RESEARCH ARTICLE

Moral contagion: Devaluation effect of immorality on hypothetical judgments of economic value

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Abstract

Moral contagion is a phenomenon in which individuals or objects take on the moral essence of the people who are associated with them. Previous studies have found that individuals value objects associated with moral and likable people more than those associated with immoral and dislikable people. However, the neural mechanisms underlying this “moral contagion effect” have not yet been explored. In the present study, we combined a novel “Second-hand Goods Pricing” paradigm with functional magnetic resonance imaging to (a) confirm the existence of the moral contagion effect on the hypothetical economic valuation of objects and (b) determine the neural substrates underlying it. Participants were shown second-hand goods, information regarding the moral valence of the previous owner, and an initial price assigned to the object by computer. The participants were then asked to adjust the initial price to one they deemed most reasonable. Behaviorally, we found a significant devaluation effect for immoral owners and a weaker reverse effect for moral owners. Imaging data showed that the devaluation effect was primarily driven by neural responses in the dorsal striatum (mainly the caudate nucleus) that were triggered by high initial prices assigned to the “contaminated” objects. Dynamic causal modeling revealed that the high initial price assigned to “contaminated” objects led to increased effective connectivity from the caudate nucleus to the ventromedial prefrontal cortex—the brain area that integrates values during decision making.

KEYWORDS

caudate nucleus, economic valuation, fMRI, moral contagion, ventromedial prefrontal cortex

1 | INTRODUCTION

Moral contagion is a phenomenon in which people and objects become imbued with the moral essence of the people associated with them (Tapp & Ochipinti, 2016). People believe that these essences can be transferred to objects or other individuals through physical contact, previous ownership, or other forms of association (Huang, Ackerman, & Newman, 2017; Stavrova, Newman, Kulemann, & Fetchenhauer, 2016). Morality is one of the most influencing social factors in daily decision-making (Miller & Cushman, 2016; Shenhav & Greene, 2010). A recent study in which participants could trade money against pain experienced by either themselves or an anonymous other found that most people required more money to harm others compared with harming themselves (Crockett, Siegel, Kurth-Nelson, Dayan, & Dolan, 2017), suggesting immoral actions (i.e., harming

others) can devalue money when making decisions. This result highlighted the effect of morality on social economic decision-making.

Previous studies have found “moral contagion” affect individuals’ decisions in multiple contexts (e.g., purchase decisions; auction of celerity belongings; choice of organ transplant donors) such that individuals valued objects more if they were associated with respectable people and less if they were associated with immoral people (Hood, Itajkura, Gjersoe, Byers, & Donnelly, 2011; Kramer & Lock, 2011; Newman & Bloom, 2014). The literature suggests that the economic valuation of an object can be influenced by the moral character (good or bad) of those who are associated with it. However, although the “moral contagion” phenomenon has been well established in behavioral studies, its underlying neural mechanisms have not yet been fully explored.

In the present study, we designed a “Second-hand Goods Pricing” task and systematically manipulated the moral valence of the previous

owner as “Moral” or “Immoral” and the object's initially assigned price as “High” or “Low.” The participants were instructed to adjust the initial price to a final selling price that they believed most reasonable. Rather than asking participants to directly price the objects, we asked them to adjust the price to reduce the priming effect of moral information and to increase the implicitness of the task. Combining both behavioral and neuroimaging analysis, we explored how the moral contagion affected the hypothetical judgment of economic values of objects in the given context.

The ventromedial prefrontal cortex (vmPFC)/medial orbitofrontal cortex plays a crucial role in both economic and moral decision-making (Hare, Camerer, & Rangel, 2009; Rolls, McCabe, & Redoute, 2008). This region has been suggested to reflect values throughout the whole decision process (Hunt et al., 2012) and to encode many relevant factors that are used to generate integrative value during decision-making (Kaanders & Hunt, 2018). For instance, an imaging study found that vmPFC was responsible for receiving inputs from regions involved in social cognition such as the anterior insula and posterior superior temporal cortex during charitable decision-making (Hare, Camerer, Knoepfle, & Rangel, 2010). Besides, integrative moral values are also represented in this region (Brosch, Coppin, Schwartz, & Sander, 2012; Shenhav & Greene, 2014).

Another critical region in the current task likely to be critical is the dorsal striatum, which has been implicated in responses to aversive or unexpected stimuli (Carretie et al., 2009; Fouragnan, Retzler, & Philastides, 2018). Studies have found that striatal neurons are sensitive to the expected “moral value” in moral judgment tasks (Decety & Porges, 2011; Shenhav & Greene, 2010; Yoder & Decety, 2014). In particular, the caudate nucleus was found to be activated in when making multiple types of moral decisions (Fumagalli & Priori, 2012), including charitable donation (Harbaugh, Mayr, & Burghart, 2007) and altruistic punishment (de Quervain et al., 2004). In an Implicit Association Test of morality, Luo et al. (2006) found that moral incongruency triggered stronger caudate nucleus activation than moral congruency. In addition, psychopathy was reported to be associated with lower than normal activity in the caudate nucleus when viewing harmful versus helpful social interactions and making implicit moral evaluations (Yoder, Harenski, Kiehl, & Decety, 2015). These findings suggest that the caudate nucleus might be sensitive to moral incongruencies such as high prices assigned to objects “contaminated” by immoral people or low prices assigned to objects “elevated” by moral people.

Based on the existing literature, we hypothesized that high initial prices assigned to objects associated with immoral people and low initial prices assigned to objects associated with moral people would violate the object's expected value that results from the moral contagion effect. At the behavioral level, this should induce larger adjustments to the initial price, and at the neuronal level, we hypothesized that the dorsal striatum would be sensitive to unexpected stimuli and moral incongruencies. In addition, the vmPFC would also be sensitive to them, and its integration of multiple factors to reflect dynamic values during decision-making would be crucial in producing the overt bias.

2 | MATERIALS AND METHODS

2.1 | Participants

Twenty-eight right-handed participants recruited from Shenzhen University participated in the functional magnetic resonance imaging (fMRI) experiment. Participants were screened for a history of neurological disorders, brain injury, and developmental disabilities. All had a normal or corrected-to-normal vision. Four participants who had excessive head movements $>2^\circ$ in the rotation or >2 mm in translation during the scanning were excluded, leaving 24 participants for data analysis (13 females, age: 22.7 ± 2.8 years). The sample size was sufficient for a within-participant-designed fMRI study (Friston, 2012). The study was conducted according to the ethical guidelines and principles of the Declaration of Helsinki and was approved by the Medical Ethical Committee of Shenzhen University Medical School. Informed consent was obtained from all participants after they fully understood the procedures.

2.2 | Materials

Before the fMRI experiment, we sent two lists to 20 participants (healthy adults from the local universities, 10 females, age: 22.7 ± 2.1 years, who would not participate in the later fMRI experiment). The first list included 100 daily objects (e.g., folder, screwdriver, pen) comprising each object's name (in Chinese) and a photo of the object. They were instructed to rate the familiarity of the objects on a 5-point Likert scale (from “not familiar at all” to “very familiar”) and to choose a suitable price range for each object (0–20, 20–40, 40–60, 60–80, or 80–100 RMB, 1 US dollar $\approx$ 6.8 RMB). Objects used in the fMRI experiment were selected based on ratings from this pretest: (a) average familiarity scores ≥ 3 to exclude unfamiliar objects; (b) comparable pricing from male and female participants for the given objects to exclude gender-sensitive objects. Sixty objects were selected for the subsequent fMRI experiment. The familiarity rating was 4.08 ± 0.42 , and the pricing range was 2.12 ± 0.68 (mean $\pm$ s.d.).

The second list included 50 “moral” and 50 “immoral” characteristics (e.g., “Exam cheater” or “Blood donor”). For each character, participants were instructed to rate the familiarity on a 5-point scale and their perceived moral valence on a 9-point scale (1: very immoral; 5: not moral or immoral; 9: very moral). After rejecting any unfamiliar characteristics (average familiarity score < 3), 30 moral characteristics and 30 immoral characters were selected for the subsequent fMRI experiment. The moral ratings were 7.24 ± 0.38 for the moral characters and 1.93 ± 0.38 for the immoral characters (mean $\pm$ s.d., $p < 0.001$) (see Supplementary Information S1).

2.3 | Design and procedures

The fMRI experiment had a 2 (moral valence of the previous owner: moral vs. immoral) $\times$ 2 (initial price: high vs. low) within-participant design. Four conditions were generated accordingly: moral character's object with high initial price (M_Hp), moral character's object with low initial price (M_Lp), immoral character's object with high initial price (IM_Hp), and immoral character's object with low initial price (IM_Lp).

Participants were informed that they would play a “Second-hand Goods Pricing” game. They were shown information about the previous owner of the object (the information would concern their moral characteristics) and an initial price randomly assigned by a computer. Their task was to adjust the initial price to a price that they felt was suitable for sale at a second-hand store. They were encouraged to offer the price that they believed was the most reasonable.

Although we told the participants that the initial price was randomly assigned by a computer, this was a cover story. In fact, the initial prices were calculated intentionally. One week before a participant's scanning day, s/he was sent a list of 60 objects and was instructed to choose a price range that they believed was suitable for each object. These prices were used as subject-specific baselines in the fMRI experiment. “High” initial prices were calculated as 125% of the baseline prices, and “Low” initial prices were calculated as 75% of the baseline prices (e.g., a chosen range of 60–80 RMB for an object the week before yielded a baseline price of ¥70, a high initial price of ¥87.5, and a low initial price of ¥52.5).

Each trial began by presenting the moral valence of the previous owner with a photograph of the object lasting for 3 s. The initial price was then shown for 2 s. After a 4–6 s fixation, the participants were asked to choose the most suitable price from five horizontally presented options ranging from 60 to 140% of the individual specific baseline price with a step of 20% (Figure 1). The order of the five options was either increase or decrease randomized trial by trial. To avoid any priming effect, the starting position of the cursor was pseudo-randomized such that it appeared equally on each option within the scale.

FIGURE 1 Experimental procedure and sample trials. At the beginning of each trial, a photograph of the object and its previous owner presented for 3 s. Then, the initial price presented for 2 s. After a 4–6 s wait, the participant had 4 s to give a suitable final price. In the example, before the experiment, the participant chooses “20–40 RMB” range for the umbrella; therefore, the baseline price is calculated as 30 RMB. In the Hp conditions, the initial price was 30 (the baseline) $\times$ 125% = 37.5 RMB. In the pricing stage, the five options available would be 18 (30 $\times$ 60%), 24 (30 $\times$ 80%), 30 (baseline), 36 (30 $\times$ 120%), and 42 (30 $\times$ 140%)

To make their choices, participants first moved the cursor left or right by pressing one of two preassigned buttons on an MRI-compatible button-box, then they pressed the third button to confirm their choice. The experiment consisted of five runs of 24 trials and lasted approximately 40 min. Trials in each run were pseudorandomized such that each condition was presented six times. Thus, overall, there were 120 trials, 30 for each experimental condition. Before the scanning, participants were familiarized with the task using a practice block consisting of 12 trials. During the recruiting process, the participants were asked to fill out the Chinese version of the Moral Sensitivity Questionnaire (MSQ) (Huang et al., 2016).

2.4 | Behavioral data analysis

We hypothesized that the initial price would modulate the final price through an “anchoring effect” such that high initial prices would push the price higher, whereas low initial prices would make them lower. The effect of owner morality would be such that prices would increase from baseline for moral owners and decrease from baseline for immoral owners. Previous studies suggested that perceiving moral violations often evokes negative emotional responses (Russell & Giner-Sorolla, 2013), whereas observing others behaving morally triggers positive emotions (Haidt, 2003). Furthermore, behavioral studies regarding the contagion effect have highlighted the differences between positive and negative contagions (Huang et al., 2017; Stavrova et al., 2016). Therefore, it is unlikely that moral and immoral information modulates the valuation process via the same mechanisms. Accordingly, we tried to find a behavioral index that (a) only represents the effect of morality but not the initial price because we are not interested in the effect of initial price and (b) can separately indicate the effect of moral and immoral information.

Among the three behavioral indexes: final price, the change in price (ΔY = final price – initial price) and the absolute value of the change in price ($|\Delta Y|$ = |final price – initial price|), only the $|\Delta Y|$ can exclude the effect of initial price and separately index the effect of moral and immoral information. Therefore, we used $|\Delta Y|$ as the behavioral index to indicate the effect of moral contagion on the hypothetical valuation of objects. Specifically, both of the effects of moral and immoral contagion can be illustrated as the difference in the $|\Delta Y|$ s between the Hp and Lp conditions. Larger differences indicate larger modulating effects (see Supplementary Information S2).

We then performed 2×2 repeated-measures analysis of variances (ANOVAs) on the final price, ΔY , and $|\Delta Y|$ to examine the effect of both independent variables, respectively. To explore how the above effects related to individual differences in moral sensitivity, we ran a correlation analysis between participant MSQ scores and their $|\Delta Y|$ for moral and immoral conditions.

2.5 | Neuroimaging data acquisition and analysis

2.5.1 | fMRI data acquisition and preprocessing

We used a Siemens TrioTim 3.0T MRI machine for data acquisition. Functional volumes were acquired using a multiple slice T2-weighted echo planar imaging (EPI) sequences with the following parameters: repetition time = 2000 ms; echo time = 25 ms; flip angle = 90°; field

of view = 192 mm; 41 slices covering the entire brain, slice thickness = 3 mm. Both resting-state and task-fMRI scans were performed. The resting-state scan lasted 6 min and was followed by the task scan that lasted ~40 min. During the resting-state fMRI scans, participants were asked to stay relaxed with their eyes closed and not to fall asleep.

Resting-state fMRI data were preprocessed using the DPARSF toolbox (Chao-Gan & Yu-Feng, 2010). The first 10 volumes of functional images were discarded. Next, images were slice-time corrected, motion corrected, and normalized to Montreal Neurological Institute (MNI) space for each individual with a spatial resolution of $3 \times 3 \times 3 \text{ mm}^3$. Images were then smoothed using an isotropic 4-mm Gaussian kernel. The smoothed images were used for the subsequent stochastic dynamic causal modeling (DCM) analysis.

Task fMRI data were preprocessed in SPM12 (Wellcome Department of Imaging Neurosciences, University College London, U.K., <http://www.fil.ion.ucl.ac.uk/spm>). Images were slice-time corrected, motion corrected, and normalized to MNI space for each individual with a spatial resolution of $3 \times 3 \times 3 \text{ mm}^3$. Images were then smoothed using an isotropic 4-mm Gaussian kernel and high-pass filtered at a cutoff of 128 s. The significance level was set to uncorrected $p < 0.001$, with a contiguous-voxel extent threshold $k > 10$ for subsequent whole-brain analysis. Clusters that survived the cluster-level family-wise error correction at $p < 0.05$ were marked with “*” (see tables).

2.5.2 | Whole-brain activation analysis

At the beginning of the fMRI data analysis, we first used the whole-brain activation analysis to test our hypothesis. Statistical parametric maps were generated on a voxel-by-voxel basis with a hemodynamic model to estimate the brain response. The owner's moral valence, the initial price, and final price choice were included in the general linear model (GLM) at the single-participant level. The six rigid body parameters were also included in the GLM to exclude head-motion nuisance. GLM1 was set up to explore the neural response to the presentation of the moral characteristics of the previous owner. The effect of the experimental conditions on the regional BOLD responses was estimated with GLM2 according to the first presentation of the initial price with all conditions (M_Hp, M_Lp, IM_Hp, and IM_Lp) as independent regressors. Further analysis of brain activation was based on these regressors. Single-participant *t*-contrasts were computed for the four conditions. For GLM1, we defined effect as the owner's moral character as the contrast (M_Hp + M_Lp) versus (IM_Hp + IM_Lp). For GLM2, we defined the main effect of moral valence as the contrast (M_Hp + M_Lp) versus (IM_Hp + IM_Lp), the main effect of initial price as the contrast (M_Hp + IM_Hp) versus (M_Lp + IM_Lp), and defined the interaction effect between moral valence and initial price as the contrast (IM_Hp + M_Lp) versus (M_Hp + IM_Lp). We then decomposed the interaction into two simple contrasts: M_Lp > M_Hp and IM_Hp > IM_Lp to elaborate on the pattern of interaction. For the group-level analysis, a one-sample *t*-test was conducted using the whole brain as the volume of interest.

2.5.3 | Region of interest analysis

To further explore the intensity of neural activation under different experimental conditions, we ran an additional region of interest (ROI) analysis. Based on the hypothesis that dorsal striatum might be sensitive to moral incongruencies, we chose to explore activation differences between conditions within the anatomically defined dorsal striatum. For each participant and for each condition, we calculated mean parameter-estimates within the anatomical subregion mask for the dorsal striatum (bilateral putamen and bilateral caudate based on the human Brainnetome Atlas; (Fan et al., 2016)). We then performed a 2×2 repeated-measure ANOVA on the extracted values to determine the effects of the two experimental factors.

2.5.4 | Correlation analysis

To identify the brain activity related to the behavioral index ($|\Delta Y|$), we performed a correlation analysis between each participant's $|\Delta Y|$ and their *t*-contrast maps for each experimental condition. Specifically, the correlation analysis for immoral conditions included 48 observations (24 participants' data $\times$ 2 conditions [IM_Hp and IM_Lp]) for each variable.

2.5.5 | Effective connectivity analysis: Dynamic casual modeling

We used DCM (Friston, Harrison, & Penny, 2003) to investigate how the brain regions sensitive to the congruency between initial price and moral value (i.e., right caudate and left putamen, see Results) and the regions correlating with the value adjustment (i.e., the vmPFC, see Results) interact with each other to generate the overt behavioral bias. We hypothesized that in the condition with larger price adjustment (IM_Hp), the dorsal striatum would have stronger functional connectivity to the vmPFC than in the condition with smaller value adjustment (IM_Lp). Accordingly, effective connectivity among the right caudate nucleus, the left putamen, and the vmPFC nodes were examined. Stochastic DCM for resting-state fMRI was first applied to the resting-state data to explore the intrinsic connections among the three nodes (Daunizeau, Stephan, & Friston, 2012).

2.6 | Stochastic DCM for resting-state fMRI data

The intrinsic connectivities among the right caudate nucleus, the left putamen, and the vmPFC nodes were explored using stochastic DCM for resting-state fMRI data, which is implemented in DCM12 (Daunizeau et al., 2012). Stochastic DCM allows inverting models with uncertainty about the temporal specification of inputs which can represent intrinsic fluctuations, thus it is particularly useful for model inversion of resting-state data (Stephan et al., 2010). We first setup a GLM with the smoothed resting-state data, which included the signal extracted from the cerebrospinal fluid, the white matter, as well as head motion parameters including the six rigid body parameters and the volume-based frame-wise displacement as regressors to exclude the impact of nuisance variables (Power, Barnes, Snyder, Schlaggar, & Petersen, 2012). Next, for each participant, the principal eigenvariate for the volume of interest (the first principal component of the local multivariate time series over all voxels in the volume of interest) was

defined as the seed of the models (radius = 8 mm). A data-driven method was adapted to discover all possible models. A full reciprocally connected model was constructed between each pair of nodes for each participant. Generalized filtering was then used for model inversion and parameter estimation (Li et al., 2011). A Bayesian network discovery scheme was applied to search for the best model in model space (Friston, Li, Daunizeau, & Stephan, 2011). The model with the highest evidence was chosen as the winning model.

2.7 | DCM for task fMRI

We used DCM12 to examine the effective connectivity among the caudate nucleus, the putamen, and the vmPFC during the task (Friston et al., 2003). The first eigenvariate for the single-participant time courses was extracted from volumes located in the caudate nucleus, the putamen, and the vmPFC, using a sphere with an 8-mm radius that was centered at individual maxima and adjusted for the effects of interest. The ROI time series were extracted from within the whole-brain activation for the IM_Hp and IM_Lp conditions. According to the winning model obtained by resting-state stochastic DCM, we defined the endogenous connection among the three nodes as fully reciprocally connected with each other (see Results). Our model space consisted of seven families, which were differentiated by where the driving input entered (the caudate nucleus, the putamen, the vmPFC, any two nodes, or all three nodes; see Figure 5a). As the modulation effect of our experimental condition (i.e., IM_Hp and IM_Lp conditions) was assumed to work on the interaction between the moral processing system and the economic valuation system, we excluded the possibility that the interconnection between the caudate nucleus and the putamen could be modulated by either of our experimental conditions. Thus we included all combinations of possible modulations between the caudate nucleus and the vmPFC, between the putamen and the vmPFC, or between both the caudate and putamen and the vmPFC, which added up to 13 models in each family (See Figure 6a; the modulation effect on unidirectional connections: vmPFC → putamen/putamen → vmPFC/vmPFC → caudate nucleus/caudate nucleus → vmPFC; the modulation effect on bidirectional connections: vmPFC ↔ putamen/vmPFC ↔ caudate nucleus/both vmPFC ↔ caudate nucleus and vmPFC ↔ putamen; the modulation effect on the vmPFC ↔ putamen bidirectional connections and the vmPFC → caudate nucleus/caudate nucleus → vmPFC unidirectional connections; the modulation effect on the vmPFC ↔ caudate nucleus bidirectional connections and the vmPFC → putamen/putamen → vmPFC unidirectional connections; the modulation effect on the putamen → vmPFC unidirectional connection and vmPFC → caudate nucleus/caudate nucleus → vmPFC/vmPFC → putamen unidirectional connections). We specified all 91 models separately for each run and each participant. We then estimated all models and subjected them to random-effect Bayesian Model Selection (BMS) to select the best-fitted family from our model space based on the model evidence (Stephan et al., 2010). Bayesian model averaging (BMA) was then used to calculate weighted-model parameters for the winning family.

3 | RESULTS

3.1 | Behavioral results

First, to investigate how the moral valence of the previous owner and the initial price modulated the final price, we performed a 2×2 repeated-measure ANOVA on the final price. The main effect of moral valence ($F_{(1,23)} = 21.87$, $p < 0.001$, $\eta_p^2 = 0.49$), initial price ($F_{(1,23)} = 12.63$, $p = 0.002$, $\eta_p^2 = 0.36$) were significant. When the previous owner was moral, the participants assigned a higher price than when the previous owner was immoral. Meanwhile, when the initial price was high, participants valued the object higher than when the initial price was low (M_Hp: 26.93 ± 2.90 ; M_Lp: 24.79 ± 2.57 ; IM_Hp: 18.92 ± 2.10 ; IM_Lp: 17.81 ± 1.89) (Figure 2a).

Second, to explore how the two factors influenced the adjustment of the price, we calculated the difference between the initial and final price ($\Delta Y = \text{final price} - \text{initial price}$) and run four paired *t*-test between the ΔY in each condition and the baseline of 0. We found that when the initial price was high, ΔY was significantly smaller than 0 (M_Hp: -11.60 ± 1.37 ; IM_Hp: -19.61 ± 2.34 ; $p < 0.001$), whereas when the initial price was low, ΔY was significantly larger than 0 (M_Lp: 14.79 ± 2.11 ; IM_Lp: 7.82 ± 1.34 ; $p < 0.001$). We can then conclude that the direction of the adjustment was determined by the initial price (Figure 2b).

When participants perceived the previous owner as moral, they tended to retain initially high prices and increase initially low prices ($|\Delta Y|_{\text{M_Hp}} < |\Delta Y|_{\text{M_Lp}}$). In contrast, when the previous owner was immoral/unethical, they tended to retain initially low prices and reduce the initial high price ($|\Delta Y|_{\text{IM_Hp}} > |\Delta Y|_{\text{IM_Lp}}$). Therefore, the effects of moral valence on price adjustment involved the size of the difference between $|\Delta Y|$ in Hp and Lp conditions. Greater disparities indicate a stronger impact of moral valence on economic valuation.

We then performed a 2×2 repeated-measures ANOVA on $|\Delta Y|$ and found significant main effects of moral valence ($F_{(1,23)} = 8.43$, $p = 0.008$, $\eta_p^2 = 0.27$), initial price ($F_{(1,23)} = 14.17$, $p = 0.001$, $\eta_p^2 = 0.38$), as well as a significant interaction ($F_{(1,23)} = 21.86$, $p < 0.001$, $\eta_p^2 = 0.49$). Pair-wise comparisons revealed that when the previous owner was moral, $|\Delta Y|$ was comparable for high and low initial prices (M_Hp = 9.32 ± 1.27 , M_Lp = 12.51 ± 2.22 , $p = 0.09$), but when the previous owner was immoral, participants adjusted the initial price significantly more when it was high than when it was low (IM_Hp = 17.33 ± 2.31 , IM_Lp = 5.54 ± 1.49 , $p < 0.001$; Figure 2c).

Furthermore, we found that $|\Delta Y|$ in moral conditions was significantly correlated with scores on the "Frequency of perception" subset of the MSQ ($r = -0.59$, $p = 0.003$), indicating that participants with keener moral sensitivity exhibited stronger effects of morality (Figure 2d). However, no significant correlation was found for the immoral/unethical conditions.

3.2 | Whole-brain activation analysis

For GLM1, it revealed no brain activation above threshold (uncorrected $p < 0.001$, $k > 10$) for the difference between the moral and immoral character (calculated as M_Hp + M_Lp > IM_Hp + IM_Lp and the reverse contrast). For GLM2, the interaction between moral

FIGURE 2 Behavioral results (a) the final price assigned in each condition; (b) price adjustment (ΔY = final price – initial price) for each condition. (c) Price adjustment ($|\Delta Y|$ = |final price – initial price| – $|\Delta Y|$ in baseline) for each condition (d) the $|\Delta Y|$ in the contrasts of (M_Lp-M_Hp) and (IM_Hp-IM_Lp) correlates with the scores of “Frequency of Perception” (FoP) in the moral sensitivity questionnaire (MSQ) [Color figure can be viewed at wileyonlinelibrary.com]

valence and initial price (calculated as $IM_Hp - IM_Lp > M_Hp - M_Lp$) revealed activation in left precentral gyrus, left putamen, right angular gyrus, bilateral posterior-medial frontal gyrus, right superior and medial frontal gyri, and right caudate nucleus (Figure 3a, Table 1). We found weak brain activation in the right middle temporal gyrus in the main effect of moral valence (contrast: $M_Hp + M_Lp > IM_Hp + IM_Lp$). The reverse contrast (contrast: $IM_Hp + IM_Lp > M_Hp + M_Lp$) revealed no brain activation above threshold (uncorrected $p < 0.001$, $k > 10$), indicating no brain regions specifically related to the differences between moral/ethical and immoral/unethical owners during pricing. No differential brain activation was observed for higher or lower initial prices (contrast: $M_Hp + IM_Hp > M_Lp + IM_Lp$ and the reverse). The simple effect contrast of ($IM_Hp > IM_Lp$) revealed greater activation in the bilateral anterior cingulate cortex, left putamen, right middle frontal gyrus, left parahippocampal gyrus, and right putamen (Figure 3b, Table 1). The other simple effect contrast of ($M_Lp > M_Hp$) showed no significant brain activation. The overlap between the interaction-effect map and the simple effects map ($IM_Hp > IM_Lp$) was located in the right caudate nucleus and left

putamen (Figure 3c, Table 1). As the whole-brain analysis revealed no significant simple effect of $M_Lp > M_Hp$, combined with the behavioral results, we concluded that the interaction effect of moral valence $\times$ initial price was driven primarily by the simple effect of an immoral previous owner. Thus, in the subsequent analyses, we focused on explaining how different neural systems interact to support this effect of immoral behavior on economic valuation.

3.3 | ROI analysis

We selected four ROIs from an anatomical brain atlas (Fan et al., 2016): bilateral caudate nucleus and bilateral putamen. A 2×2 repeated-measures ANOVA was applied separately to each ROI.

We only found significant interaction in the right caudate (region 220 [MNI: 15, 14, -2] and region 228 [MNI: 14, 15, 14]) ($F_{(1,23)} = 6.39$, $p = 0.018$, $\eta_p^2 = 0.19$). Pair-wise comparisons revealed that: greater activity was observed in the IM_Hp condition than in the IM_Lp condition ($p = 0.002$), whereas the difference between M_Hp and M_Lp were not significant ($p = 0.834$). Notice that the Bonferroni corrected threshold was $p < 0.0125$, therefore, the presented result

FIGURE 3 Whole-brain activation results (a) the whole-brain interaction contrast ($IM_Hp - IM_Lp > M_Hp - M_Lp$); (b) the contrast of $IM_Hp > IM_Lp$; (c) overlap of the interaction and contrast between IM_Hp and IM_Lp revealed the activation of left putamen and the right caudate; (d) correlation between brain activation and the behavioral index (price adjustment) in immoral conditions (IM_Hp and IM_Lp) [Color figure can be viewed at wileyonlinelibrary.com]

here was shown for “illustrative purposes” of the interaction effect and not for statistical inference.

3.4 | Correlation analysis

As the behavioral result did not reveal any significant effect of absolute price adjustment ($|\Delta Y|$) between the moral conditions (M_Hp and M_Lp) (see Behavioral Results), we focused on the neural mechanisms related to the effect of immoral/unethical previous owners (IM_Hp and IM_Lp) in the correlation analysis. We found that activation intensity in the vmPFC ($[0\ 33\ 12]$) was positively correlated with $|\Delta Y|$ (Figure 3d, Table 2, Supplementary Information S3).

3.5 | Effective connectivity analysis: dynamic casual modeling

We chose the regions of overlap between the interaction-effect map and simple-effect map for the immorality effect as nodes to represent the key brain regions that are responsible for it. The activation peak of the overlap resulted in two ROIs: the right caudate nucleus $[18\ 18\ 6]$

and the left putamen $[-18\ 18\ -6]$. We then chose the vmPFC $[0\ 33\ 12]$ as the third ROI, which was obtained from the peak value in the correlation map. We intended to explore how the interaction of three nodes results in the modulation of economic valuation when items are associated with immoral/unethical owners.

3.5.1 | Stochastic DCM for resting-state fMRI data

We searched for all possible models generated from the intrinsic connections of the selected ROIs. The model evidence for all reduced models was compared with the full connected model using the network discovery procedure. The results showed that the best-fitted model was the fully connected model (Figure 4, posterior probability > 0.99).

3.5.2 | DCM for task fMRI

The BMS result showed that family 1 (driving input entering through the vmPFC) offered the best fit to the data (Figure 5a,b exceedance probability $[xp] = 0.94$). The remaining seven families showed very low exceedance probabilities ($xps < 0.02$). Within the winning family,

TABLE 1 Brain activation results of the whole-brain analysis

Hem.	Brain region	BA	Coordinates			Vol.	T
			(X, Y, Z)				
Interaction between moral character and initial price							
L	Precentral gyrus*	6	−24	−24	69	25	5.57
		6	−24	−27	60		
R	Middle frontal gyrus	10	36	57	9	14	5.43
L	Lenticular nucleus, putamen*	11	−18	18	−6	21	5.37
R	Angular gyrus	40	54	−48	30	20	5.30
		22	63	−51	27		
		39	54	−57	33		
R	Caudate nucleus*		18	18	6	11	5.23
R	Supplementary motor area	6	6	−15	60	17	4.91
		0	0	−12	51		
L	Superior frontal gyrus, medial	32	−3	36	36	12	4.55
R	Middle frontal gyrus	45	48	45	12	11	4.52
L	Superior frontal gyrus, dorsolateral	8	−15	21	54	11	4.26
		8	−15	30	54		
M_Lp > M_Hp							
No brain regions found							
IM_Hp > IM_Lp							
L	Hippocampus	35	−12	−12	−15	20	5.63
			−12	−6	−27		
		34	−15	0	−18		
L	Anterior cingulate and paracingulate gyri*	32	−6	42	6	112	5.16
		24	3	27	18		
			0	51	−6		
R	Middle frontal gyrus	44	39	21	33	11	5.02
R	Lenticular nucleus, putamen	48	24	15	6	10	4.99
R	Vermis		6	−36	−3	14	4.95
L	Lenticular nucleus, putamen*	11	−15	15	−6	37	4.84
		47	−21	21	−3		
		11	−6	24	−12		
R	Superior frontal gyrus, dorsolateral*	9	24	42	33	27	4.62
		32	15	33	30		
R	Inferior frontal gyrus, orbital part	38	27	15	−27	10	4.51

Note: all the results reported above were significant at $p < 0.001$, uncorrected at the voxel level, and * indicate the cluster-level FWE correction at $p < 0.05$.

the model defined by a modulation effect that worked on the unidirectional connection from the caudate nucleus to the vmPFC could best account for the data (Figure 6a, exceedance probability [xp] = 0.68, mean-variance explained 19.79%). Other models exhibited significantly lower probabilities (xps < 0.05; see details in Figure 6b).

TABLE 2 Brain regions revealed by the correlation between task-related brain activation and behavioral price adjustment

Hem.	Brain region	BA	Coordinates			Vol.	T
			(X, Y, Z)				
Immoral (IM_Hp & IM_Lp)							
L	vmPFC	24	0	33	12	16	3.94
L	vmPFC	10	0	48	0	13	3.76

vmPFC = ventromedial prefrontal cortex. Note: all the results reported above were significant at $p < 0.001$, uncorrected at the voxel level.

BMA was then used to calculate weighted-model parameters within the winning family, which were then used for statistical analysis. We found that the intrinsic connectivity between all three nodes were significantly greater than zero ($p < 0.05$, FDR correction), and the self-connectivity of the three nodes were significantly less than zero ($p < 0.05$, FDR correction). In both the IM_Hp and IM_Lp conditions, the connectivity from the caudate nucleus to the vmPFC was significantly different from zero (IM_Hp: $t_{(23)} = 2.56$, $p = 0.02$; IM_Lp: $t_{(23)} = -2.19$, $p = 0.04$). The modulation effect for IM_Hp was significantly larger than that for IM_Lp ($t_{(23)} = 3.08$, $p < 0.001$; Table 3).

3.6 | Validation of behavioral results

The experimental has two potential limitations. First, the intensity of moral valence was imbalanced such that the immoral characters were

FIGURE 4 Winning model of the intrinsic connectivity obtained from resting-state stochastic dynamic causal modeling. (a) Visual representation of the connections between nodes for the winning model. (b) The log-posterior for all models. (c) The exceedance probability for all models. (d) Group-averaged connection strengths using Bayesian model averaging [Color figure can be viewed at wileyonlinelibrary.com]

further from the neutral point (five on the nine point rating scale) than the moral characters (immoral: 3.01 ± 0.10 ; moral: 2.23 ± 0.14 ; $p < 0.001$). We need to clarify whether the nonsignificant difference between M_Hp and M_Lp conditions was due to the imbalance in the moral valence. Second, the effect of moral/immoral information might be better illustrated with a “pure” baseline in which no owner information presented with the objects.

Thus, to validate the behavioral results, we ran a behavioral experiment with balanced materials and an extra pure baseline condition. From the 60 characters used previously, we selected 21 moral characters and 21 immoral characters that were balanced in valence intensity (immoral: 2.81 ± 0.10 ; moral: 2.62 ± 0.10 ; $p = 0.16$). A baseline condition with no owner characters and baseline price as the initial price was also added to the task. Thus there were five

FIGURE 5 Model structures of all the families and BMS results of the task-functional magnetic resonance imaging dynamic causal modeling. (a) All the seven families of model structures. The families differed in the location of the input information. Within each family, models differ based on where modulation effects, that is, the immoral character, act on the system. The family model in the red box indicated the winning family model. (b) The exceedance probabilities of the seven model families [Color figure can be viewed at wileyonlinelibrary.com]

FIGURE 6 The model structure of all the models in the winning family and the results of BMA. (a) Illustration of all 13 models structures in the winning family. The models in the family differed in the modulation effect acts on which directional connection among the nodes. The red box highlighted the winning model within the family, the gray line showed where the modulation effect lies on. (b) Parameters of the winning model. The solid lines indicate the intrinsic connectivity between nodes. The dashed lines indicate the modulation effect of IM_Hp and IM_Lp condition from the caudate nucleus to the ventromedial prefrontal cortex, the data showed the mean connectivity strength or mean modulation strength of each edge [Color figure can be viewed at wileyonlinelibrary.com]

experimental conditions. Sixty participants who did not join the fMRI study took part in this behavioral experiment. Four people were excluded, two were due to recording failures, and two for not understanding the task. Thus, 56 participants were included in the analysis (27 females, age: 24.7 ± 2.6 years).

All four experimental conditions showed significant differences compared with the baseline condition, indicating a valid experimental

manipulation. Similar to the results in the fMRI experiment, the interaction effect of moral valence $\times$ initial price was significant ($F_{(1,55)} = 29.33$, $p < 0.001$, $\eta_p^2 = 0.35$) with $|\Delta Y|$ as the dependent variable. The pair-wise comparison revealed significantly larger $|\Delta Y|$ in the IM_Hp condition than in the IM_Lp condition ($p < 0.001$) and a significantly larger $|\Delta Y|$ in the M_Lp condition than in the M_Hp condition ($p < 0.001$). A paired t -test indicated that the $|\text{IM_Hp} - \text{IM_Lp}|$ was significantly larger than $|\text{M_Hp} - \text{M_Lp}|$ ($t_{(55)} = 2.27$, $p = 0.03$). Details of this validation analysis are included in Supplementary Information S4.

TABLE 3 Statistical analysis results of weighted model parameters in task-functional magnetic resonance imaging dynamic causal modeling analysis

Brain region	Mean (Hz)	SD (Hz)	$t(23)$	p -value
Intrinsic connectivity (A)				
Putamen $\rightarrow$ vmPFC*	0.08	0.15	2.47	0.02
Caudate $\rightarrow$ vmPFC*	0.07	0.12	2.90	0.01
vmPFC $\rightarrow$ putamen*	0.10	0.17	2.83	0.01
Caudate $\rightarrow$ putamen*	0.05	0.10	2.43	0.02
vmPFC $\rightarrow$ caudate*	0.09	0.13	3.55	<0.001
Putamen $\rightarrow$ caudate*	0.05	0.09	2.95	0.01
Modulation in IM_Hp (B)				
Caudate $\rightarrow$ vmPFC	0.18	0.34	2.56	0.02
Modulation in IM_Lp (B)				
Caudate $\rightarrow$ vmPFC	-0.13	0.29	-2.19	0.04
IM_Hp vs. IM_Lp (B)				
Caudate $\rightarrow$ vmPFC*			3.08	<0.001

vmPFC = ventromedial prefrontal cortex. Note: * indicated the significance survived after FDR correction at $p < 0.05$.

4 | DISCUSSION

By combining a novel paradigm and fMRI, the present study demonstrated that the moral contagion effect does exist in the hypothetical monetary valuation of objects. This moral contagion effect was more pronounced when objects were associated with immoral people than with moral people, which was confirmed on both behavioral and neural levels.

The behavioral results fit our hypothesis that when the previous owner behaved morally participants assigned significantly higher final prices, confirming that the valence of the previous owner's behavior (moral/immoral) does influence object valuation. In addition, a high initial price also resulted in a higher final price, whereas a low initial price showed the opposite effect. This can be explained by an "anchoring effect" in which participants rely on an initially offered piece of

information when making subsequent decisions (Ma, Li, Shen, & Qiu, 2015). We further explored how much the price was adjusted to better examine the effect of moral valence. Theoretically, if moral valence has no effect, then the absolute price adjustment ($|\Delta Y|$) for all four conditions should be comparable because all of the initial prices were offset from the baseline price by 25% (either 125% or 75% of baseline). When the object was associated with a moral person, we would expect $|\Delta Y|$ be lower in the M_Hp condition than in the M_Lp condition because a higher final price was expected. In contrast, when the object was associated with an immoral person, we would expect the $|\Delta Y|$ be higher in the IM_Hp condition than in the IM_Lp condition because a lower final price was expected. In general, an effect of moral valence should enlarge the difference in $|\Delta Y|$ between Hp and Lp conditions. Behavioral data from the fMRI experiment revealed a significant difference between IM_Hp and IM_Lp, but not between M_Hp and M_Lp. However, validating behavioral experiment with a larger sample size revealed that the effects of both moral and immoral characters were significant, with the effect of moral characters being significantly weaker. Our finding that the effect of moral characters was less pronounced is consistent with the literature. Studies suggest that compared with moral actions, immoral actions receive more weight, perhaps because negative behaviors are more diagnostic than positive behaviors in judging a person and forming impressions in the moral domain (Mende-Siedlecki, Baron, & Todorov, 2013; Wojciszke, Brycz, & Borkenau, 1993).

On the neural level, we found that activity in the dorsal striatum (right caudate nucleus or/and left putamen) was revealed in the interaction effect, simple contrast, and the ROI analysis: significantly stronger responses were observed in the IM_Hp condition than in the IM_Lp condition, but the difference between M_Hp and M_Lp conditions was comparable. Our finding is in line with the previous finding that the dorsal striatum showed reduced responses to profit from harming others (Crockett et al., 2017). The caudate nucleus has also been implicated in responses to unexpected stimuli and has been suggested to encode negative emotional feelings when observing unexpected outcomes (Carretie et al., 2009; Fouragnan et al., 2018). Meanwhile, recent studies have highlighted the caudate nucleus's role in processing implicit moral congruencies. Luo et al. (2006) found that moral incongruencies that went against implicit moral attitudes resulted in stronger activity in the caudate nucleus than moral congruencies that went along with implicit moral attitudes. Furthermore, high psychopathy is associated with reduced activity in the caudate nucleus in implicit evaluations of immoral stimuli (Yoder et al., 2015). Notice that we did not observe any activation above the threshold when participants observing the owner's moral information. The dorsal striatum was only significantly activated when the initial price was presented, which indicates that the dorsal striatum does not automatically respond to the owner's moral status, but rather to the incongruent initial prices that violate their moral expectations.

Information about the moral characters was presented first, followed by the initial price. Based on their judgments of the owners, participants might have had an opportunity to form an expectation of the price before it's presented (Ballard, Miller, Piantadosi, Goodman, &

McClure, 2017; Fouragnan et al., 2018). Once the initial price was revealed, participants might have been assessing whether this price was congruent with their expectation or not essentially. When observing a high initial price, the stronger their implicit moral attitudes against immoral owners, the stronger the observed price would violate their expectations, which would lead to stronger activation of the caudate nucleus. Thus, based on our activation results, we propose that the dorsal striatum, especially the caudate nucleus might drive the moral contagion effect.

The DCM analyses with the caudate nucleus, putamen, and the vmPFC as nodes revealed that the effective connectivity from the caudate nucleus to the vmPFC was significantly modulated by the initial price. This connection was significantly stronger in the IM_Hp condition than in the IM_Lp condition. Previous research on typical moral judgments (e.g., moral dilemmas) has suggested that the vmPFC is involved in emotionally driven moral decisions (Greene et al., 2009; Greene, Nystrom, Engell, Darley, & Cohen, 2004). The vmPFC can collect multiple factors to dynamically represent the subjective value during decision makings and therefore guide behavior within complex social/moral contexts (Grabenhorst & Rolls, 2011; Hunt et al., 2012; Kaanders & Hunt, 2018; Padoa-Schioppa & Cai, 2011; Rangel & Hare, 2010). The connectivity findings here suggest a possible underlying mechanism wherein greater positive connectivity from the caudate nucleus to the vmPFC may result from the vmPFC representation of object value after moral incongruencies are detected by the caudate nucleus.

The current study raises the question of how information about someone's moral character transfers to objects associated with that person. Money has symbolic power as a social resource. Individuals use the money to gain resources as they navigate society (Zhou, Vohs, & Baumeister, 2009). A practical way to punish people who violate moral norms is to deprive them of money, such as in a third-party punishment task (Krueger & Hoffman, 2016). To devalue the objects associated with immoral, people can discourage their involvement in monetary trades and deprive them of future access to resources in the long term, which might be a possible evolutionary explanation for this moral contagion effect. However, according to the validation experiment, the moral contagion effect for moral condition reached to significance with larger samples size. Thus, the neural correlates for moral contagion effect in moral condition were not enclosed in the current study. Future fMRI study should enlarge the sample size and raise the moral valence intensity of moral characters to investigate the question.

Overall, the present study demonstrated the existence of moral contagion effect in hypothetical judgments of economic value. The effect related to the devaluation of objects associated to immoral people was significant across the entire sample, whereas the effect related to increasing the value of objects associated to moral people was relatively weaker and seemed to partially depend on the individual's trait moral sensitivity. We also identified the neural basis for the (im)moral contagion effect of immoral behavior on the hypothetical judgments of economic value; the effect was driven by neural responses in the dorsal striatum, especially the right caudate nucleus that was triggered by high prices assigned to objects of immoral owners, and the effective connectivity from the caudate nucleus to

vmPFC. Our findings have significant implications for future research on the manner in which morality shapes human valuation systems.

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AUTHOR CONTRIBUTIONS

F.C. designed the research; C.L. and J.L. collected the data; J.L. analyzed data; F.C., J.L., and Y.L. wrote the paper. The authors declare no competing financial interests.

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SUPPORTING INFORMATION

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