Emotion prediction errors guide socially adaptive behaviour

BSE662A – MIDTERM REPORT – Team Hoomans

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Background for the study and relevance of the study

Decision-making plays a crucial role in the life of all individuals. It enables decision-makers to choose among alternatives based on their preferences and values The primary topic of research that has been under investigation is the factors that influence decision-making. The rewards expectation greatly influences an agent's choice during decision making. While its violations, which are termed Prediction Errors (PEs), help an agent upgrade his knowledge of its habitat to facilitate his survival. The rewards can act as positive reinforcers during and after the learning process. In the former, one's behavioural reaction increases while the latter maintains well-established appetitive behaviour. The Standard decision-making models embedded reinforcement learning framework, encapsulating these insights. The violation of expected outcomes is supposed to encourage even sophisticated behavioural patterns. The background for the study arises from the literature demonstrating a significant influence of emotion on choice apart from reward in decision-making. The transition between distinct emotional states and expected aversive emotions shaping social interactions have been predicted in earlier works using sophisticated mental models of emotion[1]. But, significantly fewer studies related to the violation of expected emotions or emotion PEs & their influence in decision-making, especially in social interactions, have been done so far. Also, the relationship between reward and emotion is not well understood, and in previous work, either emotion is neglected or assumed to be synonymous with reward value[2].

This study examined the relative contributions of emotion and reward PEs to behavior by mapping and unfolding the mechanisms that guide adaptive social decision-making. The model of emotions used here classifies emotions into distinct affective components: valence (pleasurableness) and arousal (alertness/activation), which constitute the core effect of emotion when taken together. The authors' findings establish that people's social decisions heavily rely on violations of their emotional expectations. This paper will improve the specificity of decision-making theories by providing consensus and clarity. It broadens the field for research that uses the generalizable framework for anticipated emotions and does not rely upon or include discrete feelings such as regret or guilt[3]. Also, during the depression, alteration of emotional processes happens, which was also found in this study. This study can help understand depression through the use of emotion PEs and understanding human learning and decision-making.

## Main questions, tractability through experiments and how suitably they are addressed

Historically, emotions have always been ignored in decision-making studies or considered to be overlapping with reward response. This paper primarily tries to address the open questions related to the effect of emotion on decision making by studying prediction errors (PEs) arising from reward, arousal and emotion prediction. These questions are:

- Are decisions only reward-based, or do the agent's emotions also play a role? That is, would emotion be a redundant nuisance variable if added to the 'decision-making equation'?·
- If emotion does influence social choice, are reward and emotion independent? Additionally, is there a possibility that emotional prediction errors merely account for differences in the subjective value of rewards among various individuals?
- How does the fluctuation of emotions with time affect social behavior?
- How do mood disorders like depression affect emotional range and decisions?

As shown by the authors, these questions can be answered experimentally to a reasonable extent. This paper highlights four main experiments involving 1016 participants who played the Ultimatum Game or Justice Game. The 'dynamic affective representation mapping' or dARM is an emotion classification

task where emotions are rated in terms of valence and arousal. This is done along with social interaction (JG or UG).

In the first experiment, the participants played UG, where a participant responded to a skewed monetary offer. The participant could choose to accept the money he was being offered or select the 'punish' option, which would imply that both proposer and responder get nothing. dARM was used to map expected emotions and errors. In the second experiment, participants played UG, but dARM was done before the proposer's offer, as well as after the offer and before decision making.
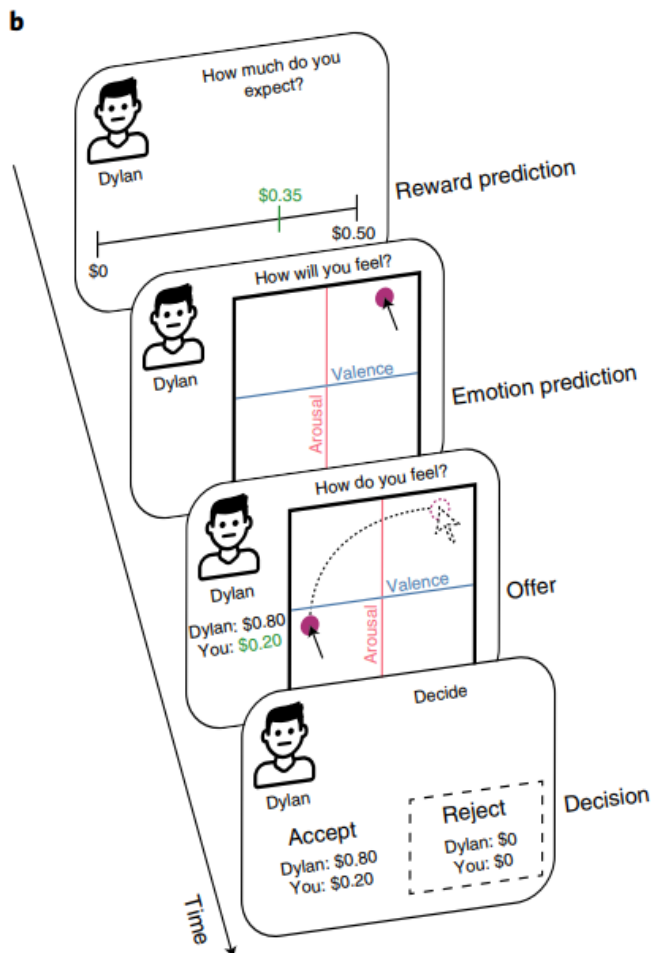
These experiments enabled the understanding of the effect of emotions and reward prediction errors in social behaviour. Furthermore, the experiments together help to study the relative dependence between arousal, valence and reward as dARM provides a framework that enables the calculation of prediction errors. Moreover, to resolve the issue of whether emotion PEs are placeholders for the subjective value of different individuals, the empirical model arising from these experiments has been compared with classic models that use subjective value. This greatly adds to the validity of the tasks done.

In the third experiment, participants play the Justice Game, where the concepts of 'compensation' (responder gets to match

the proposer's offer) and 'reverse' (responder gets the amount proposer was initially getting and vice versa) are introduced along with the standard accept and reject. Two of these four options are presented to the responder after the monetary affair is made. dARM is used with data being collected in 10ms intervals. This enables studying the development of emotions over time and their effect on choice.

To study how people with depression make decisions and their emotional diversity, a 4th experiment was performed by the authors. Participants were made to play UG and fill out questionnaires regarding mood disorders. Also, dARM was used to study the emotional range of at-risk individuals using healthy ones as a standard. These help to understand whether emotion and reward value are disjoint.

Overall, these experiments have quite adeptly answered the salient questions that the authors desired to answer. The unfair monetary offers capture what agents pay more heed to while making decisions- value or emotions. The Justice Game, along with dARM tracking emotion information every 10ms captures the dynamic nature of feelings quite well. While people can be inaccurate while recording emotions, this error can be minimized by having a large number of participants and trials like the authors have done. Studying at-risk or depressed individuals helps decide the dependency of reward value and emotion on each other, as comparison of PEs with healthy agents indicates how they scale with respect to each other.

Main Results & their Robustness

After conducting the experiments, it was found that both reward and emotional PEs make distinguishable contributions towards making a choice. As discussed earlier, we divided emotional PE into two parts, valence PE and arousal PE. It was also found that participants who experienced more arousal PE or less valence PE or less reward PE were more punishing.
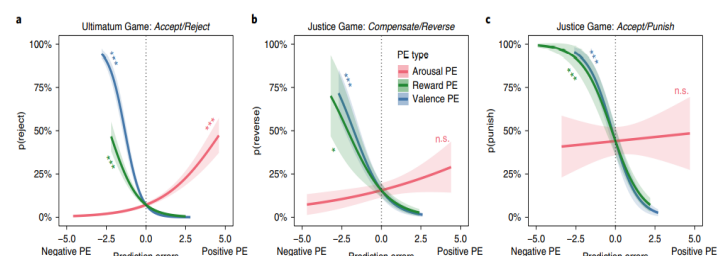
To ensure that the emotion PEs weren't just accounting for the subjectivity of reward PE, the standard utility model was transformed to incorporate non-linear valuation of reward (sRPE) using the softmax function. The empirical model, which included valence PE and rewards PE outperformed the sRPE model, thus

proving that emotion PEs don't just account for subjective reward.

A mixed regression was run with all the possible combinations, and it was found that all the PEs had significant interaction with each other except for the interaction between valence PEs and reward PEs. This result indicated that the strength of a given PE is partially modulated by other PEs, such that arousal PEs appear to augment the role of valence and reward PEs.

A mixed-effect model was used to determine the non-linear effects of PEs on choice, which conclusively shows that valence PEs had more impact than reward PEs. To test the strength of PEs, expectations of all PEs were controlled and computed in the same regression. The result further showed that valence and reward PEs still explained a significant portion of the variance in punitive decisions.

There are mainly three major implications from the results obtained. Firstly, both reward and emotional PEs make distinguishable contributions towards making a punitive decision. Secondly, the beta values indicate that valence PEs have the highest impact on punitive decisions. Thirdly, when the direct contributions of experienced reward and emotion are evaluated, reward appears to bias behavior more strongly than emotion, demonstrating that emotion only surpasses reward if PEs are taken into account.

The third experiment separated monetary reward from emotion, which eased the analysis of how emotion PEs influence decision-making. The use of dARM allowed the continuous measurement of emotion at every ten milli-seconds using mouse tracking. This showed that negative valence emotion PEs pretty successfully predicted choices to punish and the reverse, but did not outperform reward PEs for accept/punish, as well as compensate/reverse. However, arousal PEs appear to depend on context as they did not predict decisions to punish or reverse very well.

The 4th experiment, used to determine whether reward or emotion contributes primarily to mood disorders, showed that people at risk for depression did not rely at all on arousal PEs, relied a lot on reward, and very little on valence. Moreover, while the risk of depression affected punishing, it did not affect reward PEs. Therefore, emotion and reward may be separable. Emotion classification tasks revealed that at-risk individuals have a limited emotional range, which explains why emotion PEs were not very impactful.

How sufficiently the results addressed the questions raised

Are our decisions only reward-based? Do emotions play a role or are they just nuisance variables?

Most previous literature on reward and reward prediction errors completely ignores how people feel. The author made an interesting point that emotion prediction error may be an important predictor of behaviour and took them into account.

Can reward and emotion be treated as independent entities?

The author claims to make emotion and reward separate and independent entities by introducing new aspects to Ultimate Game, in the form of Justice Game. But the core argument still exists that reward and emotions are intertwined. Getting a reward or not getting it generates emotions; basically, people's emotional expectations are also based upon their reward expectation. Example situation we can create like say, Aman regularly offer chocolates to a kid named Tanishq, now from next time whenever Aman comes to meet

Tanishq automatically feels aroused and happy as he expects chocolate from Aman. The reward expectations of Tanishq are responsible for generating emotions. If Aman does not give chocolate this time, i.e., reward prediction error, it will make Tanishq feel disappointed or sad, leading to an emotional prediction error. Similarly, in Justice Game, the emotions arising are somewhat dependent upon the participant's reward. Therefore the strong claim by the author to make reward and emotions independent seems to be error-prone. More complex games/experiments can be constructed, which may truly separate emotion and reward as different domains.

How depressed individuals can help with separating emotion and reward?

The author experimented on depressed people to minimize the role of emotions in decision-making and compare the result with the rest of the data to conclude how much emotions affect the person's behavior. But low-mood people are just less dependable when reporting emotion. They have more decision noise when reporting emotion. Also, they have less variance/range in their emotion reports, i.e. people who suffer from depression have a narrower variety of emotional experiences.

The results depend entirely upon valence and arousal, but are there measurements correct in the first place?

To achieve the valence and arousal rating in experiments 1, 2, and 4, the participants were asked to click anywhere on a

500*500 pixel, the dARM measure. This technique is quite old research[4] (the 1980s), and more optimal strategies to measure valence and arousal are now present. Apart from that, it is highly doubtable that a participant will effectively mark their emotion. In the case of a participant at risk of depression, researchers observed that they display restricted emotional range and emotional blunting[5]; hence their inputs may not be accurate.

In experiment 3, the author tried to capture the real-time emotions of the participants, but the author didn't provide any compelling explanation about how the real-time mouse tracking is actually achieving the results correctly.

Can social experiments be designed to test and prove the hypothesis claimed by the author?

The two social experiments conducted in the study, The Ultimate Game and The Justice Game test the hypothesis to different extents.

The Ultimate Game: The prospect that if the participant is getting some reward, whether it is fair or unfair, makes accepting the offer more profitable seems to be misdirected to the hypothesis the author is trying to test. Let's say the proposer proposes to offer only 10 Rs to the participant and decides to keep the rest 90 Rs to himself, making it a very unfair deal. However, if the participant rejects the offer, he will get 0 Rs, which seems to be a losing deal. So whether feeling happy about it or not, the participant is most likely to accept the offer as that's the best deal he could get. This contradicts the claim the paper is trying to make and therefore be optimized for better conclusions.

The Justice Game: The criticism for the ultimate game is eradicated in this game by giving participants a chance to make a fair deal for themselves. The option chosen by the participant in an offer can provide insight into reward PE and emotion PE experienced by him during the experiment, giving viable data to conclude the results the author is trying to claim. But still, the question that arose above, "Can reward and emotion be treated as independent entities?" is still cannot be answered in this game which leaves scope for improvement for designing a better game experiment.

Is the data sufficient enough to come to any conclusion?

There are 54 trials in the justice game, with two of four potential alternatives provided on each trial. So there are 6 possible choice combinations. There will only be 9 trials for each of the two crucial comparisons: compensate vs reverse and accept vs punish (comprising roughly 3 trials with low, 3 with medium, and 3 with high unfairness of offers). They conducted the real-time emotional experience analysis using just the most unfair offers,

which amounted to only three compensate versus reverse trials and three accept versus punish trials per participant, which is too few to draw any conclusions.

Which PE serves as the dominant factor for determining the decision?

Results show that both reward and emotion PE significantly impact individuals' behavior. Still, emotion PE takes the edge as the dominant factor among the two, and the same can be inferred from the beta test.

Follow up study and Conclusion

The estimation of valence and arousal correctness is quite uncertain. A good follow-up study will be to do the above experiments using a more modern and novel technique like one such study can estimate emotional valence and arousal by analyzing images of human faces[6]. This technique is not only easily implementable and will provide real-time results as well; hence we can use it in all of the experiments and get even more robust results.

A simple suggestion will be to increase the sample size and even precise results. However, a good idea will be to add people from different cultures and backgrounds. For example, in the games, only around 0.5$ was at stake. Losing or winning that amount to many participants may not provoke any emotion but to others (underprivileged) it will be a great deal. Getting data from different cultures will also give us more insight into to what extent the reward and emotions are separable. Dissociating reward and emotion may more generalize the research by accurately depicting emotions in decision-making. One more solution may be to remove the reward aspect of the experiment and evaluate the effect of emotion PE on individual behavior. For example, The Justice Game can be updated by introducing a third person, a referee, who is just an observer and s/he decides whether to punish (reverse) the offerer or not. This will work because we feel for others as empathy.

A Study Mapping brain waves can perform more comprehensive research to determine how emotion and prediction errors are produced inside our brains[7]. Are their pathways separated from influencing an individual's decision or work collectively to determine behaviour as a whole? As we further dive into the processes involved in the brain due to prediction errors, we can analyze how neural networks associated with emotion PEs evolve with time as we develop more complex emotions like trust, envy, love, etc.

The paper provided a different perspective on the decision-making process and challenged the belief that only reward PEs are the sole factor influencing our decisions. The results of the social experiment conducted in the paper answer the vital question of how many of our decisions are motivated by emotions, and among reward-oriented and emotion-oriented decisions, which one is more dominant? Emotions are a critical part of our life, shaping us as unique individuals and navigating us through the ever-evolving social world. From our actions to our learning processes, every domain can be determined by our emotional experiences. By understanding how they are encoded in our brain, we can find the vital key to solving the mystery of making decisions!

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