to the findings by Kang and
11 Camerer (2013), which found stronger activation in some brain regions in the
12 hypothetical WTP choice compared to the WTP real choice, such as left thalamus.
13 Therefore, we hypothesized that these regions could be reflecting the brain
14 representation of “hypothetical bias” in the WTP computation.

15 Besides, some limitations of this study need to be discussed as well. First, the
16 current study has relatively fewer foci in the hypothetical WTP choice compared to the
17 foci in the real WTP choice. Moreover, the different types of rewards in the real and
18 hypothetical WTP conditions which may also affect the robustness of the results. This
19 makes us need to be more cautious when interpreting and generalizing this result.
20 Second, the current meta-analysis classified the types of stimuli used in the included
21 studies into primary and non-primary rewards. Although these studies that have used
22 food stimuli as reward, there was some heterogeneity among them. For example, some
23 studies selected rewards for appetite foods and one for aversive foods. Therefore, it is
24 uncertain whether there are different neural representations between these specific
25 stimuli.

26 Taken together, our results demonstrated that a set of brain region was correlate
27 with WTP for food and nonfood rewards computation. These results confirm that a
28 widespread neural circuit contributes to the WTP process. Moreover, the results
29 revealed the distinct and common neural basic on the WTP for different rewards. Lastly,
30 our results provide evidence from neural representations for the hypothetical bias.

31

32 **Reference ¹**

33 Anderson, J. C., Jain, D. C., & Chintagunta, P. K. (1992). Customer value assessment in business
34 markets: A state-of-practice study. *Journal of Business-to-Business Marketing*, 1(1), 3-29.

¹ Asterisk denotes articles included in the meta-analysis.

1 Bartra, O., McGuire, J. T., & Kable, J. W. (2013). The valuation system: a coordinate-based meta-analysis
2 of BOLD fMRI experiments examining neural correlates of subjective value. *Neuroimage*, 76, 412-
3 427.

4 Becker, G. M., DeGroot, M. H., & Marschak, J. (1964). Measuring utility by a single-response sequential
5 method. *Behavioral science*, 9(3), 226-232.

6 *Chib, V. S., Rangel, A., Shimojo, S., & O'Doherty, J. P. (2009). Evidence for a common representation
7 of decision values for dissimilar goods in human ventromedial prefrontal cortex. *Journal of*
8 *neuroscience*, 29(39), 12315-12320.

9 Clithero, J. A., Carter, R. M., & Huettel, S. A. (2009). Local pattern classification differentiates processes
10 of economic valuation. *Neuroimage*, 45(4), 1329-1338.

11 *Contreras-Rodriguez, O., Mata, F., Verdejo-Román, J., Ramírez-Bernabé, R., Moreno, D., Vilar-Lopez,
12 R., . . . Verdejo-García, A. (2020). Neural-based valuation of functional foods among lean and obese
13 individuals. *Nutrition Research*, 78, 27-35.

14 *De Martino, B., Kumaran, D., Holt, B., & Dolan, R. J. (2009). The neurobiology of reference-dependent
15 value computation. *Journal of neuroscience*, 29(12), 3833-3842.

16 Eickhoff, S. B., Bzdok, D., Laird, A. R., Kurth, F., & Fox, P. T. (2012). Activation likelihood estimation
17 meta-analysis revisited. *Neuroimage*, 59(3), 2349-2361.

18 Eickhoff, S. B., Bzdok, D., Laird, A. R., Roski, C., Caspers, S., Zilles, K., & Fox, P. T. (2011). Co-
19 activation patterns distinguish cortical modules, their connectivity and functional differentiation.
20 *Neuroimage*, 57(3), 938-949.

21 Eickhoff, S. B., Heim, S., Zilles, K., & Amunts, K. (2006). Testing anatomically specified hypotheses in
22 functional imaging using cytoarchitectonic maps. *Neuroimage*, 32(2), 570-582.

23 Eickhoff, S. B., Laird, A. R., Grefkes, C., Wang, L. E., Zilles, K., & Fox, P. T. (2009). Coordinate-based
24 activation likelihood estimation meta-analysis of neuroimaging data: A random-effects approach
25 based on empirical estimates of spatial uncertainty. *Human brain mapping*, 30(9), 2907-2926.

26 Eickhoff, S. B., Paus, T., Caspers, S., Grosbras, M.-H., Evans, A. C., Zilles, K., & Amunts, K. (2007).
27 Assignment of functional activations to probabilistic cytoarchitectonic areas revisited. *Neuroimage*,
28 36(3), 511-521.

29 Eickhoff, S. B., Stephan, K. E., Mohlberg, H., Grefkes, C., Fink, G. R., Amunts, K., & Zilles, K. (2005).
30 A new SPM toolbox for combining probabilistic cytoarchitectonic maps and functional imaging
31 data. *Neuroimage*, 25(4), 1325-1335.

32 *Enax, L., Krapp, V., Piehl, A., & Weber, B. (2015). Effects of social sustainability signaling on neural
33 valuation signals and taste-experience of food products. *Frontiers in behavioral neuroscience*, 9,
34 247.

35 *Enax, L., Hu, Y., Trautner, P., & Weber, B. (2015). Nutrition labels influence value computation of food
36 products in the ventromedial prefrontal cortex. *Obesity*, 23(4), 786-792.

1 *Gospic, K., Sundberg, M., Maeder, J., Fransson, P., Petrovic, P., Isacsson, G., ... & Ingvar, M. (2014).
2 Altruism costs—the cheap signal from amygdala. *Social cognitive and affective neuroscience*, 9(9),
3 1325-1332.

4 *Grueschow, M., Polania, R., Hare, T. A., & Ruff, C. C. (2015). Automatic versus choice-dependent
5 value representations in the human brain. *Neuron*, 85(4), 874-885.

6 *Hare, T. A., O'doherty, J., Camerer, C. F., Schultz, W., & Rangel, A. (2008). Dissociating the role of the
7 orbitofrontal cortex and the striatum in the computation of goal values and prediction errors. *Journal*
8 *of neuroscience*, 28(22), 5623-5630.

9 *Hare, T. A., Camerer, C. F., Knoepfle, D. T., O'Doherty, J. P., & Rangel, A. (2010). Value computations
10 in ventral medial prefrontal cortex during charitable decision making incorporate input from regions
11 involved in social cognition. *Journal of Neuroscience*, 30(2), 583-590.

12 Holroyd, C. B., & Yeung, N. (2012). Motivation of extended behaviors by anterior cingulate cortex.
13 *Trends in cognitive sciences*, 16(2), 122-128.

14 *Huijsmans, I., Ma, I., Micheli, L., Civai, C., Stallen, M., & Sanfey, A. G. (2019). A scarcity mindset
15 alters neural processing underlying consumer decision making. *Proceedings of the National*
16 *Academy of Sciences*, 116(24), 11699-11704.

17 Kang, M. J., & Camerer, C. F. (2013). fMRI evidence of a hot-cold empathy gap in hypothetical and real
18 aversive choices. *Frontiers in neuroscience*, 7, 104.

19 *Kang, M. J., Rangel, A., Camus, M., & Camerer, C. F. (2011). Hypothetical and real choice differentially
20 activate common valuation areas. *Journal of neuroscience*, 31(2), 461-468.

21 Kennerley, S. W., Walton, M. E., Behrens, T. E., Buckley, M. J., & Rushworth, M. F. (2006). Optimal
22 decision making and the anterior cingulate cortex. *Nature neuroscience*, 9(7), 940-947.

23 Laird, A. R., Eickhoff, S. B., Kurth, F., Fox, P. M., Uecker, A. M., Turner, J. A., . . . Fox, P. T. (2009).
24 ALE meta-analysis workflows via the brainmap database: progress towards a probabilistic
25 functional brain atlas. *Frontiers in neuroinformatics*, 3, 23.

26 Laird, A. R., Lancaster, J. L., & Fox, P. T. (2009). Lost in localization? The focus is meta-analysis.
27 *Neuroimage*, 48(1), 18-20.

28 Langner, R., Leiberg, S., Hoffstaedter, F., & Eickhoff, S. B. (2018). Towards a human self-regulation
29 system: common and distinct neural signatures of emotional and behavioural control. *Neuroscience*
30 *& Biobehavioral Reviews*, 90, 400-410.

31 *Lawn, W., Mithchener, L., Freeman, T. P., Benattayallah, A., Bisby, J. A., Wall, M. B., ... & Morgan, C.
32 J. (2020). Value-based decision-making of cigarette and nondrug rewards in dependent and
33 occasional cigarette smokers: An FMRI study. *Addiction biology*, 25(4), e12802.

34 Levy, D. J., & Glimcher, P. W. (2012). The root of all value: a neural common currency for choice.
35 *Current opinion in neurobiology*, 22(6), 1027-1038.

36 *Linder, N. S., Uhl, G., Fliessbach, K., Trautner, P., Elger, C. E., & Weber, B. (2010). Organic labeling

1 influences food valuation and choice. *NeuroImage*, 53(1), 215-220.

2 *Mackey, S., Olafsson, V., Aupperle, R. L., Lu, K., Fonzo, G. A., Parnass, J., ... & Paulus, M. P. (2016).
3 Greater preference consistency during the Willingness-to-Pay task is related to higher resting state
4 connectivity between the ventromedial prefrontal cortex and the ventral striatum. *Brain imaging
5 and behavior*, 10(3), 730-738.

6 *Medic, N., Ziauddeen, H., Vestergaard, M. D., Henning, E., Schultz, W., Farooqi, I. S., & Fletcher, P.
7 C. (2014). Dopamine modulates the neural representation of subjective value of food in hungry
8 subjects. *Journal of Neuroscience*, 34(50), 16856-16864.

9 Miller, K. M., Hofstetter, R., Krohmer, H., & Zhang, Z. J. (2011). How should consumers' willingness
10 to pay be measured? An empirical comparison of state-of-the-art approaches. *Journal of marketing
11 research*, 48(1), 172-184.

12 *Motoki, K., Sugiura, M., & Kawashima, R. (2019). Common neural value representations of hedonic
13 and utilitarian products in the ventral striatum: An fMRI study. *Scientific reports*, 9(1), 1-10.

14 Nichols, T., Brett, M., Andersson, J., Wager, T., & Poline, J.-B. (2005). Valid conjunction inference with
15 the minimum statistic. *Neuroimage*, 25(3), 653-660.

16 Padoa-Schioppa, C., & Assad, J. A. (2006). Neurons in the orbitofrontal cortex encode economic value.
17 *Nature*, 441(7090), 223-226.

18 Padoa-Schioppa, C., & Conen, K. E. (2017). Orbitofrontal cortex: a neural circuit for economic decisions.
19 *Neuron*, 96(4), 736-754.

20 Peters, J., & Büchel, C. (2010). Neural representations of subjective reward value. *Behavioural brain
21 research*, 213(2), 135-141.

22 *Plassmann, H., O'doherty, J., & Rangel, A. (2007). Orbitofrontal cortex encodes willingness to pay in
23 everyday economic transactions. *Journal of neuroscience*, 27(37), 9984-9988.

24 *Plassmann, H., O'Doherty, J. P., & Rangel, A. (2010). Appetitive and aversive goal values are encoded
25 in the medial orbitofrontal cortex at the time of decision making. *Journal of neuroscience*, 30(32),
26 10799-10808.

27 *Rihm, J. S., Menz, M. M., Schultz, H., Bruder, L., Schilbach, L., Schmid, S. M., & Peters, J. (2019).
28 Sleep deprivation selectively upregulates an amygdala-hypothalamic circuit involved in food
29 reward. *Journal of neuroscience*, 39(5), 888-899.

30 Rushworth, M. F., Noonan, M. P., Boorman, E. D., Walton, M. E., & Behrens, T. E. (2011). Frontal cortex
31 and reward-guided learning and decision-making. *Neuron*, 70(6), 1054-1069.

32 Schmidt, J., & Bijmolt, T. H. (2020). Accurately measuring willingness to pay for consumer goods: a
33 meta-analysis of the hypothetical bias. *Journal of the Academy of Marketing Science*, 48(3), 499-
34 518.

35 Sescousse, G., Caldú, X., Segura, B., & Dreher, J.-C. (2013). Processing of primary and secondary
36 rewards: a quantitative meta-analysis and review of human functional neuroimaging studies.

1 *Neuroscience & Biobehavioral Reviews*, 37(4), 681-696.

2 Sescousse, G., Redouté, J., & Dreher, J.-C. (2010). The architecture of reward value coding in the human

3 orbitofrontal cortex. *Journal of neuroscience*, 30(39), 13095-13104.

4 Shenhav, A., Botvinick, M. M., & Cohen, J. D. (2013). The expected value of control: an integrative

5 theory of anterior cingulate cortex function. *Neuron*, 79(2), 217-240.

6 *Tang, D. W., Fellows, L. K., & Dagher, A. (2014). Behavioral and neural valuation of foods is driven

7 by implicit knowledge of caloric content. *Psychological Science*, 25(12), 2168-2176.

8 Turkeltaub, P. E., Eden, G. F., Jones, K. M., & Zeffiro, T. A. (2002). Meta-analysis of the functional

9 neuroanatomy of single-word reading: method and validation. *Neuroimage*, 16(3), 765-780.

10 Turkeltaub, P. E., Eickhoff, S. B., Laird, A. R., Fox, M., Wiener, M., & Fox, P. (2012). Minimizing within-

11 experiment and within-group effects in activation likelihood estimation meta-analyses. *Human*

12 *brain mapping*, 33(1), 1-13.

13 *Verdejo-Román, J., Fornito, A., Soriano-Mas, C., Vilar-López, R., & Verdejo-García, A. (2017).

14 Independent functional connectivity networks underpin food and monetary reward sensitivity in

15 excess weight. *Neuroimage*, 146, 293-300.

16 Wallis, J. D. (2007). Orbitofrontal cortex and its contribution to decision-making. *Annu. Rev. Neurosci.*,

17 30, 31-56.

18 *Waskow, S., Markett, S., Montag, C., Weber, B., Trautner, P., Kramarz, V., & Reuter, M. (2016). Pay

19 what you want! A pilot study on neural correlates of voluntary payments for music. *Frontiers in*

20 *psychology*, 7, 1023.

21 *Weber, B., Aholt, A., Neuhaus, C., Trautner, P., Elger, C. E., & Teichert, T. (2007). Neural evidence for

22 reference-dependence in real-market-transactions. *Neuroimage*, 35(1), 441-447.

23 Wertenbroch, K., & Skiera, B. (2002). Measuring consumers' willingness to pay at the point of purchase.

24 *Journal of marketing research*, 39(2), 228-241.

25 *Winston, J. S., Vlaev, I., Seymour, B., Chater, N., & Dolan, R. J. (2014). Relative valuation of pain in

26 human orbitofrontal cortex. *Journal of Neuroscience*, 34(44), 14526-14535.

27 Xia, M., Wang, J., & He, Y. (2013). BrainNet Viewer: a network visualization tool for human brain

28 connectomics. *PloS one*, 8(7), e68910.

29 *Zangemeister, L., Grabenhorst, F., & Schultz, W. (2019). Neural activity in human ventromedial

30 prefrontal cortex reflecting the intention to save reward. *Social cognitive and affective*

31 *neuroscience*, 14(12), 1255-1261.