Social Comparison in the Brain: A Coordinate-Based meta-Analysis of Functional Brain Imaging Studies on the Downward and Upward Comparisons

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Abstract: Social comparison is ubiquitous across human societies with dramatic influence on people's well-being and decision making. Downward comparison (comparing to worse-off others) and upward comparison (comparing to better-off others) constitute two types of social comparisons that produce different neuropsychological consequences. Based on studies exploring neural signatures associated with downward and upward comparisons, the current study utilized a coordinate-based meta-analysis to provide a refinement of understanding about the underlying neural architecture of social comparison. We identified consistent involvement of the ventral striatum and ventromedial prefrontal cortex in downward comparison and consistent involvement of the anterior insula and dorsal anterior cingulate cortex in upward comparison. These findings fit well with the "common-currency" hypothesis that neural representations of social gain or loss resemble those for non-social reward or loss processing. Accordingly, we discussed our findings in the framework of general reinforcement learning (RL) hypothesis, arguing how social gain/loss induced by social comparisons could be encoded by the brain as a domain-general signal (i.e., prediction errors) serving to adjust people's decisions in social settings. Although the RL account may serve as a heuristic framework for the future research, other plausible accounts on the neuropsychological mechanism of social comparison were also acknowledged. *Hum Brain Mapp 00:000–000, 2017*. © **2017 Wiley Periodicals, Inc.**

Key words: activation likelihood estimation (ALE); common-currency hypothesis; meta-analysis; reinforcement learning; social comparison

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INTRODUCTION

Social comparison—"Is this person better looking? More successful?"— is a key and inevitable aspect of human social life. Social comparison has an early evolutionary origin and emerges early in human life. Nonhuman primates evaluate their outcomes in relative terms, comparing their own payoffs with those of available others [Brosnan et al., 2005] and humans exhibit distinct reactions to different relative outcomes (e.g., equal vs. unequal) as early as 15 months of age [Geraci and Surian, 2011; Sommerville et al., 2013]. Furthermore, social comparison often occurs fast, requires few cognitive resources, and can happen automatically [Galinsky and Schweitzer, 2015]. For instance, subliminal exposure to the picture of Albert Einstein resulted in lower self-evaluations about one's intelligence, whereas subliminal exposure to the picture of a clown led to higher self-evaluations about one's intelligence [Stapel and Blanton, 2004].

Similar to absolute outcomes, relative outcomes derived from social comparison processes can have dramatic impacts on personal well-being and interpersonal interactions [Bault et al., 2008; Gibbons and Buunk, 1999; Hughes and Beer, 2013; Muscatell et al., 2012; Olson et al., 2014; Rutledge et al., 2016; Zhen et al., 2016]. Evidence from a worldwide survey revealed that the impact of relative income was even larger than that of absolute income on self-reported happiness [Ball and Chernova, 2008]. Likewise, social comparison processes play a critical role in the etiology and maintenance of mood disorders (e.g., depression) [Feinstein et al., 2013; Swallow and Kuiper, 1988; Tabachnik et al., 1983]. Furthermore, social comparison can also influence interpersonal relationships—it can sometimes help build healthy group affiliation [Baumeister and Leary, 1995; Brosnan et al., 2005; Mitchell and Heatherton, 2009], but it can also cause envy and scorn experiences that increase psychological distance between people [Fiske, 2010].

The fundamental mechanisms underlying social comparison have always drawn psychologists' interest [Anderson et al., 2006; Dvash et al., 2010; Lindner et al., 2014; Moore et al., 2014; Mussweiler et al., 2004; Swencionis and Fiske, 2014; Taylor and Lobel, 1989]. The social comparison theory posits that people are driven to compare themselves to others for accurate self-evaluations [Festinger, 1954]. Specifically, people compare themselves to others in two opposite directions—downward and upward comparisons—that differ in motivations, comparison targets and consequences [Latané, 1966; Wills, 1981]. On the one hand, downward comparison refers to comparing to those who are considered to be doing worse. Downward comparison is most likely done to fulfill the motivation of self-enhancement. This type of comparison elevates positive emotion such as relief or schadenfreude and reduces anxiety [Amoroso and Walters, 1969; Crocker and Gallo, 1985; Gibbons, 1986; Jankowski and Takahashi, 2014]. Accordingly, downward comparison often enhances or protects subjective well-being [Suls et al., 2002; Wills, 1981]. On the other hand, upward comparison refers to comparing to those who are thought to be doing better. Upward comparison is most likely done to fulfill the motivation of self-improvement. This type of social comparison invokes threat to the self [Brickman and Bulman, 1977] and provokes negative emotions such as envy [Chester et al., 2013; Jankowski and Takahashi, 2014; Tesser et al., 1988]. In short, downward comparison—being better than others—is often associated with positive feelings, whereas upward comparison—being worse than others—usually triggers negative feelings [Dvash et al., 2010; Swencionis and Fiske, 2014].

Building on extensive behavioral studies in the domain of social psychology, the past decade has witnessed an increased interest in unveiling the neural signatures of social comparison [Bault et al., 2011; Beer and Hughes, 2010; Fliessbach et al., 2007; Hughes and Beer, 2013; Luo et al., 2015; Wu et al., 2012]. To have participants compare themselves to others, these studies usually employed experimental paradigms in which participants are exposed to both their own and another person's/group's performance or outcomes [Boksem et al., 2011; Fliessbach et al., 2007; Qiu et al., 2010; Zhen et al., 2016; Zink et al., 2008]. These studies suggest that downward comparison often evokes activation of the ventral striatum (VS) and ventromedial prefrontal cortex (vmPFC) known to be implicated in primary or monetary reward processing [Bartra et al., 2013; Du et al., 2013; Fliessbach et al., 2012; Kang et al., 2013; Zink et al., 2008]. For instance, Dvash and colleagues [2010] showed that a relative gain—an absolute loss in the context of another person's greater loss—induced activation in the VS similar to the one measured when experiencing an absolute gain. In contrast, a relative loss—an absolute gain in the context of another person's greater gain—was associated with deactivation in the VS similar to the one measured when experiencing an absolute loss. Furthermore, vmPFC and VS have often been shown to be involved when one wins in interpersonal competitive games [Beyer et al., 2014; Delgado et al., 2008; Fareri and Delgado, 2014; Kätsyri et al., 2012; Mobbs et al., 2013; Votinov et al., 2015]. Therefore, recent neuroimaging findings are in line with the idea that downward comparison is represented in an analogous manner to the striato-cortical encoding of material reward [Lindner et al., 2014].

On the contrary, upward comparison has been shown to recruit the dorsal anterior cingulate cortex [dACC; Takahashi et al., 2009] and anterior insula [AI; Steinbeis and Singer, 2014]. For instance, a recent meta-analysis has revealed consistent activations of the AI and dACC by disadvantageous outcomes pertaining to resource allocation (e.g., unequal and disadvantageous offers in the ultimatum game) [Feng et al., 2015]. Likewise, being inferior to others in performance or competence can induce an envy feeling that was associated to the activity of the dACC or AI [Steinbeis and Singer, 2014; Takahashi et al., 2009]. For instance, in Takahashi et al's [2009] study, subjects were presented with target persons who possessed superior or average ability and quality. The authors found that superior others, compared to average others, triggered higher self-reported envy and stronger dACC activation. In addition, neural responses of dACC to superior others were correlated with envy feelings, such that people who exhibited stronger dACC responses reported higher envy scores. Finally, losing to others in interpersonal competitive games also involves the AI and dACC [Beyer et al., 2014a,b]. Considering the reliable involvement of the dACC and AI in processing negative events in the non-social domain, including but not limited to physical pain and monetary loss [Craig, 2009; Lamm et al., 2011; Lieberman and Eisenberger, 2008; Shackman et al., 2011; Wu et al., 2014a], previous findings on upward comparison suggest common neural signatures of social and non-social loss.

Taken together, previous neuroimaging studies on human social comparison have revealed a neural network consisting of VS, vmPFC, AI and dACC that is also engaged in non-social reward/loss processing. These findings suggest that the influence of social comparison on human behaviors is implemented through a similar neuropsychological mechanism with non-social reward/loss. In this regard, we propose a plausible domain-general neuropsychological mechanism associated with reinforcement learning (RL). The RL framework argues that humans improve choices by adjusting behaviors according to prediction errors, i.e., the differences between the predicted and actual reward of an action [Schultz et al., 1997; Schultz, 2006]. Importantly, these error signals are often encoded in the neural acitivty of VS, vmPFC, dACC and AI [Haber and Behrens, 2014; Palminteri et al., 2012; Rushworth et al., 2011; Santesso et al., 2008], brain regions that have been shown to be involved in social comparisons. Accordingly, downward comparison activating the VS and vmPFC might signal positive prediction errors (i.e., better than one's expectations) whereas upward comparison activating the dACC and AI might signal negative prediction errors (i.e., worse than one's expectations). These error signals might facilitate behavioral adjustments and thus improve performance in the context of social comparison or competition. The RL model extends previous psychological hypotheses on social comparison by providing a more general framework.

Of note, however, there are other explanations on the specific functions of brain areas involved in social comparison. For example, the involvement of vmPFC during downward comparison has also been thought to contribute to self-referential processing [Northoff et al., 2006; Zaki et al., 2013]. Moreover, other researchers have proposed the role of vmPFC in social perceptiveness [Morawetz et al., 2014] due to its involvement in mentalizing [Amodio and Frith, 2006; Saxe and Powell, 2006] and empathy [Bernhardt and Singer, 2012]. Both self-referential and other-regarding processes are likely to be engaged in the social comparison. Additionally, the dACC may reflect the cognitive conflict between the positive self-concept and the mismatching external feedback [Takahashi et al., 2009], considering the important role of the dACC in monitoring and evaluating cognitive conflict [Botvinick et al., 2004; Shenhav et al., 2013, 2016]. There is also the possibility that the dACC acts as a cognitive control region to regulate the conflict [Egner, 2009]. Finally, the AI may be responsible for representing deviations from expected outcome rather than negative feelings in the context of upward comparison [Civai et al., 2012; Gu et al., 2015; Wu et al., 2016; Xiang et al., 2013]. These interpretations are not necessarily exclusive with the RL framework, in terms of understanding the process of social comparison in a more general view. Although a meta-analysis does not allow us to specifically test these hypotheses, we will discuss our findings in light of the aforementioned accounts.

Recent neuroscience studies have been examining the neural signatures of the social comparison and a couple of narrative reviews have summarized the biological basis of social comparison processes [Kedia et al., 2014b; Swencionis and Fiske, 2014]. Importantly, however, a precise characterization of the neural systems underpinning social comparison is still elusive. In this study, we utilized a coordinate-based meta-analysis to quantitatively synthesize previous neuroimaging findings on social comparison with the goal of providing a comprehensive overview of the underlying neural architecture of this phenomenon.

MATERIAL AND METHODS

Our analyses consisted of primary meta-analyses and additional validation analyses. Specifically, we first provided primary/traditional meta-analytic analyses based on all selected publications, which is a typical approach employed in coordinate-based meta-analysis studies. Second, we provided validation analyses to confirm that our primary meta-analytic results were not driven by the coordinates from a single publication using a leave-one-experiment-out (LOEO) approach.

Literature Search and Selection

A systematic online database search was performed in July of 2017 on PubMed, ISI Web of Science and Google Scholar by entering various combinations of relevant search items (e.g., ["social comparison" OR "upward comparison" OR "downward comparison" OR "competition" OR "social influence" OR "envy" OR "gloating" OR "Schadenfreude" OR "equality" OR "fair" OR "ultimatum game" OR "UG" OR "inequality aversion" OR "social preference" OR "social decision making" OR "social learning" OR "social reward" OR "social feedback" OR "peer feedback" OR "social norm" OR "social information" OR "social status" OR "social hierarchy" OR "social interaction" OR "interpersonal interaction"] AND ["fMRI" OR "magnetic resonance imaging" OR "neuroimaging"]). In addition, we explored several other sources, including (1) direct searches on the names of frequently occurring authors, (2) the bibliography and citation indices of the pre-selected articles, and (3) the reference list of related reviews [Aoki et al., 2015; Du and Chang, 2015; Falk et al., 2012; Fehr and Camerer, 2007; Insel and Fernald, 2004; Izuma, 2013; Jankowski and Takahashi, 2014; Kedia et al., 2014b; Rilling and Sanfey, 2011; Ruff and Fehr, 2014; Swencionis and Fiske, 2014; Tricomi and Sullivan-Toole, 2015]. The search resulted into 119 potential studies, which were further assessed according to the following criteria: (i) subjects were free from psychiatric or neurological diagnoses and neuropharmacological influence; (ii) subjects performed tasks in the context of social comparison; (iii) fMRI was used as the imaging modality; (iv) whole-brain general-linear-model-based analyses (rather than region of interest [ROI] analyses) were applied; (v) statistical models for contrasts of downward/upward social comparison or relevant parametric analyses were reported; and (vi) activations were presented in a standardized stereotaxic space (Talairach or MNI). Note that for studies reporting Talairach coordinates, a conversion to the MNI coordinates was implemented with the Yale BioImage Suite Package (http://sprout022.sprout.yale.edu/mni2tal/mni2tal.html). Filtering search results according to the inclusion/exclusion criteria yielded a total of 59 published fMRI articles with 28 downward contrasts (266 foci, 836 subjects) and 44 upward contrasts (383 foci, 1432 subjects) reported in a standardized stereotaxic space (Table I). We restricted the meta-analysis to experiments on comparison between the self and others, not including those comparing others to each other [e.g., Cloutier et al., 2012; Farrow et al., 2011; Hughes and Beer, 2011; Kedia et al., 2014a; Lindner et al., 2008]. A complete list of excluded publications and relevant reasons are provided in Supporting Information Table S1. A flow chart illustrating the literature search and selection process is presented in Figure 1.

Primary ALE Meta-analyses

A coordinate-based meta-analysis of reported fMRI experiments was conducted by employing the revised ALE algorithm implemented with in-house MATLAB scripts [Eickhoff et al., 2009]. Applying the ALE algorithm, the reported coordinates of brain areas associated with downward comparison and upward comparison were separately converged across different experiments. The ALE determines the convergence of foci reported from different functional (e.g., blood-oxygen-level dependent [BOLD] contrast imaging) or structural (e.g., voxel-based morphometry) neuroimaging studies with published foci in Talairach or MNI space [Laird et al., 2005; Turkeltaub et al., 2002]. ALE interpreted reported foci as three-dimensional Gaussian spatial probability distributions, whose widths were based on empirical estimates of the spatial uncertainty due to the between-subject and between-template variability of the neuroimaging data [Eickhoff et al., 2009]. Within each included study, a modulated activation (MA) map was firstly created by taking the maximum probability associated with any one focus (always the closest one) for each voxel [Turkeltaub et al., 2012]. An advantage of the modified ALE algorithm is that multiple foci from a single study will not jointly influence the individual MA value of a single voxel. The union of these individual MA maps was then calculated to obtain an ALE map across studies. This ALE map was assessed against a null-distribution of random spatial association between studies using a non-linear histogram integration algorithm [Eickhoff et al., 2012]. In addition, the average non-linear contribution of each experiment for each cluster was calculated from the fraction of the ALE values at the cluster with and without the experiment in question [Eickhoff et al., 2016]. Based on the calculated contribution, we employed two additional criteria to select significant clusters: (1) the contributions for one cluster should be from at least two experiments so that the finding would not only be driven by one single experiment; and (2) the average contribution of the most dominant experiment (MDE) should not exceed 50% and the average contribution of the two most dominant experiments (2MDEs) should not exceed 80% [Eickhoff et al., 2016].

Validation Analyses

We implemented additional analyses to validate findings derived from our primary ALE meta-analyses. Specifically, we implemented a LOEO analysis for our ALE meta-analyses on downward and upward comparisons. The LOEO approach was conducted to examine whether results from our primary meta-analyses on downward and upward social comparisons were mainly driven by a single contrast. On each fold, one contrast (i.e., experiment) was excluded and the ALE meta-analysis was conducted on the remaining $N - 1$ contrasts for downward ($N - 1 = 27$) or upward ($N - 1 = 43$) comparison, respectively. Validation findings consisted of brain regions that were identified in *every* fold of the LOEO. Importantly, results from this procedure are not mainly driven by a single contrast. For the reason of completeness, we also reported results derived from the average of all folds of LOEO (Supporting Information Fig. S1 and Table S2).

All maps were thresholded using a cluster-level family-wise error (cFWE) correction ($P < 0.05$) with a cluster-forming threshold of $P < 0.001$ using 10,000 permutations for correcting multiple comparisons [Eklunda et al., 2016; Woo et al., 2014a].

RESULTS

Primary ALE meta-Analysis Results

Consistent maxima were found in bilateral VS and vmPFC for downward comparison (Table II; Fig. 2A). Twenty out of 28 contrasts contributed to the cluster in right VS (MDE = 13.69%; 2MDE = 24.37%). Twenty out of 28 contrasts contributed to the cluster in left VS (MDE = 8.12%; 2MDE = 15.87%). Eight out of 28 contrasts contributed to the cluster in vmPFC (MDE = 21.26%; 2MDE = 35.87%) (Table III).

TABLE I. Summary of studies included for the meta-analysis focusing on downward and upward social comparisons

Study	N	Contrast	No. of foci
Downward Social Comparison			
Assaf et al. [2009]	19	Self-gain/other-lost > Self-lost/other-gain	12
Beyer et al. [2014a]	40	Self-won/other-lost > Self-lost/other-won	12
Beyer et al. [2014b]	41	Self-won/other-lost > Self-lost/other-won	3
Brunnlieb et al. [2013]	15	Self-won/other-lost > Self-lost/other-won	25
Cikara et al. [2011]	18	Favored team's success/rival team's failure > control	9
Delgado et al. [2008]	17	Self-gain/other-lost > Self-lost/other-gain	5
Du et al. [2013]	19	Self-won/others-lost > self-lost/others-won	12
Dvash et al. [2010]	16	Relative gain > relative loss	6
Emmerling et al. [2016]	15	Self-won/other-lost > Self-lost/other-won	9
Fareri and Delgado [2014]	18	Self-won/others-lost > self-lost/others-won: social > non-social	8
Fliessbach et al. [2007]	33	Self-won/other-lost > self-lost/other-won + self-lost/other-lost	8
Fliessbach et al. [2012]	64	Self-won/other-lost > self-lost/other-won + self-lost/other-lost	2
Haruno & Frith [2010]	52	Parametric analysis, positive correlation with absoluate differences between two peoeple (self > other)	4
Hertz et al. [2017]	19	better performance (positive merit) > worse performance (negative merit)	3
Kang et al. [2013]	22	Parametric analysis, positive correlation with relative income	7
Kätsyri et al. [2012]	17	Self-won/other-lost > self-lost/other-won: human > computer	2
Krämer et al. [2007]	15	Self-won/other-lost > Self-lost/other-won	15
Kishida et al. [2012]	27	parametric analysis, positive correlated with change of self's rank	2
Le Bouc and Pessiglione [2013]	32	Parametric analysis, positive correlation with relative income	2
Lindner et al. [2014]	30	Performed better > performed worse; parametric analysis, positive correlation with performance deviations in downward comparisons	12
Ligneul et al. [2016]	28	win > loss compared to another- win > loss in control condition	9
Mobbs et al. [2013]	15	Self-won/other-lost > Self-lost/other-won	1
Morawetz at al. [2014]	28	Self-won/other-lost > Self-lost/other-won	5
Op de Macks et al. [2016]	58	higher social hierarchy > monetary gain	2
Steinbeis and Singer [2014]	45	Parametric analysis, positive correlation with experienced Schadenfreude (Self-won/other-lost > Self-won/other-won)	7
van den Bos et al. [2013]	40	Self-won/others-lost > Self-not-won/other-won	2
Votinov et al. [2015]	69	Self-gain/other-no gain > self loss/other-no loss; self-no loss/other-loss > self-no gain/other-gain	65
Zink et al. [2008]	24	Self-won/other-lost > Self-lost/other-lost	17
Upward Social Comparison			
Baumgartner et al. [2011]	32	disadvantageous outcomes > equal outcomes	17
Beyer et al. [2014a]	40	Self-lost/other-won > Self-won/other-lost	7
Beyer et al. [2014b]	41	Self-lost/other-won > Self-won/other-lost	5
Cikara et al. [2011]	18	Favored team's failure/rival team's success > control	3
Civai et al. [2012]	19	disadvantageous outcomes > equal outcomes	12
Corradi-Dell'Acqua et al. [2016]	19	disadvantageous outcomes > equal outcomes	21
Emmerling et al. [2016]	15	Self-lost/other-won > Self-won/other-lost	4
Fatfouta et al. [2016]	23	disadvantageous outcomes > equal outcomes	18
Farmer et al. [2016]	18	disadvantageous outcomes > equal outcomes	6
Feng et al. [2016]	40	disadvantageous outcomes > equal outcomes	10
Fliessbach et al. [2012]	64	disadvantageous outcomes > equal outcomes	1
Gospic et al. [1983]	17	disadvantageous outcomes > equal outcomes	4
Gradin et al. [2015]	25	disadvantageous outcomes > equal outcomes	10
Guo et al. [2013a]	18	disadvantageous outcomes > equal outcomes	10
Guo et al. [2013b]	21	disadvantageous outcomes > equal outcomes	13
Güroğlu et al. [2011]	68	disadvantageous outcomes > equal outcomes	9
Halko et al. [2009]	23	disadvantageous outcomes > equal outcomes	22
Harlé and Sanfey [2012]	38	disadvantageous outcomes > equal outcomes	12
Haruno & Frith [2010]	52	Parametric analysis, positive correlation with absoluate differences between two peoeple (other > self)	9

TABLE I. (continued).

Study	N	Contrast	No. of foci
Haruno et al. [2014]	62	parametric analysis, positive correlation with disadvantageous outcomes	4
Hu et al. [2016]	23	disadvantageous outcomes > equal outcomes	4
Kirk et al. [2011]	40	disadvantageous outcomes > equal outcomes	11
Kirk et al. [2016]	50	parametric analysis, positive correlation with disadvantageous level	11
Kishida et al. [2012]	27	parametric analysis, negative correlated with change of self's rank	2
Krämer et al. [2007]	15	Self-lost/other-won > Self-won/other-lost	2
Lamichhane et al. [2014]	18	disadvantageous outcomes > equal outcomes	3
Lindner et al. [2014]	30	Performed worse > performed better	16
Lingeul et al. [2017]	28	superior other > inferior other	2
Op de Macks et al. [2016]	58	lower social hierarchy > monetary loss	1
Roalf [2010]	27	disadvantageous outcomes > equal outcomes	8
Sanfey et al. [2003]	19	disadvantageous outcomes > equal outcomes	17
Servaas et al. [2015]	114	disadvantageous outcomes > equal outcomes	32
Steinbeis and Singer [2014]	45	Parametric analysis, positive correlation with experienced Envy (Self-lost/other-won > Self-lost/other-lost)	2
Takahashi et al. [2009]	19	Superior others (high related) > average others; Superior others (low related)> average others	2
van den Bos et al. [2013]	40	Self-not-won/other-won > Self-won/others-lost	4
Verdejo-García et al. [2015a]	19	disadvantageous outcomes > equal outcomes	4
Verdejo-García et al. [2015b]	44	disadvantageous outcomes > equal outcomes	13
White et al. [2013]	20	parametric analysis, positive correlation with disadvantageous level	8
White et al. [2014]	21	parametric analysis, positive correlation with disadvantageous level	7
Wu et al. [2014a,b]	18	parametric analysis, negative correlation with subjective utility	7
Wu et al. [2015]	27	disadvantageous outcomes > equal outcomes	1
Zheng et al. [2015]	25	disadvantageous outcomes > equal outcomes	15
		Self-unequal/other-equal > Self-unequal/other-unequal	15
Zhou et al. [2014]	28	disadvantageous outcomes > equal outcomes	4
Zink et al. [2008]	24	Self-lost/other-won > Self-lost/other-lost	10

N, number of subjects.

For upward comparison, consistent maxima were found in dACC and bilateral AI (Table II; Fig. 2B). Twenty-seven out of 44 contrasts contributed to the cluster in dACC (MDE = 9.14%; 2MDE = 17.86%). Twenty-eight out of 44 contrasts contributed to the cluster in right AI (MDE = 9.86%; 2MDE = 19.06%). Twenty-six out of 44 contrasts contributed to the cluster in left AI (MDE = 8.94%; 2MDE = 15.95%) (Table III).

Validation Results (LOEO Analyses)

For downward comparison, consistent maxima in bilateral VS (Table IV; Fig. 3A) were identified in all folds of the ALE-LOEO.

For upward comparison, consistent maxima in dACC and bilateral AI were identified in all folds of the ALE-LOEO (Table IV; Fig. 3B). Therefore, the results of the LOEO approach corroborated the findings of our primary ALE meta-analysis.

DISCUSSION

Social comparison impacts people's well-being and decision making in various ways. Downward comparison—being better than others—often reduces anxiety, induces joyful feelings (e.g., schadenfreude) and satisfies the need for self-enhancement [Amoroso and Walters, 1969; Dohmen et al., 2011]. In contrast, upward comparison—being worse than others—often induces unpleasant feelings (e.g., envy), triggers threat to the self [Aoki et al., 2014; Bault et al., 2008; Dvash et al., 2010; Fiske, 2010; Takahashi et al., 2009], but also provides information for self-improvement [Tesser et al., 1988; Wood, 1989]. With a coordinate-based approach, this meta-analysis quantitatively examined brain areas consistently recruited by downward and upward comparisons based on previous functional brain imaging studies. Our results demonstrated consistent involvement of bilateral VS and vmPFC for downward comparison, as well as consistent involvement of bilateral AI and dACC

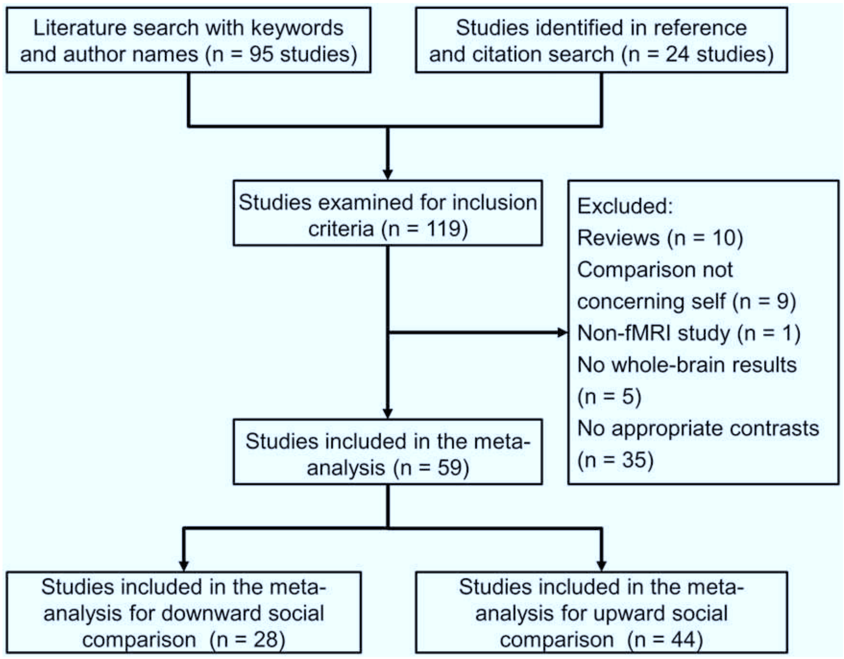

Figure 1.
Flowchart of literature search and selection process.

for upward comparison. Critically, our main findings remained robust after excluding the effect of a single contrast using a LOEO approach.

Our meta-analysis first identified a consistent involvement of the VS and vmPFC in downward comparison. Based on the role of these regions in reward processing [Carlson et al., 2011; Cromwell et al., 2005; McClure et al., 2004; Rushworth et al., 2011; Sescousse et al., 2015], our findings dovetail with the notion that downward comparison is experienced as rewarding [Bault et al., 2011; Dvash et al., 2010; Fliessbach et al., 2007]. Prior studies have shown the involvement of the VS in the processing of other types of social rewards, including good reputation [Izuma et al., 2008; Meshi et al., 2013] and social approval [Izuma et al., 2010]. These findings have led researchers to propose that the VS and vmPFC, in addition to being key brain areas for material reward (e.g., food and money) processing, also play a crucial role in registering a broad spectrum of social rewards [Delgado, 2007].

Our meta-analysis next revealed consistent engagement of the bilateral AI and dACC in response to upward comparison. These findings echo the assertion that relative losses or being inferior to others might be experienced as negative feelings in the social contexts [Dvash et al., 2010; Steinbeis and Singer, 2014; Takahashi et al., 2009]. In accord with the current findings, prior studies have implicated these regions in many other social loss or social pain contexts, including the observation of other's physical pain [Cui et al., 2015; Gu et al., 2012; Singer, 2006], the experience of social exclusion [Eisenberger et al., 2003; Eisenberger, 2012; Rotge et al., 2015] and the exposure to deceased loved one's pictures [Gündel et al., 2003]. Furthermore, similar regions have been reliably engaged by a broad range of negative event processing in the non-social domain [Apkarian et al., 2005; Craig et al., 1996; Peyron et al., 2000].

Taken together, our findings indicate that reward- and loss-related processing induced by downward and upward comparisons respectively—which are social in nature—induce reward/loss-relevant brain responses very similar to those observed for non-social reward/loss processing. Our results thus suggest that neuropsychological signatures of social comparison could be understood in a more general framework.

Indeed, the VS, vmPFC, AI, and dACC identified in the current meta-analysis play a key role in encoding prediction errors during general RL involving non-social reward/loss processing [Diederen et al., 2016; Garrison et al., 2013; Hare et al., 2008; Hayden et al., 2011; Limongi et al., 2013; Liu et al., 2011; Modirrousta and Fellows, 2008; Nieuwenhuis et al., 2005; Rushworth and Behrens, 2008]. Therefore, the consistent involvement of the VS, vmPFC, AI and ACC during social comparison might reflect prediction errors that signal the need for behavioral changes. In line with this idea, Bault et al. [2011] highlighted the impact of social comparison on behavior adjustment by showing that social gains (i.e., wining a higher score than the other player) induced a more

TABLE II. ALE meta-analysis results for downward social comparison and upward social comparison

Brain Regions	BA	MNI Coordinates (mm) x	y	z	Peak Z score	Cluster Size (voxels)
Downward Social Comparison						
R VS	-	12	10	−10	6.18	578
L VS	-	−12	8	−8	5.62	448
vmPFC	10	−8	52	0	4.29	140
Upward Social Comparison						
dACC	32	−4	16	46	7.31	952
R AI	13	34	24	−4	7.32	846
L AI	13	−30	24	0	6.17	679

BA, Brodmann area; L, left; R, right; VS, ventral striatum; AI, anterior insula; vmPFC, ventromedial prefrontal cortex.
Cluster-level family-wise error correction ($P < 0.05$) with a cluster-forming threshold of $P < 0.001$ using 10,000 permutations.

competitive behavioral pattern—seeking more rewarding and risky options—in subsequent trials. At the neural level, activity of the VS to social gains predicted the activation of medial prefrontal cortex in subsequent choices in the social context, which might serve as the neural substrates of behavior adjustments induced by social comparisons. These findings are in line with the RL account positing that social reward/loss induced by social comparison may be encoded by the brain as a domain-general signal (i.e., prediction errors) serving to adjust people's decisions in the social settings [Bhanji and Delgado, 2014; Montague and Lohrenz, 2007; Rilling and Sanfey, 2011].

In the context of social comparison, a dominant prediction may be being equal with others, as people have a tendency to believe that others are like oneself [Gilovich et al., 1983]. Accordingly, the equality in performance or outcomes between oneself and others may serve as a social expectation (or "social norm") when no further information is provided [Blake et al., 2014; Civai et al., 2012; Fehr and Schmidt, 1999]. When people received feedbacks indicating differences between self and others, norm prediction errors might be detected [Montague and Lohrenz, 2007]. On the one hand, downward comparison indicating superiority to others might induce positive norm prediction errors (better

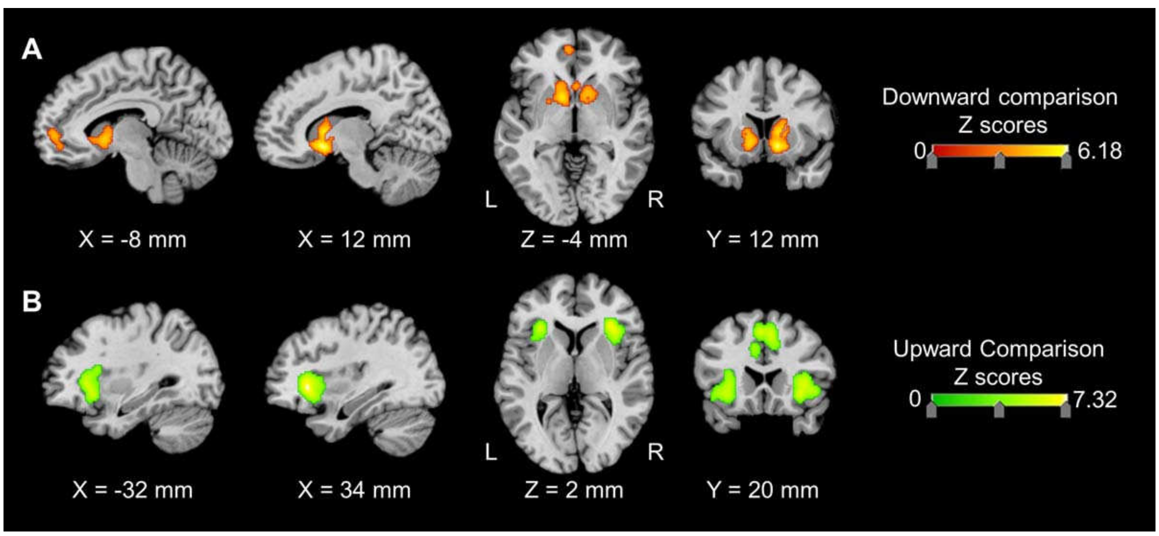

Figure 2.

Significant clusters from the primary coordinate-based ALE (activation likelihood estimation) meta-analysis (cluster-level family-wise error correction ($P < 0.05$) with a cluster-forming threshold of $P < 0.001$ using 10,000 permutations) for downward social comparison and upward social comparison. A) Consistent maxima for downward social comparison were found in the bilateral ventral striatum (VS), and ventromedial prefrontal cortex. B) Consistent maxima for upward social comparison were found in bilateral anterior insula (AI) and dorsal anterior cingulate cortex (dACC). L, left; R, right. [Color figure can be viewed at wileyonlinelibrary.com]

TABLE III. Average contribution of each experimental contrast for significant clusters identified for the meta-analysis of downward and upward social comparisons

Cluster name	Study	*N*	Contrast	Average contribution (%)
Downward Social Comparison				
R VS	Assaf et al. [2009]	19	Self-gain/other-lost > Self-lost/other-gain	5.02
	Beyer et al. [2014a]	40	Self-won/other-lost > Self-lost/other-won	5.19
	Beyer et al. [2014b]	41	Self-won/other-lost > Self-lost/other-won	6.00
	Brunnlieb et al. [2013]	15	Self-won/other-lost > Self-lost/other-won	1.86
	Cikara et al. [2011]	18	Favored team's success/rival team's failure > control	2.08
	Delgado et al. [2008]	17	Self-gain/other-lost > Self-lost/other-gain	2.10
	Du et al. [2013]	19	Self-won/others-lost > self-lost/others-won	1.95
	Dvash et al. [2010]	16	Relative gain > relative loss	6.90
	Emmerling et al. [2016]	15	Self-won/other-lost > Self-lost/other-won	4.65
	Fareri and Delgado [2014]	18	Self-won/others-lost > self-lost/others-won: social > non-social	4.27
	Fliessbach et al. [2007]	33	Self-won/other-lost > self-lost/other-won + self-lost/other-lost	6.43
	Fliessbach et al. [2012]	64	Self-won/other-lost > self-lost/other-won + self-lost/other-lost	6.05
	Krämer et al. [2007]	15	Self-won/other-lost > Self-lost/other-won	2.95
	Kishida et al. [2012]	27	parametric analysis, positive correlated with change of self's rank	4.01
	Le Bouc and Pessiglione [2013]	32	Parametric analysis, positive correlation with relative income	4.71
	Lindner et al. [2014]	30	Performed better > performed worse; parametric analysis, positive correlation with performance deviations in downward comparisons	10.70
	Mobbs et al. [2013]	15	Self-won/other-lost > Self-lost/other-won	3.29
	Morawetz at al. [2014]	28	Self-won/other-lost > Self-lost/other-won	5.26
	Steinbeis and Singer [2014]	45	Parametric analysis, positive correlation with experienced Schadenfreude (Self-won/other-lost > Self-won/other-won)	2.90
	Votinov et al. [2015]	69	Self-gain/other-no gain > self loss/other-no loss; self-no loss/other-loss > self-no gain/other-gain	13.67
L VS	Assaf et al. [2009]	19	Self-gain/other-lost > Self-lost/other-gain	7.19
	Beyer et al. [2014a]	40	Self-won/other-lost > Self-lost/other-won	6.22
	Cikara et al. [2011]	18	Favored team's success/rival team's failure > control	2.75
	Delgado et al. [2008]	17	Self-gain/other-lost > Self-lost/other-gain	5.95
	Du et al. [2013]	19	Self-won/others-lost > self-lost/others-won	1.45
	Dvash et al. [2010]	16	Relative gain > relative loss	6.63
	Emmerling et al. [2016]	15	Self-won/other-lost > Self-lost/other-won	4.90
	Fareri and Delgado [2014]	18	Self-won/others-lost > self-lost/others-won: social > non-social	6.92
	Fliessbach et al. [2007]	33	Self-won/other-lost > self-lost/other-won + self-lost/other-lost	7.37
	Fliessbach et al. [2012]	64	Self-won/other-lost > self-lost/other-won + self-lost/other-lost	7.75
	Hertz et al. [2017]	19	better performance (positive merit) > worse performance (negative merit)	3.95
	Krämer et al. [2007]	15	Self-won/other-lost > Self-lost/other-won	2.89
	Kishida et al. [2012]	27	parametric analysis, positive correlated with change of self's rank	3.80
	Le Bouc and Pessiglione [2013]	32	Parametric analysis, positive correlation with relative income	8.12
	Ligneul et al. [2016]	28	win > loss compared to another- win > loss in control condition	4.82
	Lindner et al. [2014]	30	Performed better > performed worse; parametric analysis, positive correlation with performance deviations in downward comparisons	2.11
	Morawetz at al. [2014]	28	Self-won/other-lost > Self-lost/other-won	6.40
	Steinbeis and Singer [2014]	45	Parametric analysis, positive correlation with experienced Schadenfreude (Self-won/other-lost > Self-won/other-won)	3.31
	Votinov et al. [2015]	69	Self-gain/other-no gain > self loss/other-no loss; self-no loss/other-loss > self-no gain/other-gain	5.65
	Zink et al. [2008]	24	Self-won/other-lost > Self-lost/other-lost	1.80
vmPFC	Brunnlieb et al. [2013]	15	Self-won/other-lost > Self-lost/other-won	13.71
	Du et al. [2013]	19	Self-won/others-lost > self-lost/others-won	14.19
	Fliessbach et al. [2007]	33	Self-won/other-lost > self-lost/other-won + self-lost/other-lost	14.34

TABLE III. (continued).

Cluster name	Study	*N*	Contrast	Average contribution (%)
	Hertz et al. [2017]	19	better performance (positive merit) > worse performance (negative merit)	10.04
	Kätsyri et al. [2012]	17	Self-won/other-lost > self-lost/other-won: human > computer	0.79
	Krämer et al. [2007]	15	Self-won/other-lost > Self-lost/other-won	11.03
	Ligneul et al. [2016]	28	win > loss compared to another-win > loss in control condition	14.61
	Votinov et al. [2015]	69	Self-gain/other-no gain > self loss/other-no loss; self-no loss/other-loss > self-no gain/other-gain	21.26
Upward Social Comparison				
dACC	Baumgartner et al. [2012]	32	disadvantageous outcomes > equal outcomes	0.39
	Cikara et al. [2011]	18	Favored team's failure/rival team's success > control	0.42
	Civai et al. [2012]	19	disadvantageous outcomes > equal outcomes	9.14
	Corradi-Dell'Acqua et al. [2016]	19	disadvantageous outcomes > equal outcomes	0.79
	Fatfouta et al. [2016]	23	disadvantageous outcomes > equal outcomes	4.12
	Feng et al. [2016]	40	disadvantageous outcomes > equal outcomes	3.35
	Guo et al. [2013a]	18	disadvantageous outcomes > equal outcomes	4.32
	Guo et al. [2013b]	21	disadvantageous outcomes > equal outcomes	2.73
	Güroğlu et al. [2011]	68	disadvantageous outcomes > equal outcomes	5.32
	Halko et al. [2009]	23	disadvantageous outcomes > equal outcomes	2.83
	Harlé and Sanfey [2012]	38	disadvantageous outcomes > equal outcomes	3.40
	Haruno & Frith [2010]	52	Parametric analysis, positive correlation with absoluate differences between two peoeple (other > self)	5.20
	Haruno et al. [2014]	62	parametric analysis, positive correlation with disadvantageous level	3.04
	Hu et al. [2016]	23	disadvantageous outcomes > equal outcomes	3.04
	Kirk et al. [2011]	40	disadvantageous outcomes > equal outcomes	2.39
	Kirk et al. [2016]	50	parametric analysis, positive correlation with disadvantageous level	7.86
	Kishida et al. [2012]	27	parametric analysis, negaitive correlated with change of self's rank	4.01
	Lindner et al. [2014]	30	Performed worse > performed better	1.90
	Sanfey et al. [2003]	19	disadvantageous outcomes > equal outcomes	5.18
	Servaas et al. [2015]	114	disadvantageous outcomes > equal outcomes	8.72
	Takahashi et al. [2009]	19	Superior others (high related) > average others; Superior others (low related)> average others	4.83
	van den Bos et al. [2013]	40	Self-not-won/other-won > Self-won/others-lost	3.32
	Verdejo-García et al. [2015b]	44	disadvantageous outcomes > equal outcomes	2.83
	White et al. [2013]	20	parametric analysis, positive correlation with disadvantageous level	2.16
	White et al. [2014]	21	parametric analysis, positive correlation with disadvantageous level	2.75
	Zheng et al. [2015]	25	disadvantageous outcomes > equal outcomes Self-unequal/other-equal > Self-unequal/other-unequal	2.97
	Zhou et al. [2014]	28	disadvantageous outcomes > equal outcomes	2.95
R AI	Baumgartner et al. [2012]	32	disadvantageous outcomes > equal outcomes	9.86
	Beyer et al. [2014a]	40	Self-lost/other-won > Self-won/other-lost	2.07
	Beyer et al. [2014b]	41	Self-lost/other-won > Self-won/other-lost	3.08
	Cikara et al. [2011]	18	Favored team's failure/rival team's success > control	1.78
	Civai et al. [2012]	19	disadvantageous outcomes > equal outcomes	6.42
	Corradi-Dell'Acqua et al. [2016]	19	disadvantageous outcomes > equal outcomes	1.33
	Fatfouta et al. [2016]	23	disadvantageous outcomes > equal outcomes	5.13
	Feng et al. [2016]	40	disadvantageous outcomes > equal outcomes	2.95
	Guo et al. [2013a]	18	disadvantageous outcomes > equal outcomes	2.53
	Guo et al. [2013b]	21	disadvantageous outcomes > equal outcomes	2.93

TABLE III. (continued).

Cluster name	Study	*N*	Contrast	Average contribution (%)
	Halko et al. [2009]	23	disadvantageous outcomes > equal outcomes	6.15
	Harlé and Sanfey [2012]	38	disadvantageous outcomes > equal outcomes	3.00
	Haruno & Frith [2010]	52	Parametric analysis, positive correlation with absoluate differences between two peoeple (other > self)	2.22
	Haruno et al. [2014]	62	parametric analysis, positive correlation with disadvantageous level	3.05
	Kirk et al. [2011]	40	disadvantageous outcomes > equal outcomes	3.53
	Kirk et al. [2016]	50	parametric analysis, positive correlation with disadvantageous level	0.68
	Lindner et al. [2014]	30	Performed worse > performed better	5.71
	Roalf [2010]	27	disadvantageous outcomes > equal outcomes	3.69
	Sanfey et al. [2003]	19	disadvantageous outcomes > equal outcomes	3.20
	Servaas et al. [2015]	114	disadvantageous outcomes > equal outcomes	9.20
	van den Bos et al. [2013]	40	Self-not-won/other-won > Self-won/others-lost	3.28
	White et al. [2013]	20	parametric analysis, positive correlation with disadvantageous level	0.09
	White et al. [2014]	21	parametric analysis, positive correlation with disadvantageous level	1.85
	Wu et al. [2014a,b]	18	parametric analysis, negative correlation with subjective utility	2.85
	Wu et al. [2015]	27	disadvantageous outcomes > equal outcomes	2.97
	Zheng et al. [2015]	25	disadvantageous outcomes > equal outcomes Self-unequal/other-equal > Self-unequal/other-unequal	3.64
	Zhou et al. [2014]	28	disadvantageous outcomes > equal outcomes	3.55
	Zink et al. [2008]	24	Self-lost/other-won > Self-lost/other-lost	3.25
L AI	Baumgartner et al. [2012]	32	disadvantageous outcomes > equal outcomes	3.89
	Beyer et al. [2014a]	40	Self-lost/other-won > Self-won/other-lost	2.37
	Civai et al. [2012]	19	disadvantageous outcomes > equal outcomes	8.94
	Corradi-Dell'Acqua et al. [2016]	19	disadvantageous outcomes > equal outcomes	2.49
	Fatfouta et al. [2016]	23	disadvantageous outcomes > equal outcomes	3.74
	Feng et al. [2016]	40	disadvantageous outcomes > equal outcomes	4.71
	Gospic et al. [1983]	17	disadvantageous outcomes > equal outcomes	4.25
	Gradin et al. [2015]	25	disadvantageous outcomes > equal outcomes	0.98
	Guo et al. [2013a]	18	disadvantageous outcomes > equal outcomes	3.80
	Guo et al. [2013b]	21	disadvantageous outcomes > equal outcomes	4.04
	Halko et al. [2009]	23	disadvantageous outcomes > equal outcomes	4.68
	Harlé and Sanfey [2012]	38	disadvantageous outcomes > equal outcomes	4.98
	Haruno & Frith [2010]	52	Parametric analysis, positive correlation with absoluate differences between two peoeple (other > self)	3.66
	Haruno et al. [2014]	62	parametric analysis, positive correlation with disadvantageous level	4.05
	Hu et al. [2016]	23	disadvantageous outcomes > equal outcomes	3.23
	Kirk et al. [2011]	40	disadvantageous outcomes > equal outcomes	2.22
	Kirk et al. [2016]	50	parametric analysis, positive correlation with disadvantageous level	2.49
	Op de Macks et al. [2016]	58	lower social hierarchy > monetary loss	4.84
	Roalf [2010]	27	disadvantageous outcomes > equal outcomes	2.07
	Sanfey et al. [2003]	19	disadvantageous outcomes > equal outcomes	3.50
	Servaas et al. [2015]	114	disadvantageous outcomes > equal outcomes	7.01
	Steinbeis and Singer [2014]	45	Parametric analysis, positive correlation with experienced Envy (Self-lost/other-won > Self-lost/other-lost)	4.20
	van den Bos et al. [2013]	40	Self-not-won/other-won > Self-won/others-lost	3.37

TABLE III. (continued).

Cluster name	Study	*N*	Contrast	Average contribution (%)
	White et al. [2014]	21	parametric analysis, positive correlation with disadvantageous level	2.26
	Zheng et al. [2015]	25	disadvantageous outcomes > equal outcomes Self-unequal/other-equal > Self-unequal/other-unequal	3.96
	Zink et al. [2008]	24	Self-lost/other-won > Self-lost/other-lost	4.22

N, number of subjects; L, left; R, right; VS, ventral striatum; AI, anterior insula; dACC, dorsal anterior cingulate cortex; vmPFC, ventromedial prefrotnal cortex.

than expected) that are coded by the VS and vmPFC, leading to joyfull feelings in such circumstances. This kind of signal may motivate people to seek behaviors that maintain their advantages. On the other hand, upward comparison indicating inferiority to others might induce negative norm prediction errors (worse than expected) which are processed by the AI and dACC. These negative prediction errors are likely to serve as progenitors of negative feelings (e.g., envy) in response to upward comparison [Montague and Lohrenz, 2007]. This kind of signal may motivate people to seek behaviors that would change this situation. However, the influence of social comparison on human behaviors could be more complex, depending on a variety of social contexts (e.g., comparing with in-group or out-group others) [Blanton et al., 2000], gender [Jones, 2001], and cultures (e.g., collectivism or individualism) [Kang et al., 2013]. More studies are needed in this interesting line of research.

Notably, it should be noted that the RL account is mainly based on the observations that social and non-social reward/loss engages overlapping brain regions. However, such evidence has been demonstrated to be insufficient for the inference of similar functions of the overlapping regions between different tasks, due to the reason that commonly used brain imaging techniques (e.g., fMRI) only provide pooled signal from a large volume of gray matter rather than signal of individual neurons [Logothetis, 2008]. Further studies with advanced imaging techniques (e.g., multi-voxel pattern analysis and fMRI adaptation paradigms) would provide promising approaches to compare the neural patterns of overlapping regions at the sub-voxel level [Corradi-Dell'Acqua et al., 2016; Woo et al., 2014b]. Therefore, these techniques could be used to assess the functional significance of overlaps in activity induced by social comparisons and non-social reward/loss processing. Until now, this line of research has yielded inconsistent findings; some evidence has shown that social and non-social experiences induce similar multi-voxel neural patterns [Corradi-Dell'Acqua et al., 2011; Corradi-Dell'Acqua et al., 2016], whereas other evidence has indicated that social and non-social experiences elicit distinct neural patterns [Krishnan et al., 2016; Wager et al., 2013; Woo et al., 2014b]. Moreover, pharmacological studies provide another way to examine whether social and non-social reward/loss processing shared common neuropsychological mechanisms. Consistent with the RL account, several studies have demonstrated that physical pain-killers could decrease self-

TABLE IV. Significant clusters identified in all folds (100%) of the leave-one-experiment-out (LOEO) analysis for downward social comparison and upward social comparison

Brain Regions	BA	MNI Coordinates (mm) *x*	*y*	*Z*	Probability	Cluster Size (voxels)
100% Downward Social Comparison						
R VS	-	14	8	−14	1	228
L VS	-	−16	4	−12	1	149
100% Upward Social Comparison						
R AI	47	34	16	−16	1	554
L AI	47	−30	18	−14	1	372
dACC	32	10	24	32	1	439
dACC	32	8	26	22	1	29

BA, Brodmann area; L, left; R, right; VS, ventral striatum; AI, anterior insula; dACC, dorsal anterior cingulate cortex; clusters with size over 5 voxels are reported.

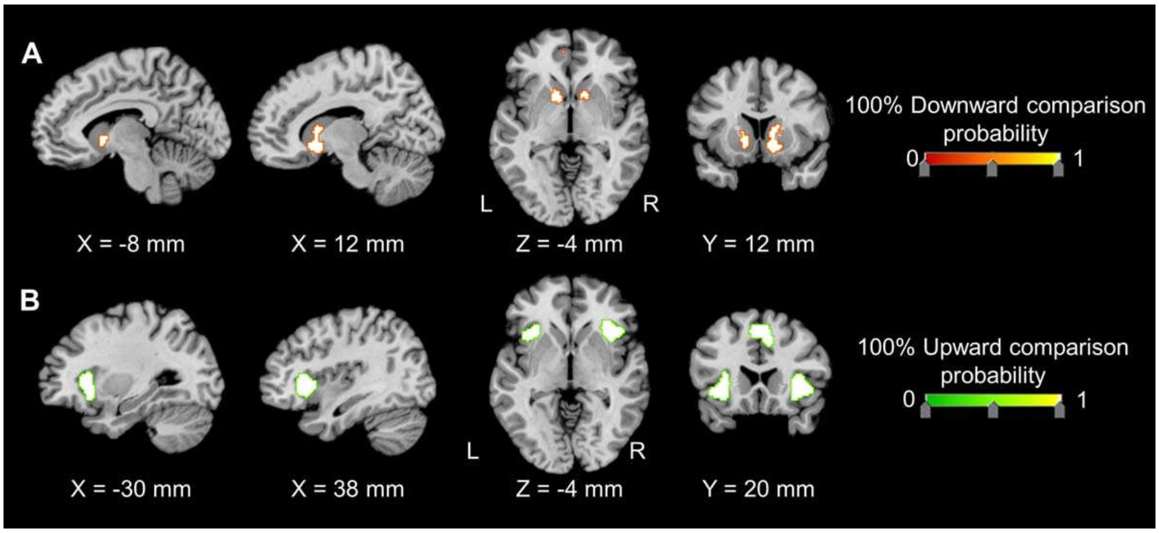

Figure 3.

Significant clusters identified in all folds of the leave-one-experiment-out (LOEO) analysis for downward social comparison and upward social comparison (cluster-level family-wise error correction ($P < 0.05$) with a cluster-forming threshold of $P < 0.001$ using 10,000 permutations). A) Consistent maxima for downward social comparison were found in the ventral striatum (VS). B) Consistent maxima for upward social comparison were found in the bilateral anterior insula (AI) and dorsal anterior cingulate cortex (dACC). L, left; R, right. [Color figure can be viewed at wileyonlinelibrary.com]

reported social distress and the corresponding neural responses [DeWall et al., 2010] and even empathy for the distress of others [Mischkowski et al., 2016].

Finally, it is noteworthy that there are many other accounts on the functions of brain regions revealed in the current meta-analysis. In particular, vmPFC has been shown highly involved in self-related and social processing [Northoff et al., 2006; Zaki et al., 2013]. Our meta-analysis only included those social comparison contexts in which the self is concerned, and thus coincides with this account. In addition, the account of theory-of-mind ability and empathy for vmPFC also hints the process of mentalizing during comparing the self with others. Furthermore, the convergence for downward comparison also covers a part of dorsal striatum, which has been found to be related to motor control [Doyon et al., 2003]. Finally, the AI and dACC were found to be commonly involved in conflict process [Botvinick et al., 1999; Fan et al., 2008], cognitive control [Chein and Schneider, 2005; Egner, 2009], and salience detection [Menon and Uddin, 2010; Seeley et al., 2007]. A previous meta-analysis indicated that the ACC might be the region where pain, negative affect and cognitive control are integrated [Shackman et al., 2011]. Likewise, the AI has also been identified in a variety of tasks associated with cognition, emotion or the interaction between them [Gu et al., 2012, 2013a,b; Fan et al., 2011]. However, these potential accounts do not necessarily contradict with the RL framework, since the control/error signal used for behavior adjustment might manifest in different forms depending on specific contexts, including emotional salience and conflict with others [Lindner et al., 2014].

In summary, our meta-analysis identified (i) a convergence within the VS and vmPFC for downward comparison; and (ii) the convergence within the AI and dACC for upward comparison. Although there exists many other plausible accounts, our findings may be accounted for by the RL theory, holding that reward delivered in different modalities are evaluated by a common metric in the brain to guide decision making [Rangel et al., 2008; Sanfey, 2007]. In this regard, downward comparison might signal positive norm prediction errors coded in the VS and vmPFC and trigger pleasant feelings (e.g., schadenfreude). In contrast, upward comparison might signal negative norm prediction errors detected by the AI and dACC and evoke unpleasant feelings (e.g., envy).

Several limitations related to the current study should be noted. First, the ALE meta-analysis used in the current study considers only the reported coordinates and number of subjects in each study. In comparison, using coordinates of unthresholded statistical maps might be able to provide insights beyond existing reports that may have been biased to report matches to existing publications. Second, the RL account of functions for regions identified in the current study were based on reverse inference, and it should be noted that the RL framework utilized to interpret neural signatures of social comparison may be not mutually exclusive with other accounts. However, the RL account offers some interesting insights on the human social comparison processes, which may provide future studies in this line a heuristic working framework.

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