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Cognitive computation of jealous emotion

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Abstract: The computational role of jealous emotion has been proposed in a model of emotion, in which the desirable gain (or loss) is used as a measure for computing the emotional feedback that assesses the discrepancy between what an individual wants and gets. The jealous emotion is elicited when the perception that the other individuals have more than one has, or that the desire of wanting what others have, but cannot get. Such self-identified error measure is used as an internal measure to monitor the incongruence between model prediction and actual outcome, such that the accuracy of predictions by the brain can be assessed. Jealousy can serve as a motivating signal to an individual to self-correct errors that may exist. This error signal signifies the incongruence between the desirable and the actual outcomes. This (unhappy) jealous emotion provides the necessary feedback to self-correct any potential source of errors, which may originate from the errors in (input) perception, (output) execution or (internal) model. An ultimatum game (UG) paradigm is used to elicit self-generated emotion. Results showed that the emotional intensity of jealousy is inversely proportional to perceived gains (and proportional to the perceived losses). Subjective jealousy biases are represented by shifting of the emotional stimulus-response function. This suggested that jealousy can be resolved by correcting (1) the perception of unfairness (perceptual error), (2) wrong decision (execution error) and (3) faulty assumption of entitlement (model prediction error) in this experimental UG paradigm. The results confirmed the hypothesis that self-regulated jealousy is processed cognitively in proportional to the perceived loss, when one wants to gain something that one cannot get. Implications on emotional intelligence are also addressed.

Keywords: Emotion, Jealousy, Fairness, Ultimatum Game, Decision Making, Error Minimization, Emotional Intelligence

1. Introduction

Toward the goal of understanding the computational nature of emotion, we have developed a neurobiological model of emotion that allows us to examine the hidden variables involved in emotional processing [1, 2]. The model essentially identified emotion as a feedback for self-discovery of errors between the internal model and actual reality in the real world. Accurate representation and prediction of the external world by the internal brain model will increase the chance of survival of an animal, such that it is less likely to encounter catastrophic failure.

Emotion serves as an indicator to self-identify the existence of error that may exist by comparing the discrepancy between the outcomes of the internal model prediction and the actual outcome. This discrepancy signal corresponds to the error that needs to be corrected in order to achieve congruency. Happy emotion emerges as an internal indicator for congruency, and unhappy emotion as a feedback for incongruency. Unhappy emotion is a feedback that assesses the discrepancy between self and others. Thus, if an individual gets what he/she wants, he/she will be happy. If not, he/she will experience unhappiness. According to this model, jealousy is an unhappy emotion that indicates the desire to want what the other individuals have (and cannot accept the fact that the others have more), but cannot get it. It is an emotional feedback, which signifies the inadequacy of the individual for his/her inability to get what others have. This provides the theoretical basis of the computational model for assessing the adequacy of the individual, such that corrective actions can be made to fulfill the void of its inadequacy, when the jealous emotion is experienced.

This model differs from most other common descriptions of jealousy in which jealousy is viewed as an unique attribute to romantic love relationships [3], human relationships [4], or in pathological conditions such as delusional jealousy [5].

The neurobiological origins of the jealous emotion can be traced to the prefrontal cortex that involves dopamine as the neurotransmitter [6].

1.1. Emotional Processing Steps: Self-Discovery, Self-Identification and Self-Correction of Error

The key for deriving the computational processing of emotion in animals is this self-bootstrap approach to the self-discovery of errors that may exist, even without any *a priori* knowledge of what these potential errors may be. That is because error conditions in interacting with the real world are often unpredictable and unforeseen. The computational task essentially requires the ability to self-identify the existence of errors and self-discover the source of errors for self-survival and self-preservation before correction of errors may be made.

The source of errors can come from multiple sources, including sensory (input) perceptual error, motor (output) execution error, and modeling (internal belief/prediction) error. Thus, the first step in this self-corrective error process is self-detection of the existence of errors. The second step is the self-identification of the source of errors. The third step is the self-correction of errors. All these steps require the processing of emotion, which involves internal error-processing autonomously (without needing external assistance). The crucial steps for emotional processing are the error-discovery, error-identification and error-correction processes, such that the system can minimize the errors. Thus, the role of emotional feedback to the system is to reduce the errors such that there is congruence between what one wants and gets in order to achieve happiness.

1.2. Emotional Processing Task: System Optimization by Error-Minimization

The computational task for emotional processing becomes an optimization process that minimizes any errors that may exist. In order to minimize errors, the existence of error can be detected by comparing the difference between the internal model prediction and actual outcome. The internal model prediction can be considered as the expected outcome, i.e., expectancy or what the individual wants. This represents the subjective reality. The actual outcome in the real world is what the individual gets. The difference between when a person wants and gets can be quantified by the gain (or loss) signals. If a person gains what it wants (or loses what it does not want), this will result in the happiness feedback in emotional processing, such that it signifies to the person that congruency is achieved. This results in a happy (or satisfaction) state. Conversely, if a person loses what it wants (or gain what it does not want), this results in unhappy feedback, so that it sends a feedback to the person that such incongruence exists between the expected outcome and the actuality. This implicitly indicates an error condition that must be corrected, if happiness were to be achieved subsequently. The unhappy state provides the individual with the indicator for self-correction of errors to achieve congruency with the real world eventually.

1.3. Emotional Processing Quantification: Assessment of Gain and Loss

The difference between what an individual wants but actually gets can also be assessed by computing the gain and loss signals. Assessing the internal gain and loss corresponds to the essential process in emotional processing for self-correction of error autonomously. In order to compute the motivation that is needed to direct the attention of an animal to address the error-minimization task, emotional intensity provides the signal for such internal feedback. That is, the greater the emotional intensity, the greater the feedback signal is resulted in motivating the individual to address the incongruency issue (often subconsciously). This provides the internal drive for an animal to self-correct error conditions autonomously and automatically (without necessarily needing conscious/cognitive awareness).

In the EMOTION model (the acronym for Emotional Model Of The Interpretations Of Neuroprocessing) [1, 2], it hypothesizes that the intensity of emotion is proportional to the size of gain (or loss) signals, such that the computation by emotion can be derived from assessing the gain (or loss). This allows us to derive an emotion model using basic neurobiological principles of survival in neuro-engineering objectively with minimal subjective assumptions about emotions psychologically. This also provides a means to quantify emotions based on the quantifiable measures of gain (and loss) to test the hypothesis experimentally.

1.4. Experimental Verification of the EMOTION Model

In order to test our hypothesis of the proportionality relationship between emotional intensity and the gain/loss measures, we have used the classical ultimatum game (UG) paradigm in behavioral economics [7-10] to assess the emotional response with respect to perceived gains and losses in money and fairness. The UG paradigm is essentially a split-the-money game, where an amount of money is split between two players (a proposer and a responder). If the responder accepts the offer, both keep the money. If the responder rejects it, both lose the money. This provides an experimental approach to elicit emotional response subconsciously without explicitly controlling whether the emotion should be happy or unhappy. The emotions elicited are self-generated depending on how the subject perceives the gain and loss, and decides on accepting or rejecting the offer in this transaction. Note that even though most UG studies address the decision-making process primarily [11-16], our focus is to elicit self-generated emotions to evaluate the gain/loss disparity. It is known that emotions often interact with decisions [11, 13, 14, 17-25], which is revealed in our analysis also [26-29].

2. Methods

The UG paradigm is used to assess the emotional response

of human subjects with respect to the gain/loss relative to the proposer's monetary offer. To minimize the influence of the experimenter on the subject's emotional response, the computer is used as the proposer to offer the money (without any hint of human behind the scene or any facial expression that may alter the subject's perception). Randomized one-shot offers (without repeating) were proposed, ranging from \$1 to \$9. Subsequent to each offer, subjects are asked to self-report their emotional response (rating from +5 to –5) to that offer. The study was approved by the University Institutional Review Board.

We recorded the self-reported emotional ratings to assess their cognitive response as a measure of their own perception of their emotion rather than measuring the physiological response, even though the self-reported responses are often filtered/biased by their subjectivity, the objective of our analysis is to assess the subjective biases of emotions that may exist. We have revealed the proportionality relationship between emotional intensity and perceived gain/loss, and how subjective bias can be quantified by the emotional curves in our analysis of happy emotion [28, 29] and angry (unhappy) emotion [27]. This paper focuses on the jealous (unhappy) emotion.

3. Results

A total of 230 subjects (age ranging from 18 to 40, median age = 21) participated in this study. The self-reported rating of jealous emotion is shown in Fig. 1, independent of whether they accept or reject the offer for the entire sampled population. The graph shows an approximate inverse proportionality relationship (regression function: $y = –0.442x + 0.082$; $r = 0.940$; $r^2 = 0.884$) with monetary offer amount (gain ratios) (Fig. 1A). That is, the more inequitable the offer, the higher the jealous emotional intensity was reported.

Alternatively, the graph can be subdivided into two subsets (Fig. 1B) — the inequitable (unfair) trials (<\$5 : \$5 in left-half of Fig. 1B) and the hyper-equitable (hyper-fair) trials (>\$5 : \$5 in right-half of Fig. 1B). It shows distinctly different inverse proportionality relationship from unfavorable (unfair) (regression function: $y = –0.284x + 0.064$; $r = 0.989$; $r^2 = 0.978$ in left-half of Fig. 1B) to favorable (hyper-fair) offers (regression function: $y = –0.204x + 1.531$; $r = 0.831$; $r^2 = 0.691$ in right-half of Fig. 1B,). The (self-rated) jealous emotional intensity for unfavorable (unfair) offers is higher than the favorable (hyper-fair) offers by 15% (1.5 points in the scale of –5 to +5) (Fig. 1B), as expected, and consistent with our hypothesis. The self-reported jealousy intensity is inversely proportional to the perceived monetary gain, i.e., proportional to the perceived loss, for both equitable and inequitable offers.

Note that the stimulus-response function is below the y-axis and the intercept is at zero (Fig. 1A and 1B). This means that, on average, the overall response of the subjects is that they did not perceive jealousy to any of the offers (when their responses are combined in this analysis, regardless of whether they accepted or rejected the offer). Nonetheless, the jealousy intensity is inversely proportional to the ratio of the offer. The more unfavorable the offer is, the more jealous the subject perceived.

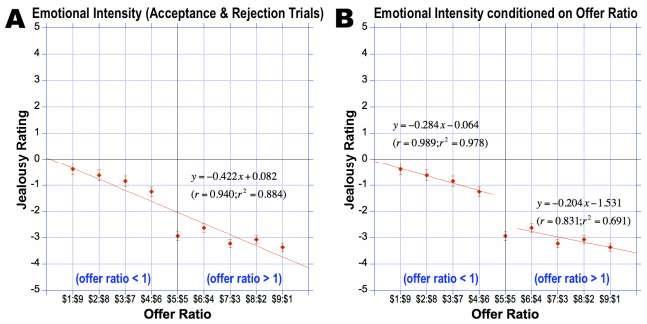

Figure 1. *Self-reported jealousy rating with respect to monetary offer for entire population (n = 230). (A) Curve-fitting to the entire sample showed an inverse proportional relationship. (B) Curve-fitting according to unfair (unfavorable) and hyper-fair (favorable) and trials for the same set of data as in (A), which showed different proportionality relationships depending on whether the offers are equitable or not. The error bar represents standard error of mean (SEM).*

Under the conditions of the UG paradigm, when the offers are unfavorable to them, it creates the classical dilemma for the subjects that they were forced to choose between fairness and money. That is, when the offer is unfavorable (<\$5 : \$5), they can only get one (*either* money *or* fairness) but not both (money *and* fairness). Rather than regarding the rejection decisions as irrational in the analysis [30, 31], we address the emotions generated by the subjects with respect to gain/loss and decision independent of whether such decisions are rational or not. Previous UG studies [32, 33] had shown that the decision to reject an offer is not necessarily irrational, but depends on the perception of fairness in accepting or rejecting the offer.

Most UG studies [13, 14, 34, 35] use the assumption that fairness is centered at the even-split (offer-ratio of \$5 : \$5), such that favorable monetary offers (>\$5 : \$5) are considered as hyper-fair, while unfavorable offers (<\$5 : \$5) are considered as unfair. This is based on the assumption that money and fairness are the desirable targets wanted by the subjects. But the decision to accept or reject an offer can be biased by the perception of fairness. Such bias in fairness can occur when an inequitable offer is considered as fair, when the subject is tolerant to inequity by being lenient to unfairness and accepts the offer, rather than using the absolute equity as the criterion for determining fairness [32]. On the other hand, the decision to reject is often associated with the bias in fairness toward greediness by expecting more than equity. Previous findings also suggested that the perception of fairness is not based on the absolute equity criteria, but skewed towards either hyper-equity or inequity (leniency or greediness) [36, 37]. This fairness bias puts influence on their decision to accept or reject an offer [38, 39]. Similarly, we will determine how the jealous emotion affects their decision to accept or reject the offer.

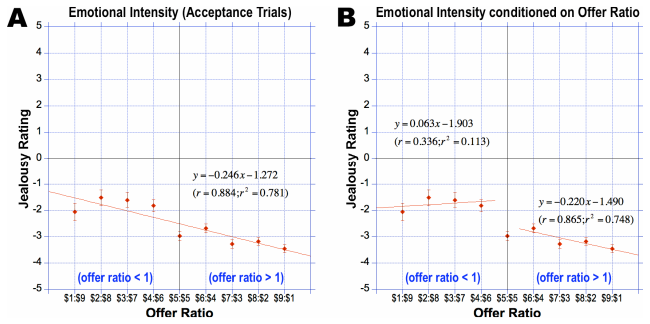

Figure 2. *Self-reported jealousy rating with respect to monetary offer for acceptance trials only.* (A) *Curve-fitting to the entire sample showed an inverse proportional relationship.* (B) *Curve-fitting according to inequitable (unfair) and hyper-equitable (fair) and trials for the same set of data as in (A), which showed different proportionality relationships depending on whether the offers are equitable or not. The error bar represents standard error of mean (SEM).*

To delineate how jealousy can affect decisions, the acceptance trials (Fig. 2) are separated from the rejection trials (Fig. 3). The stimulus-response functions of both acceptance trials (regression function: $y = –0.246x – 1.272$; $r = 0.884$; $r^2 = 0.781$ in Fig. 2A) and rejection trials (regression function: $y = –0.446x – 1.199$; $r = 0.936$; $r^2 = 0.876$ in Fig. 3A) show inverse-proportionality relationship, with the exception that the acceptance stimulus-response function is shifted below the rejection stimulus-response function. This indicates that when the subjects rejected the offers, they were more jealous than if they accepted the offers.

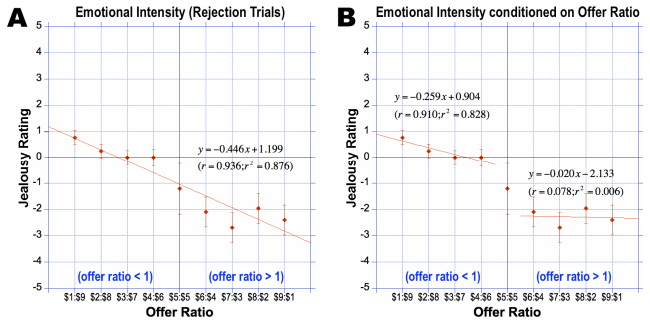

Figure 3. *Self-reported jealousy rating with respect to monetary offer for rejection trials only.* (A) *Curve-fitting to the entire sample showed an inverse proportional relationship.* (B) *Curve-fitting according to inequitable (unfair) and hyper-equitable (fair) and trials for the same set of data as in (A), which showed different proportionality relationships depending on whether the offers are equitable or not. The error bar represents standard error of mean (SEM).*

The subjects reported “not jealous” when they accepted the offers (Fig. 2A), for all favorable (fair) and unfavorable (unfair) offers. This is consistent with the hypothesis that jealousy would not be perceived, if they get what they want (by accepting the money). On the other hand, if they decided to reject the offers, they reported jealous when the offer was unfavorable (unfair) (Fig. 3B, left half). This created the unwinnable condition in which they cannot have either money or fairness, when they rejected the offer. This is consistent with the jealousy condition that they cannot get what others have — when they want fairness, but cannot have fairness while losing the money in their decision to reject it. On the contrary, when the offer was favorable (hyper-fair), they did not report jealous even when they rejected the hyper-fair offers (Fig. 3B, right half). This is consistent with the fact that they can have at least fairness, but not money (by rejecting the offer). This finding is consistent with the hypothesis that jealousy is an emotion that arises from the desire wanting what others have because they have more, but cannot get what they have.

This analysis also shows quantitatively how the jealous emotion is biased with respect to decision. Comparing the jealousy acceptance stimulus-response function (Fig. 2A) with the rejection stimulus-response function (Fig. 3A), it can be shown that the stimulus-response curve is shifted down by 20% (2 points in the scale of –5 to +5). This shows that jealousy perception was 20% greater for those who made the rejection decisions compared to those who accepted the offers. Thus, the jealous perception is dependent on the decision they made on whether to accept or reject the offer. When they rejected the unfavorable (unfair) offers, they could get neither fairness nor money when the offer was unfavorable (unfair) to them, but favorable (hyper-fair) to the proposer. The more the discrepancy is between what the proposer and responder gets, the greater the jealous emotional intensity is.

4. Discussion

The results are consistent with the hypothesis that the greater the discrepancy between what we want and what we get, the greater the jealous emotional intensity is, especially when we cannot get what others have. The subjects did report their jealous emotional intensity that is inversely proportional to the discrepancy between the proposer and responder, even though the proposed offer-ratios were randomized during the experiment. This indicates that they are aware of their jealous emotion, even though it may be subconscious. The subjective bias in jealousy intensity is also correlated with their decision to accept or reject the offers (Figs. 2 and 3) and perceived fairness [11, 34-37].

This emotional bias of jealousy sensitivity can be revealed by the slope of the stimulus-response function (i.e., the proportionality relationship). The slope of the stimulus-response function represents the emotional bias of jealousy sensitivity.

Note that the slope of the emotional curves is different for the inequitable offers (Fig. 1, left half) vs. the hyper-equitable offers (Fig. 1, right half). This indicates the influence of fairness perception on the jealous emotion. For inequitable offers, the proportionality curve is steeper for the rejection trials (Fig. 3) than acceptance trials (Fig. 2). That is, each increment of $1 potential monetary loss induces an emotional response that is much greater for inequitable offers than hyper-equitable offers for rejected trials. They are also more sensitive to jealousy when they reject the unfair offers (Fig. 3, left half) than when they accept them (Fig. 2, left half).

These two parameters (slope w, and intercept b) can be used to account for how emotions are biased (by different decisions or perceived fairness) by the following empirical equation, similar to the happy emotional curve [40] and angry emotional curves reported earlier [41], except for the different proportionality relationships:

$$E = wG + b \quad (1)$$

where E denotes jealous emotional intensity, G denotes the (monetary) gain ($G > 0$, represents gain, and $G < 0$, represents loss), w is the sensitivity factor (weighing-factor for the emotional sensitivity), and b is the residual baseline jealous emotion (intercept in the graph). The emotional sensitivity to a particular gain is computed by the weighing-factor w, and the baseline emotion for a given condition is represented by the residual emotion b.

The baseline jealousy b (intercept) is higher for the rejection offers (Fig. 3) than the acceptance offers (Fig. 2), suggesting how the jealousy perception can affect their decisions. The sensitivity w (slope) to jealousy is higher when they reject unfair offers (when they get neither money nor fairness) than any other choices or offers. The skewing effects of emotions can be quantified in the emotional curve by either (a) shifting the emotional intensity curve up or down from its baseline, (b) shifting it left or right, (c) changing the slope of the curve or (d) changing the linearity (or nonlinearity) of the proportionality relationship.

Some subjects did reject hyper-equitable offers, for whatever reasons. This could be because if money is not what they want/starve for (such as, when they are rich), see the money-offer as bribery, or feel that they are not entitled to the money, so fairness or money is not an issue. This is consistent with their self-reported jealousy rating, in which the jealousy sensitivity is rather flat (i.e., did not change) with increasing monetary offers or presumed hyper-equity.

Such decision to reject hyper-equitable is rather rational; it is irrational only if we assume they want both money and fairness [30, 31]. If they didn't want the money nor fairness, it would not create any discrepancy error between the wants and gets. As predicted, they would not be unhappy — which is consistent with the hypothesis in the model prediction.

These results provided both quantitative and qualitative confirmation of our hypotheses that jealous emotion is proportional to the loss, derived from the discrepancy between desired goal (wants) and actual reality (gets). The results are also consistent with the findings that happy emotion is proportional to desirable gains [28, 29] and angry (unhappy) emotion is inversely proportional to desired gains [27], similar to jealousy except for the different proportionality constant and emotional sensitivity. This confirms computational emotional processing that involves the assessment of the proportionality relationship of gain/loss signals.

4.1. Emotion Cognition

The computational role of jealous emotion is to assess the discrepancy between the desirable and the actuality. It provides a means to use the different emotional sensitivity and emotional baseline (which is influenced by different circumstances) to self-motivate behavioral correction any discrepancies between what one wants and gets. It is one of the first steps in the emotional recognition process by using the jealous emotion to make corrective actions. Jealous represents an emotional feedback that indicates a person is either not getting what one wishes to have, or others are getting more than one wishes to have. It indicates the existence of such error — the awareness of self-inadequacy, wanting something in another person that one cannot get. This motivates the individual to resolve such emotional confliction between wants and gets, so that congruency can be achieved subsequently. The feedback provides the behavioral drive for seeking solutions to correct such incongruency and inadequacy.

Thus, the computation for jealous emotion plays an important role in motivated behavior cognitively and subconsciously. Jealousy often occurs in a failed attempt to get what one wants, i.e., a failed attempt to bring congruency in self-correcting the discrepancy error. This is exemplified by the decision to reject unfair offers — an attempt to resolve the anger, wishing to get both money and fairness, but cannot. If the attempt were successful, it would result in either changing the decision to accept the inequitable (unfair) offers or changing the perception of jealousy (or unfairness) in the following ways:

If a successful attempt were made to correct the decision error, an alternate decision would be made to accept unfair offers. This would result in being rewarded with some monetary gain (achieving partial goal), which allows them to gain something rather than getting none, resolving the jealous emotion. Indeed, subjects did report not being jealous when they accept inequitable (unfair) offers, resolving the unhappiness (jealousy).

If successful attempt were made to correct the perceptual error of unfairness, the monetary offer would have been considered a gift, no matter what the offer-ratio is. Fairness becomes a non-issue when one considers the monetary offer as free money with no strings attached. In fact, the perception of jealousy or unfairness only arises when they made the assumption of entitlement. If they think they are entitled to the money that the proposer offers, unfavorable offers would be perceived as unfair to them. But if they realized they were never entitled to the free money to start out with, jealousy is a non-issue.

Ironically, this entitlement is only an assumption in the responder's part (erroneous assumption in the model prediction), which triggered the feeling of jealousy. Had they made the alternate assumption (belief) that the money was hard-earned money owned by the proposer, the perception of jealousy could be changed. Any monetary offer would be free give-away money to the responder that he/she did not earn. This would be considered as a gift — i.e., a gain rather than a loss — to the responder. Indeed, subjects did report not jealous (Fig. 2) and self-reported happy (Fig. 2 in [40]), and not angry (Fig. 2 in [41]), when they accept unfavorable

offers (although most UG studies considered such offers as unfair offers, but our fairness UG studies indicated otherwise [32, 33]). This is consistent with the hypothesis, and predicted in the emotion model that unhappiness (jealous or anger) is felt when they perceive it as a loss versus happiness (if they perceive it as a gain).

4.2. Cognitive Identification of the Source of Erroneous Biases for Error-Correction

This shows jealousy provides an emotional feedback for the unresolved conflict between what a person wishes to have (that others have) and what he/she actually gets. The conflict can be resolved by altering the perception of jealousy (perceiving the monetary offer as an honor to receive the lucky money) or by altering the decision to accept the offer (so as to gain some money rather than getting none). These self-corrective actions can be achieved if the source of error is identified — by figuring out whether it is:

(a) a perceptual error of unfairness, or
(b) an execution error of making the wrong decision, or
(c) a modeling error in making the faulty assumption of entitlement (erroneous belief system),
(d) then the jealousy feeling would be resolved.

This is consistent with the emotion model that unhappy emotion (jealous, in this case) provides the starting point for identification of error as a feedback to the system, so that it motivates the individual to seek resolution to the conflict of incongruence between what one wants and gets. Resolution of such emotion can be achieved by addressing the source of error that caused the discrepancy.

4.3. Cognitive Resolution of Jealousy by Correcting Perceptual, Decision or Modeling Errors

By resolving the perceptual error, decision-choice error or model false-assumption error, congruency can be achieved. Jealousy feeling remains only when the attempt to correct such incongruency failed. The computational prediction of the emotional processing by our model provides a means to cognitively resolve unresolved emotions by identifying the existence of error, addressing the source of error, and correcting any perceptual biases, false assumptions or erroneous decisions, such that congruency can be achieved, resulting in a satisfying happy state. Cognitive awareness of such internal jealous emotional processing can provide us with effective skills to achieve emotional intelligence.

5. Summary

The jealous emotional intensity is quantified by the stimulus-response function, such that an inverse-proportionality relationship exists between the emotional intensity and the offer-ratio in the UG paradigm. This confirms that the bigger the difference between the desirable outcomes and the actual outcomes, the greater the jealous emotion intensity, when the subjects cannot get what they want. This is consistent with the prediction of the emotion model that the unhappy emotion (including jealousy) serves as a feedback for error-correction by assessing the discrepancy between the desirable and actual outcomes. Using the UG paradigm to explore the decision-making process, the actual outcomes can be altered by the decision to accept or reject the monetary offers. Accepting the money rather than rejecting it resolves the jealous emotion. This resolves the conflict of not getting what the individual wants by getting some monetary rewards rather than none. Thus, by understanding the computational role of jealousy in conflict resolution, it provides the emotional intelligence to make appropriate decisions to minimize the discrepancy between what an individual wants and gets. This demonstrates that jealous emotion is quantifiable, which serves useful functions to resolve conflict when the appropriate decision is made to reduce the discrepancy between the desirable and actual outcomes. Prudent decisions can be made to resolve jealousy when such emotion is brought to the awareness.

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