

Brain mechanisms of social comparison and their influence on the reward system

Gayannée Kedia^{a,c}, Thomas Mussweiler^a and David E.J. Linden^b

Whenever we interact with others, we judge them and whenever we make such judgments, we compare them with ourselves, other people, or internalized standards. Countless social psychological experiments have shown that comparative thinking plays a ubiquitous role in person perception and social cognition as a whole. The topic of social comparison has recently aroused the interest of social neuroscientists, who have begun to investigate its neural underpinnings. The present article provides an overview of these neuroimaging and electrophysiological studies. We discuss recent findings on the consequences of social comparison on the brain processing of outcomes and highlight the role of the brain's reward system. Moreover, we analyze the relationship between the brain networks involved in social comparisons and those active during other forms of cognitive and perceptual comparison. Finally,

we discuss potential future questions that research on the neural correlates of social comparison could address. *NeuroReport* 00:000–000 © 2014 Wolters Kluwer Health | Lippincott Williams & Wilkins.

NeuroReport 2014, 00:000–000

Keywords: dorsal anterior cingulate cortex, mentalizing, medial prefrontal cortex, neuroimaging, parietal cortex, person perception, reward system, social cognition, social comparison, ventral striatum

^aDepartment of Psychology, University of Cologne, Cologne, Germany, ^bSchool of Psychology, Cardiff University, Cardiff, Wales, UK and ^cDepartment of Psychology, University of Graz, Graz, Austria

Correspondence to Gayannée Kedia, MD, PhD, Institut für Psychologie, University Karl-Franzens of Graz, Universitätsplatz 2/III, A-8010 Graz, Austria
Tel: +43 316 380 8511; fax: +43 316 380 9807; e-mail: g.kedia@uni-graz.at

Received 27 March 2014 accepted 30 July 2014

Introduction

Human judgment is by nature comparative. When people make evaluations, they do so in relation to a pertinent norm or standard. To describe oneself as tall, for example, implies that one is taller than others. Even such a basic statement about physical properties is therefore inherently comparative [1]. Comparisons constitute central mechanisms of social judgment and, as a result, stand at the core of a whole range of social cognitive processes. Person perception [2–5], stereotyping [6], attitudes [7], affect [8,9], decision making [10,11], theory of mind [12], and the concept of self [13,14] all rely on comparative processes. Over 50 years of psychological research has shown that social comparisons form one of the cornerstones of social cognition [15].

One of the reasons that could explain the ubiquity of social comparisons is that they provide efficient strategies to make judgments and decisions. By focusing on a subset of information rather than engaging in an exhaustive search of one's knowledge base, social comparisons enable humans to save scarce cognitive resources [16]. This cognitive benefit also shows at the brain level: during a judgment task, comparative information processing was associated with smaller changes in alpha-band activity, suggesting reduced mental effort [17].

In the last few years, neuroscientists have begun to study the neural correlates of social comparison using functional

neuroimaging and noninvasive electrophysiological methods. The aim of the present article is to provide an integrative summary and discussion of this research. Our review is guided by the two main research lines that social neuroscientists have pursued so far. In the first part of this review, we will examine neural evidence suggesting that humans spontaneously rely on social comparison when processing information about themselves or other people. In the second part, we will consider the potential neural structures supporting this mechanism. Finally, we will address questions that entail challenges for future directions such as the connections between the different systems that play a role in social comparison.

Brain response to objective and relative outcomes

When looking for happiness and life satisfaction, people often pursue greater wealth. Reflecting this general tendency of humans to increase their own wealth, traditional economic models of decision-making posit that individual well-being is determined primarily by one's absolute income. Real-life observation and experiments in social environments, however, offer another perspective. What seems to characterize people's subjective well-being is not only how much they own in absolute terms but also how much they own in comparison with others. Social psychologists and anthropologists have indeed shown that social comparisons influence subjective well-being and behavior [18,19]. Do they also influence brain processing of outcomes? Social neuroscience has addressed this question by investigating the influence of

This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

social comparison on two components of the brain reward system [20]: the ventral striatum (VS) and the dorsal anterior cingulate cortex (dACC).

Ventral striatum

The VS constitutes one of the main structures of the reward system. It encompasses the nucleus accumbens, the ventromedial parts of the caudate nucleus and putamen, the olfactory tubercle, and the lateral olfactory tract [21]. The VS reacts to both primary (e.g., pleasant tastes) and secondary rewards (e.g., monetary incentives) and seems to play a role in the formation of stimulus–reward association [22]. Ventral striatal activity is influenced by different kinds of comparisons such as counterfactuals, temporal comparisons, or expectations [23]. Recently, several fMRI studies have investigated whether the VS is also modulated by social comparisons.

These studies have shown that activity in the VS not only depends on absolute but also on relative rewards. For example, in Fliessbach *et al.*'s fMRI study [24], two participants were simultaneously scanned while performing a simple estimation task (Fig. 1a). Participants' monetary reward for a given trial depended only on their own performance and was, thus, unrelated to that of the other player. At the end of a trial, participants would, nevertheless, receive a feedback providing information about both participants' performance and payment. Interestingly, when reading this information, participants seemed to spontaneously engage in social comparison. Results, indeed, showed that ventral striatal activity following gains was not influenced by the absolute amount of money earned but by the relative payoff (Fig. 1b). In other terms, in this experiment, earning 30, 60, or 120 euros did not elicit any significant difference in ventral striatal activity. What caused VS activity to increase was to earn more than the other player. Similar results have been observed by other studies using slightly different paradigms [25–31] and were found in both female and male participants [26,28], suggesting that social comparison exerts a strong and reliable effect on the VS.

The relative information represented in the VS may be used to improve future decisions. To test this hypothesis, Bault *et al.* [25] ran a lottery experiment involving more or less risky decisions. They found that participants exposed to the performance of another player showed increased activity in the medial prefrontal cortex (mPFC) and other regions involved in the attribution of mental states to others. This effect was observed even though participants' outcomes did not depend on the other player's performance. This medial prefrontal activity seemed to be determined by the rewards obtained previously: striatal activation while learning about an outcome predicted mPFC activity when deciding, in the subsequent trial, which of the two lotteries to choose. This suggests that when deciding between two lotteries, participants engaged spontaneously in strategic

competitive reasoning and adjusted their behavior to the other player's to obtain higher payoffs. In line with this hypothesis, behavioral data showed that participants behaved in a more risk-seeking manner when they played in a bold environment in which their counterparts made risky choices. This research thus identifies a network composed of the VS and mPFC that would sustain the mechanism by which social comparison enables adjustment of one's behavior to the behavior of others. The activity of this network seems, however, to depend on the possibilities for self-improvement.

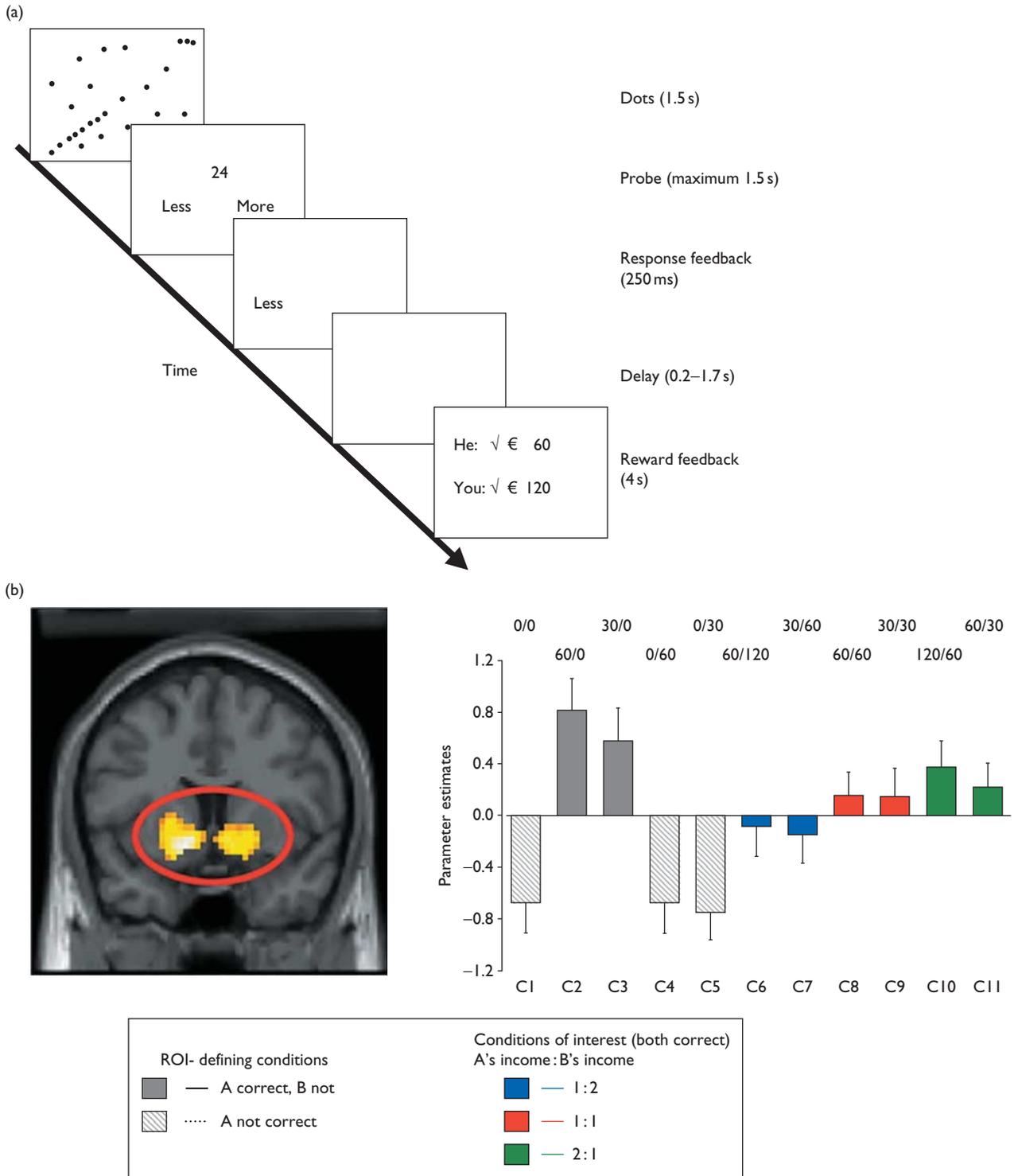
Zink *et al.* [32] have, indeed, observed mPFC activity for comparisons of social status with superior others, but they also noticed that the mPFC was only recruited if the hierarchy was unstable and offered promotion opportunities. In both stable and unstable social hierarchies, viewing a superior individual recruited perceptual–attentional, saliency, and cognitive systems. Yet, when participants had the possibility to improve their social status, additional regions were engaged related to social cognition (mPFC) and emotional processing (amygdala). Social comparison, thus, seems to stimulate self-improvement by the activity of interconnected motivational and social neural networks.

Dorsal anterior cingulate cortex

The dACC is another region that plays a key role in the processing of reward prediction and its errors. The dACC is an integrative hub connecting affective, cognitive, and motor brain regions. Its role is to monitor these functions in potentially conflicting situations, when, for example, an error has been committed or when outcomes do not follow expectancies. dACC activity therefore reflects the subjective evaluation of an outcome and can be used as a measure of the deviation from the desired outcome. This function made the dACC a potential target of social comparison.

In line with this idea, Takahashi *et al.* [33] suggested that perceiving a superior other triggers activity in the dACC and that this activity correlates with envy ratings. Participants in their study read scenarios describing more or less enviable persons. When this person was superior and self-relevant (e.g., a student studying the same major and having similar lifestyle and hobbies) participants reported stronger feelings of envy and showed increased activation in a cluster located at the border between the dACC and the supplementary motor area, a region known for its role in the resolution of cognitive conflict. Moreover, the activation of this area seemed to predict how participants would react to the misfortune of envied others. In a subsequent fMRI study involving the same participants, Takahashi *et al.* [33] presented descriptions of misfortunes happening to the protagonists of the first study (e.g., 'he was falsely accused of cheating in an exam'). Learning about the misfortune of envied individuals triggered a feeling of satisfaction, or *schadenfreude*,

Fig. 1

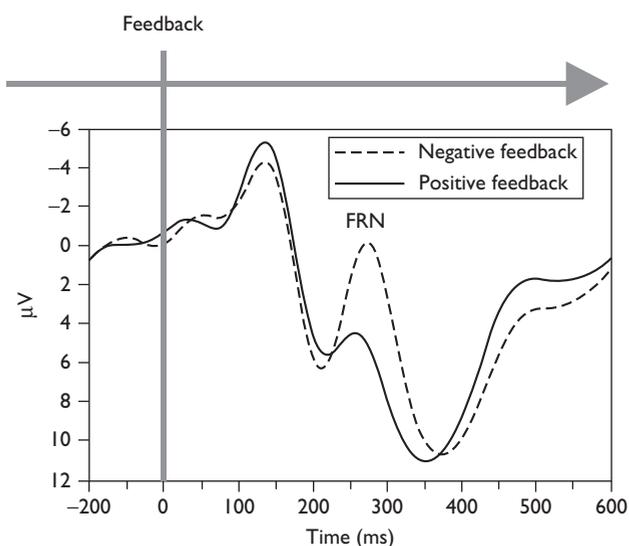


(a) Experimental paradigm classically used to study the consequences of social comparison on the ventral striatum. Participants perform a dot-estimation task at the same time as another player and then receive a feedback about their and the other participant's performance and monetary rewards. (b) Activity in the ventral striatum follows relative rewards independent of the absolute payoff. [Values above the chart bars represent the payoffs in euros of the participant (first value) and the other player (second value)]. ROI, region of interest. Reprinted from Fliessbach *et al.* [24] with permission from AAAS. Adaptations are themselves works protected by copyright. So in order to publish this adaptation, authorization must be obtained both from the owner of the copyright in the original work and from the owner of copyright in the translation or adaptation.

accompanied by an increased activity of the ventral striatum. This ventral striatal activity was, in addition, correlated with the activity observed in the first study around the dACC and supplementary motor area: the stronger the dACC activity while thinking about envied others, the greater the activation of the VS while imagining them in difficult situations. [A recently published fMRI experiment failed to replicate the results of Takahashi *et al.* [33]. Chester *et al.* [34] used a similar paradigm as Takahashi *et al.*'s [33], but in their study, misfortunes of envied others did not induce any ventral striatal activation. Instead of the VS, they found a lack of dorsomedial Prefrontal Cortex (DMPFC) activation for misfortunes of envied individuals, suggesting that envy reduces participants' empathic reactions. The discrepancy between these two fMRI studies is in line with behavioral studies that found conflicting evidence on the role of envy in predicting schadenfreude (for a review on this issue, see Powell *et al.*[35].)]

The error signal produced by the dACC can be measured as a negative event-related potential on the scalp. This feedback-related negativity (FRN) peaks around 300 ms and is maximal at frontocentral scalp electrode sites [36] (Fig. 2). The FRN is observed following losses or error feedback compared with wins or positive feedback, and can also be induced by positive prediction errors such as that produced by unexpected omissions of pain [38]. Several event-related potential (ERP) experiments tested whether the FRN is modulated by social comparison.

Fig. 2



The feedback-related negativity peaks around 300 ms after negative feedback. Reprinted from Walsh and Anderson [37] with permission from Elsevier and Springer. Adaptations are themselves works protected by copyright. So in order to publish this adaptation, authorization must be obtained both from the owner of the copyright in the original work and from the owner of copyright in the translation or adaptation.

ERP experiments investigating the effect of social comparison on reward processing reported discrepant results. In all of these studies, participants performed a simple task (e.g., an estimation of the number of dots on the screen) and received a feedback about their performance and the performance of another player whose reward was independent from the participant's reward. Yet, although these studies rely on similar experimental designs, they all report different results. Boksem *et al.* [39] found enhanced FRN when participants' own outcomes were worse than those of others, but neither Wu *et al.* [40] nor Qiu *et al.* [41] replicated these results. What seemed to matter in these two other experiments was not so much whether the participant received a higher payoff than the other player, but rather whether the two players were equitably rewarded. Surprisingly, however, results of Wu *et al.* [40] and Qiu *et al.* [41] went in opposite directions. Wu *et al.* [40] found an equity effect, that is, increased FRN for equal payoffs compared with unequal ones, whereas Qiu *et al.* [41] observed inequity effects, an enhanced negative component between 350 and 550 ms and located near the ACC in the inequity conditions. The explanation for these apparently inconsistent results may reside in the very nature of the FRN.

The FRN is modulated by several factors that can vary with slight paradigm changes [37]. For example, the FRN is sensitive to outcome probability [36]. In Wu *et al.*'s experiment [40], equal payoffs had the lowest probability: the majority of the trials led to unequal payoffs either because the answer of one of the two players was incorrect or because two correct trials were differently rewarded. This may explain why the researchers observed an enhanced FRN for equity conditions. The FRN is also sensitive to expectations [42, 43]. Qiu *et al.* [41] reported that their participants expected their rewards to be the same as the other player's when they were both correct, which may explain why they found a stronger FRN in the inequity conditions as compared with the equity conditions. Finally, the FRN decreases with perceived task difficulty [44,45]. Thus, it is possible that when the participant was incorrect, but the other player was correct, the participant assumed that the task must have been rather easy and found their error less forgivable, which in return leads to an enhanced FRN as reported by Boksem *et al.* [39]. The sensitivity of the FRN to these slight paradigm differences makes it difficult to draw clear conclusions on the influence of social comparison. It is thus still unclear whether the FRN and more generally ACC activity are influenced by social comparisons in the same way as the VS is.

Conclusion and future research on the brain response to relative outcomes

Neuroimaging studies provide evidence that the brain relies on social comparison when processing rewarding

information. Convergent findings indicate that the VS reacts to relative rewards. This research shows that the VS is modulated by social comparison even when participants' outcomes do not depend on the other player. This suggests that the brain assesses one's personal winnings or achievements in comparison with those of others even when this information is irrelevant to the task and reward at hand. These results are consistent with the hypothesis that social comparisons are 'spontaneous, effortless, and unintentional reactions to the performance of others' ([46], p. 227).

Representation of relative values in the VS influences subsequent decisions through a connection between the VS and the mPFC, an area essential for decision making in social situations. Whether other areas of the reward system are also modulated by social comparison is, however, still unclear. The modulation of the dACC by social comparison still remains to be proven. Experiments testing the influence of social comparison on the FRN are inconsistent and their results may be produced by parameters of the specific experimental paradigms rather than by an actual effect of social comparison.

To our knowledge, the effect of social comparison on the processing of negative outcomes has not been investigated so far. Yet, it has been shown that people rely on social comparisons to cope with difficult situations. Cancer patients, for example, spontaneously engage in comparisons with other patients [47]: comparisons with less fortunate others (i.e., downward comparisons) may help minimize the severity of one's situation and can be used as a strategy to maintain a flattering self-image and positive feelings [48]. Previous neuroimaging experiments have found that negative outcomes, such as punishments, involve the lateral orbitofrontal cortex. Future studies could thus investigate whether the lateral orbitofrontal cortex is modulated by social comparison.

To date, neuroimaging studies have mainly used monetary paradigms to test the influence of social comparison on the reward system (for exception see Zink *et al.* [32]). However, people rely on social comparison to evaluate a much broader set of situations and qualities than just money. People do compare their belongings with those of others, but also their personalities, physical characteristics, performances, aptitudes, achievements, statuses, social groups, relationships, emotions, opinions, and behaviors [49–58]. It is thus essential to also investigate how comparisons along these different dimensions influence motivational brain systems.

Mechanisms of social comparisons

Neuroimaging research suggests that reward processing is highly relative, which is in agreement with social psychological findings that make comparison one of the central mechanisms of social cognition. Yet, what are the cerebral processes that enable us to compare ourselves to

other people? Does social comparison rely on the same brain network as other kinds of comparative judgments or do they engage specific systems?

Comparative networks

Extensive research in cognitive neuroscience has identified a network that may be responsible for the representation and comparison of a wide range of nonsocial magnitudes. This network encompasses the intraparietal sulcus (IPS) as well as areas of the prefrontal cortex [59]. The activity of this network is modulated by a distance effect: the closer two magnitudes (e.g., two numbers), the more difficult the comparison and the greater the activity of this frontoparietal network [60,61]. This network, and in particular the IPS, is recruited by comparisons of numbers presented in different formats (e.g., digits, words), size, dot patterns, line lengths, magnitudes of angles, luminance, and money rewards [60–67]. Social neuroscientists have recently begun to investigate its role in social and person comparisons.

So far, the cerebral mechanisms that enable us to compare ourselves to others have received the attention of only one study [68]. In this fMRI experiment, participants were asked to compare their own height or intelligence with that of individuals they personally know. Results showed a greater engagement of the IPS in height comparisons than intelligence comparisons. Conversely, intelligence comparisons recruited to a larger extent the mPFC and other areas dedicated to the attribution of mental states to others. These results can be explained in two ways. They may reflect differences in the nature of the information retrieved in memory for the comparison (physical vs. psychological information) or they may result from differences in the comparative process itself (for a discussion of this issue, see Kedia *et al.* [68]). To decide between these alternative explanations, one would need to focus on the comparative process and exclude other perceptual or inferential mechanisms. To date, this approach has not been adopted for self–other comparisons, but it has been applied to other–other comparisons.

One strategy to focus on the comparative process consists of using noncomparative control conditions. Lindner *et al.* [69] relied on this method to investigate the neural networks recruited by the comparison of two celebrities' height (Who is taller: Elvis or Bush?) and intelligence (Who is more intelligent: Hanks or Einstein?). In addition to these comparative conditions, the researchers used two control conditions, in which participants had to indicate whether one of the two celebrities was a politician or a musician. This study did not find any activation in the IPS, but rather showed the activity of a network composed of the mPFC and other regions important for social information processing. This network was recruited by both intelligence and height comparisons compared with the control conditions, although activations were stronger for intelligence than height comparisons. This

led the authors to conclude that person comparisons rely on different neural comparative systems than comparisons of other categories of objects. This study does, however, entail confounds that would need to be controlled to interpret these results. First, there was no check to assess whether participants knew the celebrities' height and intelligence and thus had all necessary information to perform the comparisons. Second, the challenge of using a control condition approach is the choice of an appropriate control condition. A good control condition should notably have the same level of difficulty as the conditions of interest, which was not the case in Lindner *et al.*'s [69] study, in which response times were shorter in the control condition than in the comparative ones. Moreover, the control condition should not involve any kind of comparison, which is difficult, given that comparisons are ubiquitous (categorizing a person as a politician or a musician does involve a comparison between the target to categorize and the musician and politician group categories [70,71]). Some have thus suggested another approach that would enable researchers to overcome these limitations.

This other approach makes use of the distance effect, as commonly done to study magnitude comparison and numerical cognition. Some social neuroscientists have indeed reflected that if personal characteristics are similarly represented and compared in the brain as nonsocial magnitudes, they should elicit similar effects and these effects should engage the same neural networks. For example, if person comparisons were to follow a distance effect, one would expect comparisons of persons close on a certain characteristic (e.g., of similar attractiveness) to be more difficult and engage to a greater extent the frontoparietal network associated with nonsocial comparisons. Two articles have already tested this hypothesis for comparisons of height, attractiveness [72], and social status [73]. Both studies found behavioral distance effects and, in both studies, these distance effects engaged the IPS (Fig. 3). These results suggest that social and nonsocial comparisons overlap in the parietal cortex.

The finding that comparisons of personal characteristics recruit the same comparative network as nonsocial comparisons does not, however, imply that different kinds of judgments engage strictly identical brain regions. The studies using the distance effect also showed differences between the compared dimensions. For example, height comparisons elicited overall more IPS activity than attractiveness comparisons and attractiveness comparisons elicited overall greater activity in the fusiform gyrus, a region of the occipital cortex dedicated to face perception and recognition [72]. However, the distance effects remained unaffected by the compared dimension, which suggests that the comparative process was the same.

A putative model could explain both these similarities and differences. This model assumes that perceptual and

evaluative processes vary depending on the compared dimension: facial characteristics such as attractiveness, for example, would recruit the fusiform gyrus whereas body dimensions, such as height, may involve the parietal cortex. This model also assumes that the actual comparison of the extracted magnitudes relies on a common frontoparietal comparative system (Fig. 4).

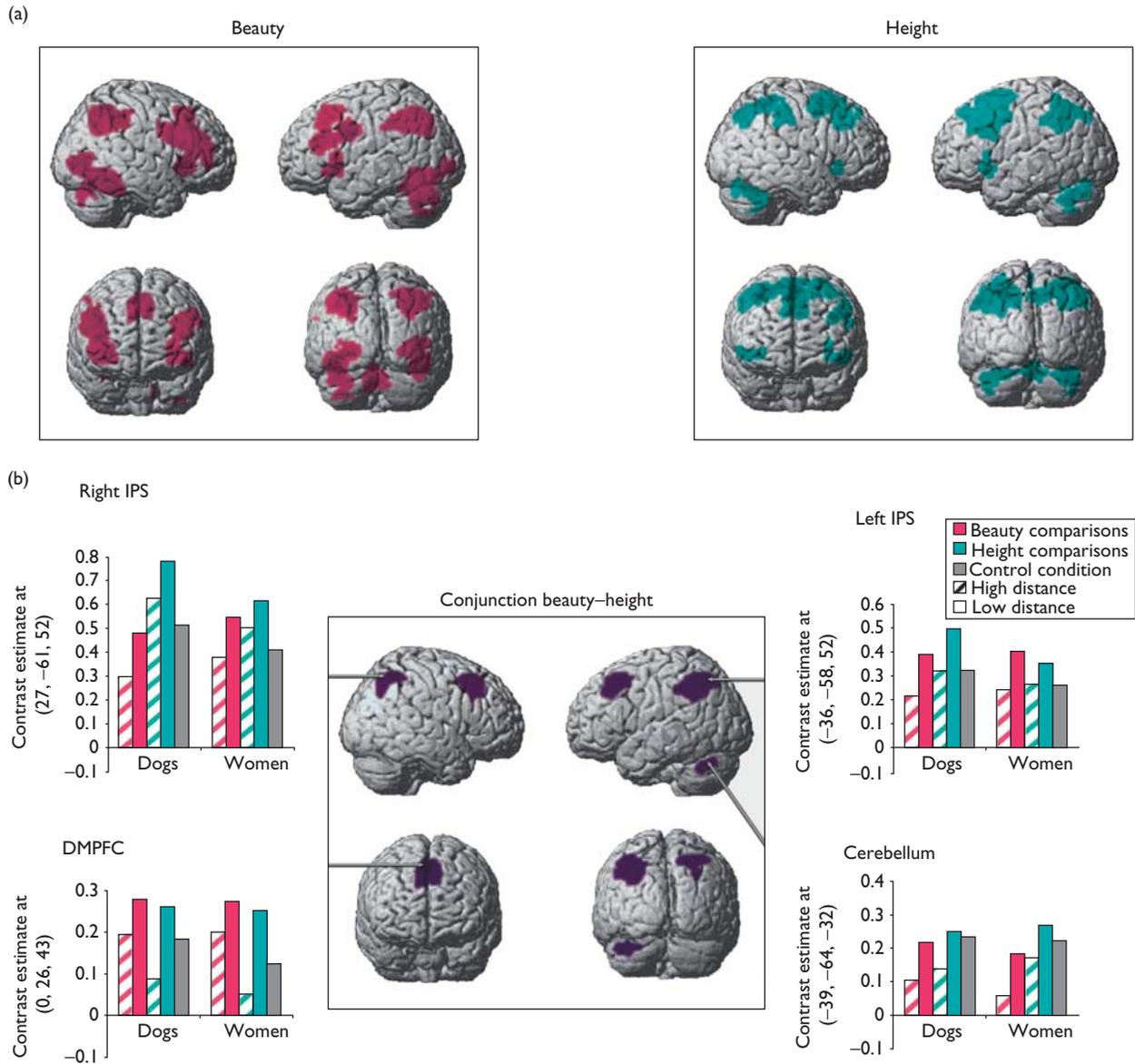
This model could be tested by investigating the time course of comparison processing using ERPs. The model would then predict differences in early perceptual processes (reflected for example by differences in the N170, the face-sensitive ERP component), but no distance effect of these neural markers. Previous ERP studies have observed that the distance effect for numbers – whether presented in words or Arabic digits – emerges at around 200 ms after stimulus onset [74]. One could thus also use electroencephalography to assess whether person comparisons, which involve more complex stimuli than numbers, follow a similar time course as numbers or whether they occur at a later latency.

Conclusion and future research on the underlying mechanisms

Research on the underlying mechanisms of social comparison points to a frontoparietal network also recruited by nonsocial comparisons. The studies that have identified this network relied on comparisons of attractiveness, height, and social status [72,73]. Further investigation is needed to test whether this frontoparietal system is also involved in comparisons of complex mental states such as trustworthiness or intelligence. Future research should also investigate whether this network is recruited by spontaneous comparisons, that is, by situations in which participants compare themselves to others even though they were not explicitly instructed to do so (see paradigms described in the first section and Fig. 1a).

On this note, a recent fMRI experiment [75] suggests that the IPS may be recruited by spontaneous comparisons of financial status. Participants of this study were asked to form an impression of targets with high or low annual salaries. Results showed that the IPS was modulated by the financial status of the targets even though participants were not explicitly instructed to evaluate it. This higher IPS activity for low than for high financial statuses can be interpreted as a distance effect: participants may have spontaneously used their own financial status as a comparison standard to judge those of the targets, and the fact that participants' incomes were closer to the low than to the high financial statuses may have created an effect of distance. This interpretation is, however, speculative, given that the study did not actually measure the distance between participants' and targets' financial situations and its effect on the IPS. The role of the IPS in spontaneous social comparisons thus still remains to be determined by more direct investigations.

Fig. 3

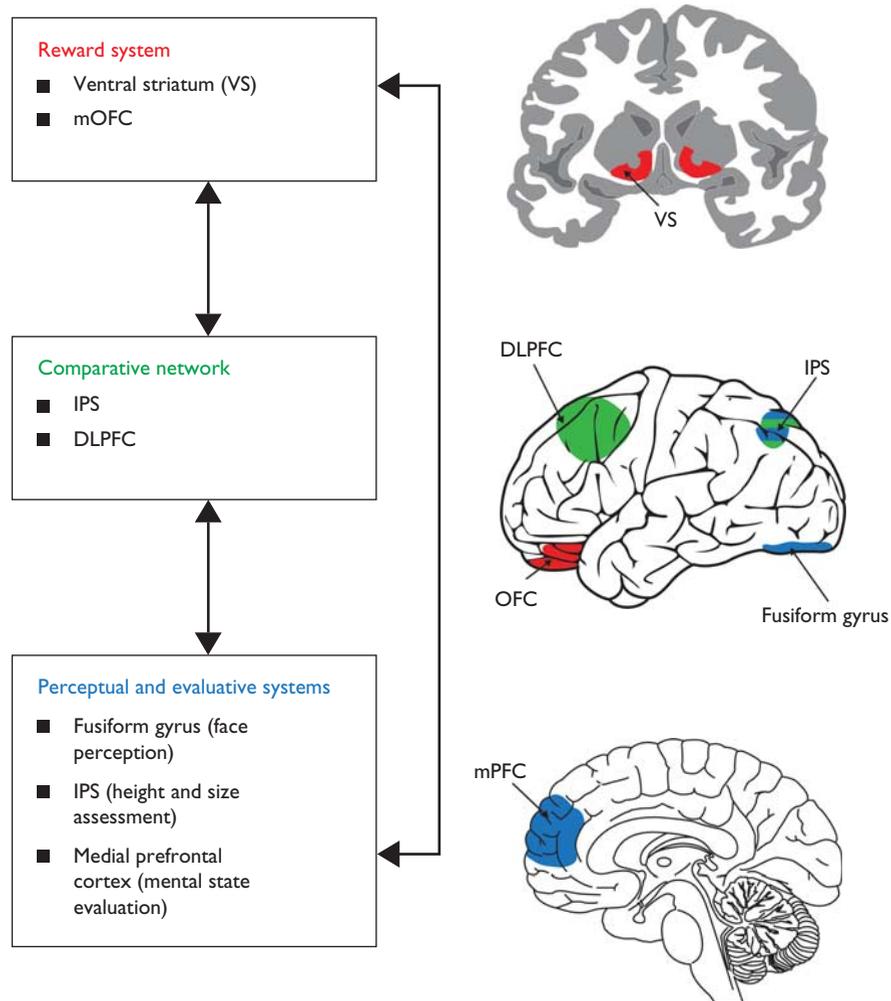


(a) Frontoparietal activations for beauty and height distance effects. (b) The beauty and height distance effects overlap in the right and left intraparietal sulcus (IPS), the DMPFC, and the cerebellum, four regions known for their involvement in comparisons of numbers and simple nonsocial magnitudes. Reprinted from Kedia *et al.* [72] with permission from Oxford University Press. Adaptations are themselves works protected by copyright. So in order to publish this adaptation, authorization must be obtained both from the owner of the copyright in the original work and from the owner of copyright in the translation or adaptation.

In general, the involvement of the comparative frontoparietal network should be tested for a broader range of self–other comparisons: it is still unclear whether self–other comparisons involve a distance effect and whether this distance effect relies on the activity of the same frontoparietal network as other–other comparisons. When comparing themselves with others, people show biases that may influence comparative brain processes. For example, people have a tendency to overestimate their qualities and to consider themselves as better than

average [76]. At the brain level, this biased evaluation occurs with decreased activation of the medial orbitofrontal cortex (mOFC; see Fig. 5 and Beer and Hughes [77]). In this context, the mOFC may enable one to correct one's initial biased evaluation and shift from one's natural response tendency [78–80]. So far, the question of whether (and how) self-related biases influence comparison processes has not received much attention. Do self–other comparisons rely on the same frontoparietal network as other–other and nonsocial comparisons? If so,

Fig. 4



Main networks recruited by social comparisons. DLPFC, dorsolateral prefrontal cortex; IPS, intraparietal sulcus; mOFC, medial orbitofrontal cortex; mPFC, medial prefrontal cortex.

is this network modulated by self-related brain regions, such as the mOFC? Or do self–other comparisons rather engage brain networks that are distinct from those supporting other kinds of comparisons? Future research should identify the different networks involved in self–other comparisons and analyze how they interact with each other.

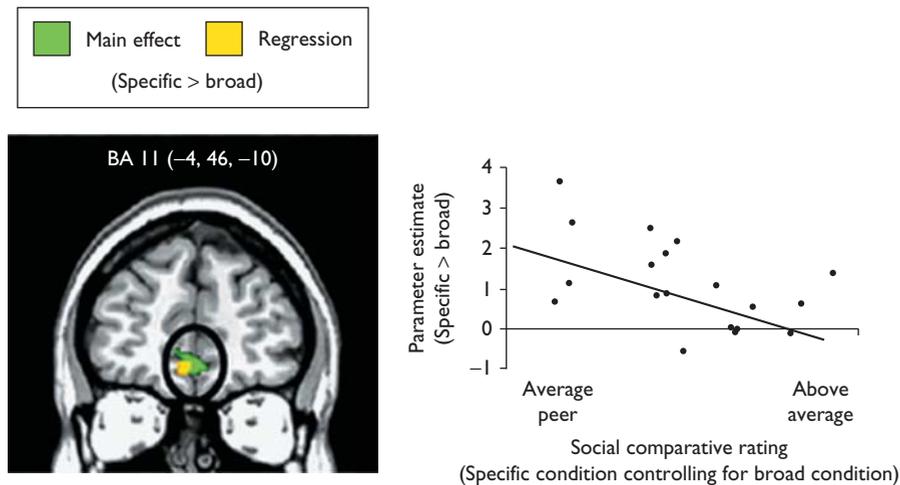
Future directions

Social comparison constitutes a fundamental social cognitive process and is the focus of one of the major theories in social psychology. This research field has recently begun to spread out to neuroscience, but many questions still remain to be explored.

So far, neuroimaging studies on social comparison have either focused on the influence of social comparison on the reward system in gaming situations or on the cognitive and neural mechanisms supporting explicit

comparisons. These two research areas have not yet, however, been linked to each other and the question of the connection between the comparative and reward systems still remains to be elucidated. Functional connectivity analyses would be well suited to address this question [81]. These analyses rely on fMRI data to characterize the interactions between spatially remote brain regions and could, thus, be used to explore the correlation between the comparative and reward brain systems. This question could also be addressed in the context of the selective accessibility model [15]. This social cognitive model posits two ways of comparing oneself with others. On the one hand, one can seek similarities between oneself and the comparison standard and assimilate to this person; on the other hand, one can focus on the dissimilarities and contrast away from the standard. These two comparative processes have opposing consequences. Assimilation to an upward standard (e.g., former race car driver Niki Lauda) leads to a

Fig. 5



People tend to consider that they possess more desirable personalities than others. At the brain level, this above-average effect comes with a reduction in medial orbitofrontal cortex activity. Reprinted from Beer and Hughes [77] with permission from Elsevier. Adaptations are themselves works protected by copyright. So in order to publish this adaptation, authorization must be obtained both from the owner of the copyright in the original work and from the owner of copyright in the translation or adaptation.

positive self-evaluation (I have high athletic abilities), whereas contrast leads to a negative self-evaluation (I have poor athletic abilities). At the brain level, assimilation and contrast comparison mindsets may reverse the effect of social comparison on the reward system and change the sign of social prediction errors. For example, participants engaging in similarity testing may show higher levels of ventral striatal activity when exposed to a more rewarded co-player. This hypothesis remains to be tested and the effects of similarity and dissimilarity testing on the comparative and affective systems should be explored.

The social psychology literature suggests that the mechanisms underlying social comparison and their connection to the reward system are likely to be modulated by several factors. The standard chosen for the comparison is of primary importance [82,83]. In experimental settings, comparison standards have usually been external persons (e.g., a familiar other, a celebrity, a confederate, or another participant) but it would also be interesting to consider internal standards (e.g., ideal, past, or future selves, societal norms). Comparisons with internal standards are frequently used in everyday life to evaluate or motivate oneself and improve one's performance [84,85]. For example, people with chronic medical problems tend to engage in comparisons with their past selves and to consider their present condition as better than it used to be at the beginning of their disease [86]. It is, however, still unclear whether comparisons with internal standards recruit the same brain networks as comparisons with external ones.

Previous research in social psychology has also shown how the characteristics of the standard influence the

comparison process: people tend to assimilate – rather than contrast away – to similar, familiar, moderate, and psychologically close standards as well as to members of their ingroup [15,87,88]. How these characteristics influence the comparative and emotional brain systems would be a question of great interest.

Besides the comparison standard, social comparisons also depend on personality and cultural influences. Although the desire to compare oneself to others is universal, some people are more prone to engage in social comparisons than others. Individuals high in social comparison orientation (SCO) engage in social comparison more often and they are also more affected by it [89]. SCO has been shown to correlate with several other personality dimensions. People high in SCO tend to be more self-conscious and show lower self-esteem and higher neuroticism [90]. In a similar vein, depressed patients report an increased proneness to compare oneself with others [91,92]. Individuals who are prone to social comparisons are more interested in what others feel and need and show higher levels of empathy [90]. This suggests that SCO does not merely reflect a competitive mindset but rather an interdependent self. It is therefore not surprising that higher SCO has been observed in women compared with men and in cultures high on interdependence and power distance belief [93]. In accordance with these observations, a recent fMRI experiment reports that Korean participants (representing an interdependent culture in the study) show a stronger modulation of the VS by social comparisons than American participants (representing an independent culture [31]). On the basis of the general differences in SCO between men and women, one might also expect a modulation by

sex. However, neuroimaging studies investigating the neural correlates of social comparison have not observed any significant difference in VS activity between men and women [26–28]. It is, however, important to note that all these studies are limited in that they relied on small samples of participants (between eight and 38 of each sex) and may lack the statistical power to show significant differences. Future experiments involving larger samples should thus clarify whether sex differences in social comparison behavior are associated with identifiable neural differences.

Conclusion

All judgments and evaluations are relative in nature and hence rely on comparisons. Social comparisons are involved in a wide range of social cognitive processes spanning from person perception to attitudes and stereotyping. The discovery of the neural correlates of social comparison would enable researchers to evaluate the role played by comparison in social cognitive processes and as a consequence to further elucidate the neural mechanisms of social cognition.

Acknowledgements

G.K., T.M., and D.L. are supported by a grant from the bilateral program between the Economic and Social Research Council of the UK (ESRC) and the German Research Foundation (DFG) (RES-062-23-0946: The Neural Substrates of Social Comparison).

Conflicts of interest

There are no conflicts of interest.

References

- Huttenlocher J, Higgins ET. Adjectives, comparatives, and syllogisms. *Psychol Rev* 1971; **78**:487–504.
- Corcoran K, Mussweiler T. Comparative thinking styles in group and person perception: one mechanism – many effects. *Soc Personal Psychol Compass* 2009; **3**:244–259.
- Herr PM. Consequences of priming: judgment and behavior. *J Pers Soc Psychol* 1986; **51**:1106–1115.
- Higgins ET, Lurie L. Context, categorization, and recall: the 'change-of-standard' effect. *Cogn Psychol* 1983; **15**:525–547.
- Mussweiler T, Ruter K, Epstude K. The man who wasn't there: subliminal social comparison standards influence self-evaluation. *J Exp Soc Psychol* 2004; **40**:689–696.
- Corcoran K, Hundhammer T, Mussweiler T. A tool for thought! When comparative thinking reduces stereotyping effects. *J Exp Soc Psychol* 2009; **45**:1008–1011.
- Sherif M, Hovland CI. *Social judgment: assimilation and contrast effects in communication and attitude change*. New Haven, CT: Yale University Press; 1961.
- Higgins ET. Self-discrepancy: a theory relating self and affect. *Psychol Rev* 1987; **94**:319–340.
- Crusius J, Mussweiler T. When people want what others have: the impulsive side of envious desire. *Emotion* 2012; **12**:142–153.
- Kahneman D, Miller DT. Norm theory: comparing reality to its alternatives. *Psychol Rev* 1986; **93**:136–153.
- Tversky A, Kahneman D. Judgment under uncertainty: heuristics and biases. *Science* 1974; **185**:1124–1131.
- Todd AR, Hanks K, Galinsky AD, Mussweiler T. When focusing on differences leads to similar perspectives. *Psychol Sci* 2011; **22**:134–141.
- Festinger L. A theory of social comparison processes. *Hum Relations* 1954; **7**:117–140.
- Higgins ET, Strauman T, Klein R. Standards and the process of self-evaluation: multiple affects from multiple stages. In: Sorrentino RM, Higgins ET, editors. *Handbook of motivation and cognition: foundations of social behavior*. New York: Guilford Press; 1986. pp. 23–63.
- Mussweiler T. Comparison processes in social judgment: mechanisms and consequences. *Psychol Rev* 2003; **110**:472–489.
- Mussweiler T, Epstude K. Relatively fast! Efficiency advantages of comparative thinking. *J Exp Psychol Gen* 2009; **138**:1–21.
- Keil A, Mussweiler T, Epstude K. Alpha-band activity reflects reduction of mental effort in a comparison task: a source space analysis. *Brain Res* 2006; **1121**:117–127.
- Hagerty MR. Social comparisons of income in one's community: evidence from national surveys of income and happiness. *J Pers Soc Psychol* 2000; **78**:764–771.
- Smith RH, Diener E, Wedell DH. Intrapersonal and social comparison determinants of happiness: a range-frequency analysis. *J Pers Soc Psychol* 1989; **56**:317–325.
- Swencionis JK, Fiske ST. How social neuroscience can inform theories of social comparison. *Neuropsychologia* 2014; **56**:140–146.
- Haber SN, Knutson B. The reward circuit: linking primate anatomy and human imaging. *Neuropsychopharmacology* 2010; **35**:4–26.
- McClure SM, York MK, Montague PR. The neural substrates of reward processing in humans: the modern role of fMRI. *Neuroscientist* 2004; **10**:260–268.
- Seymour B, McClure SM. Anchors, scales and the relative coding of value in the brain. *Curr Opin Neurobiol* 2008; **18**:173–178.
- Fliessbach K, Weber B, Trautner P, Dohmen T, Sunde U, Elger CE, Falk A. Social comparison affects reward-related brain activity in the human ventral striatum. *Science* 2007; **318**:1305–1308.
- Bault N, Joffily M, Rustichini A, Coricelli G. Medial prefrontal cortex and striatum mediate the influence of social comparison on the decision process. *Proc Natl Acad Sci U S A* 2011; **108**:16044–16049.
- Dohmen T, Falk A, Fliessbach K, Sunde U, Weber B. Relative versus absolute income, joy of winning, and gender: brain imaging evidence. *J Public Econ* 2011; **95**:279–285.
- Dvash J, Gilam G, Ben-Ze'ev A, Hendler T, Shamay-Tsoory SG. The envious brain: the neural basis of social comparison. *Hum Brain Mapp* 2010; **31**:1741–1750.
- Fliessbach K, Philippis CB, Trautner P, Schnabel M, Elger CE, Falk A, Weber B. Neural responses to advantageous and disadvantageous inequity. *Front Hum Neurosci* 2012; **6**:165.
- Grygolec J, Coricelli G, Rustichini A. Positive interaction of social comparison and personal responsibility for outcomes. *Front Psychol* 2012; **3**:25.
- Du X, Zhang M, Wei D, Li W, Zhang Q, Qiu J. The neural circuitry of reward processing in complex social comparison: evidence from an event-related fMRI study. *PLoS One* 2013; **8**:e82534.
- Kang P, Lee Y, Choi I, Kim H. Neural evidence for individual and cultural variability in the social comparison effect. *J Neurosci* 2013; **33**:16200–16208.
- Zink CF, Tong Y, Chen Q, Bassett DS, Stein JL, Meyer-Lindenberg A. Know your place: neural processing of social hierarchy in humans. *Neuron* 2008; **58**:273–283.
- Takahashi H, Kato M, Matsuura M, Mobbs D, Suhara T, Okubo Y. When your gain is my pain and your pain is my gain: neural correlates of envy and schadenfreude. *Science* 2009; **323**:937–939.
- Chester DS, Powell CA, Smith RH, Joseph JE, Kedia G, Combs DJ, DeWall CN. Justice for the average Joe: the role of envy and the mentalizing network in the deservingness of others' misfortunes. *Soc Neurosci* 2013; **8**:640–649.
- Powell CAJ, Smith RH, Schurtz DR. Schadenfreude caused by an envied person's pain. In: Smith RH, editor. *Envy: theory and research*. New York: Oxford University Press; 2008. pp. 148–164.
- Cohen MX, Elger CE, Ranganath C. Reward expectation modulates feedback-related negativity and EEG spectra. *Neuroimage* 2007; **35**:968–978.
- Walsh MM, Anderson JR. Learning from experience: event-related potential correlates of reward processing, neural adaptation, and behavioral choice. *Neurosci Biobehav Rev* 2012; **36**:1870–1884.
- Talmi D, Atkinson R, El-Deredy W. The feedback-related negativity signals salience prediction errors, not reward prediction errors. *J Neurosci* 2013; **33**:8264–8269.
- Boksem MA, Kostermans E, De Cremer D. Failing where others have succeeded: Medial frontal negativity tracks failure in a social context. *Psychophysiology* 2011; **48**:973–979.

- 40 Wu Y, Zhang D, Elieson B, Zhou X. Brain potentials in outcome evaluation: when social comparison takes effect. *Int J Psychophysiol* 2012; **85**:145–152.
- 41 Qiu J, Yu C, Li H, Jou J, Tu S, Wang T, et al. The impact of social comparison on the neural substrates of reward processing: an event-related potential study. *Neuroimage* 2010; **49**:956–962.
- 42 Bismark AW, Hajcak G, Whitworth NM, Allen JJ. The role of outcome expectations in the generation of the feedback-related negativity. *Psychophysiology* 2013; **50**:125–133.
- 43 Liao Y, Gramann K, Feng W, Deák GO, Li H. This ought to be good: brain activity accompanying positive and negative expectations and outcomes. *Psychophysiology* 2011; **48**:1412–1419.
- 44 Endrass T, Klawohn J, Gruetzmann R, Ischebeck M, Kathmann N. Response-related negativities following correct and incorrect responses: evidence from a temporospatial principal component analysis. *Psychophysiology* 2012; **49**:733–743.
- 45 Kaczurkin AN. The effect of manipulating task difficulty on error-related negativity in individuals with obsessive-compulsive symptoms. *Biol Psychol* 2013; **93**:122–131.
- 46 Gilbert DT, Giesler RB, Morris KA. When comparisons arise. *J Pers Soc Psychol* 1995; **69**:227–236.
- 47 Wood JV, Taylor SE, Lichtman RR. Social comparison in adjustment to breast cancer. *J Pers Soc Psychol* 1985; **49**:1169–1183.
- 48 Taylor SE, Wood JV, Lichtman RR. It could be worse: selective evaluation as a response to victimization. *Soc Issues* 1983; **39**:19–40.
- 49 Alicke MD, LoSchiavo FM, Zerbst J, Zhang S. The person who outperforms me is a genius: maintaining perceived competence in upward social comparison. *J Pers Soc Psychol* 1997; **73**:781–789.
- 50 Corning AF, Krumm AJ, Smitham LA. Differential social comparison processes in women with and without eating disorder symptoms. *J Couns Psychol* 2006; **53**:338–349.
- 51 Darley JM. Fear and social comparison as determinants of conformity behavior. *J Pers Soc Psychol* 1966; **4**:73–78.
- 52 Dunning D, Hayes AF. Evidence for egocentric comparison in social judgment. *J Pers Soc Psychol* 1996; **71**:213–229.
- 53 Gibbons FX, Benbow CP, Gerrard M. From top dog to bottom half: social comparison strategies in response to poor performance. *J Pers Soc Psychol* 1994; **67**:638–652.
- 54 Hobza CL, Walker KE, Yakushko O, Peugh JL. What about men? Social comparison and the effects of media images on body and self-esteem. *Psychol Men Masc* 2007; **8**:161–172.
- 55 Johnson SE, Richeson JA, Finkel EJ. Middle class and marginal? Socioeconomic status, stigma, and self-regulation at an elite university. *J Pers Soc Psychol* 2011; **100**:838–852.
- 56 Locke KD. Status and solidarity in social comparison: agentic and communal values and vertical and horizontal directions. *J Pers Soc Psychol* 2003; **84**:619–631.
- 57 Mussweiler T, Damisch L. Going back to Donald: how comparisons shape judgmental priming effects. *J Pers Soc Psychol* 2008; **95**:1295–1315.
- 58 Rothgerber H, Worchel S. The view from below: intergroup relations from the perspective of the disadvantaged group. *J Pers Soc Psychol* 1997; **73**:1191–1205.
- 59 Cohen Kadosh R, Walsh V. Numerical representation in the parietal lobes: abstract or not abstract? *Behav Brain Sci* 2009; **32**:313–328.
- 60 Cohen Kadosh R, Henik A, Rubinsten O, Mohr H, Dori H, van de Ven V, et al. Are numbers special? The comparison systems of the human brain investigated by fMRI. *Neuropsychologia* 2005; **43**:1238–1248.
- 61 Nieder A, Dehaene S. Representation of number in the brain. *Annu Rev Neurosci* 2009; **32**:185–208.
- 62 Dormal V, Andres M, Pesenti M. Contribution of the right intraparietal sulcus to numerosity and length processing: an fMRI-guided TMS study. *Cortex* 2012; **48**:623–629.
- 63 Dormal V, Pesenti M. Common and specific contributions of the intraparietal sulci to numerosity and length processing. *Hum Brain Mapp* 2009; **30**:2466–2476.
- 64 Fias W, Lammertyn J, Reynvoet B, Dupont P, Orban GA. Parietal representation of symbolic and nonsymbolic magnitude. *J Cogn Neurosci* 2003; **15**:47–56.
- 65 Hare TA, Schultz W, Camerer CF, O'Doherty JP, Rangel A. Transformation of stimulus value signals into motor commands during simple choice. *Proc Natl Acad Sci U S A* 2011; **108**:18120–18125.
- 66 Pinel P, Piazza M, Le Bihan D, Dehaene S. Distributed and overlapping cerebral representations of number, size, and luminance during comparative judgments. *Neuron* 2004; **41**:983–993.
- 67 Wunderlich K, Rangel A, O'Doherty JP. Neural computations underlying action-based decision making in the human brain. *Proc Natl Acad Sci U S A* 2009; **106**:17199–17204.
- 68 Kedia G, Lindner M, Mussweiler T, Ihssen N, Linden DE. Brain networks of social comparison. *Neuroreport* 2013; **24**:259–264.
- 69 Lindner M, Hundhammer T, Ciaramidaro A, Linden DE, Mussweiler T. The neural substrates of person comparison – an fMRI study. *Neuroimage* 2008; **40**:963–971.
- 70 Smith ER, Zárate MA. Exemplar and prototype use in social categorization. *Soc Cogn* 1990; **8**:243–262.
- 71 Smith ER, Zárate MA. Exemplar-based model of social judgment. *Psychol Rev* 1992; **99**:3–21.
- 72 Kedia G, Mussweiler T, Mullins P, Linden DE. The neural correlates of beauty comparison. *Soc Cogn Affect Neurosci* 2013; **9**:681–688.
- 73 Chiao JY, Harada T, Oby ER, Li Z, Parrish T, Bridge DJ. Neural representations of social status hierarchy in human inferior parietal cortex. *Neuropsychologia* 2009; **47**:354–363.
- 74 Dehaene S. The organization of brain activations in number comparison: event-related potentials and the additive-factors method. *J Cogn Neurosci* 1996; **8**:47–68.
- 75 Cloutier J, Ambady N, Meagher T, Gabrieli JD. The neural substrates of person perception: spontaneous use of financial and moral status knowledge. *Neuropsychologia* 2012; **50**:2371–2376.
- 76 Hoorens V. Self-enhancement and superiority biases in social comparison. *Eur Rev Social Psychol* 1993; **4**:113–139.
- 77 Beer JS, Hughes BL. Neural systems of social comparison and the 'above-average' effect. *Neuroimage* 2010; **49**:2671–2679.
- 78 Hughes BL, Beer JS. Medial orbitofrontal cortex is associated with shifting decision thresholds in self-serving cognition. *Neuroimage* 2012; **61**:889–898.
- 79 Hughes BL, Beer JS. Orbitofrontal cortex and anterior cingulate cortex are modulated by motivated social cognition. *Cereb Cortex* 2012; **22**:1372–1381.
- 80 Hughes BL, Beer JS. Protecting the self: the effect of social-evaluative threat on neural representations of self. *J Cogn Neurosci* 2013; **25**:613–622.
- 81 Rogers BP, Morgan VL, Newton AT, Gore JC. Assessing functional connectivity in the human brain by fMRI. *Magn Reson Imaging* 2007; **25**:1347–1357.
- 82 Corcoran K, Cruisus J, Mussweiler T. Social comparison: motives, standards, and mechanisms. In: Chadee D, editor. *Theories in social psychology*. Oxford, UK: Wiley-Blackwell; 2011. pp. 119–139.
- 83 Suls J, Martin R, Wheeler L. Social comparison: why, with whom, and with what effect? *Curr Dir Psychol Sci* 2002; **11**:159–163.
- 84 Redersdorff S, Guimond S. Comparing oneself over time: the temporal dimension in social comparison. In: Guimond S, editor. *Social comparison and social psychology: understanding cognition, intergroup relations and culture*. Cambridge: Cambridge University Press; 2006. pp. 76–96.
- 85 Wilson AE, Ross M. The frequency of temporal-self and social comparisons in people's personal appraisals. *J Pers Soc Psychol* 2000; **78**:928–942.
- 86 Affleck G, Tennen H. Social comparison and coping with major medical problems. In: Suls J, Wills TA, editors. *Social comparison: contemporary theory and research*. Hillsdale, NJ: Erlbaum; 1991. pp. 369–393.
- 87 Häfner M. Knowing you, knowing me: familiarity moderates comparison outcomes to idealized media images. *Soc Cogn* 2009; **27**:496–508.
- 88 Mussweiler T, Bodenhausen GV. I know you are, but what am I? Self-evaluative consequences of judging in-group and out-group members. *J Pers Soc Psychol* 2002; **82**:19–32.
- 89 Gibbons FX, Buunk BP. Individual differences in social comparison: development of a scale of social comparison orientation. *J Pers Soc Psychol* 1999; **76**:129–142.
- 90 Buunk AP, Gibbons FX. Social comparison orientation: a new perspective on those who do and those who don't compare with others. In: Guimond S, editor. *Social comparison and social psychology: Understanding cognition, intergroup relations and culture*. Cambridge: Cambridge University Press; 2006. pp. 15–32.
- 91 Hamel AE, Zaitsoff SL, Taylor A, Menna R, Le Grange D. Body-related social comparison and disordered eating among adolescent females with an eating disorder, depressive disorder, and healthy controls. *Nutrients* 2012; **4**:1260–1272.
- 92 Sheeran P, Abrams D, Orbell S. Unemployment, self-esteem, and depression: a social comparison theory approach. *Basic Appl Soc Psych* 1995; **17**:65–82.
- 93 Guimond S, Chatard A, Branscombe NR, Brunot S, Buunk AP, Conway MA, et al. Social comparison across cultures II: change and stability in self-views – experimental evidence. In: Guimond S, editor. *Social comparison and social psychology: understanding cognition, intergroup relations and culture*. Cambridge: Cambridge University Press; 2006. pp. 318–344.