



Title	Uncovering the neural dynamics underlying human bargaining behavior using drift diffusion model
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論 文 内 容 の 要 旨

氏 名 (沼 野 正 太 郎)	
論文題名	Uncovering the neural dynamics underlying human bargaining behavior using drift diffusion model (ドリフト拡散モデルを用いた、ヒト交渉行動の根底にある神経ダイナミクスの解明)
<p>論文内容の要旨</p> <p>This thesis investigates the neural mechanisms underlying the acceptance of unfair offers in economic bargaining. Traditional behavioral models typically interpret acceptance of unfair offers as simple reward-maximization. This interpretation corresponds to the behavioral model of “economic man” assumed in economics. However, it remains an open question whether human beings make decisions based solely on economic rationality when accepting unequal proposals. Suppressing emotions such as inequity aversion and pride would also play a crucial role in decisions. To uncover cognitive and neural dynamics of accepting unfair proposals, I explored this hypothesis by analyzing the ultimatum game, a representative task to examine human social decision making, by using a drift-diffusion model (DDM) that explains the distribution of behavioral choice and response time.</p> <p>I conducted an fMRI experiment using the ultimatum game, where participants decided whether to accept or reject monetary distribution offers from proposers within a 10-second time limit. All subjects (n = 71) were analyzed by DDM, while functional magnetic resonance imaging (fMRI) analysis was performed excluding eight subjects with large body movements (greater than 1 mm).</p> <p>Through behavioral analysis, I found that the best performing DDMs incorporated three key elements in the drift term: self-reward (SR), disadvantage inequity (DI), and advantage inequity (AI). The model successfully captured both choice and response time and revealed how each element contributes to bargaining behavior. In addition, complex interactions among model parameters were also revealed. For example, the parameters of boundary separation and bias were found to have unexpected relationships with behaviors. It indicated that the model is fraught with greater complexity than previously recognized.</p> <p>Next, I combined fMRI with DDM and examined both the neural activity and the dynamic decision-making processes. I found that participants who suppressed DI-driven rejection exhibited heightened dorsal anterior cingulate cortex (dACC) activity in response to DI (cluster-level family-wise error (FWE) corrected $p < 0.05$). This finding suggested a top-down control mechanism for managing emotional responses to unfair offers. Importantly, the mean response time for acceptance was significantly longer than for rejection in strong disadvantageous inequity conditions, indicating internal conflict in the decision-making process.</p> <p>Further analysis revealed a specific neural pathway involved in accepting unfair offers. I found that the dACC exhibits negative functional connectivity with the ventrolateral prefrontal cortex (vlPFC) when unfair offers are presented in whole-brain analysis (cluster-level FWE corrected $p < 0.05$). The strength of this connectivity predicted both rejection rates and response times for accepting unfair offers, suggesting its crucial role in the decision-making process. Additionally, I discovered that the vlPFC shows synchronized activity with the amygdala during offer presentations (cluster-level FWE corrected $p < 0.05$ with small volume correction). This vlPFC-amygdala connectivity specifically encoded response times for accepting DI offers but not rejection rates, indicating a distinct role in the decision-making.</p> <p>The study marks a significant advancement in understanding human social interactions, revealing that accepting disadvantageous offers requires the active suppression of emotional responses to disadvantageous inequity. This process has unique and critical implications for human social behavior and brain function.</p>	

論文審査の結果の要旨及び担当者

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論文審査の結果の要旨

ヒトは他者との報酬の分配に極めて敏感であり、自分の報酬額が多いことを好む一方、他者より少ないと怒り、多すぎると罪悪感を覚える。沼野氏は、分配における感情と意思決定のメカニズムを明らかにするため、Ultimatum Game を用いて研究を行った。特に、実際の社会行動では極めて頻繁に見られる不公平な提案を「嫌々」受け入れる際の意思決定を、行動学と神経科学の手法で解析した。前半では、Ultimatum Game における受諾・拒否の意思決定と反応時間を drift diffusion model (DDM) を用いて定量的に解析した。DDMの拡散係数を「受け取る報酬 (SR)」 「相手の報酬の相対的な多さ (DI)」 「自分の報酬の相対的な多さ (AI)」 の線形和で近似すると、選択確率と反応時間の両方を予測できることを示した。後半では、fMRI を用いて、不公平な状況での「嫌々」受諾の神経基盤を調べた。被験者ごとの DI の係数 を求め、DI に鈍感な者ほど活動する領域を解析したところ、背側前帯状回 (dACC) が特定された。さらに、DI が大きいときに dACC と機能結合が変化する領域として 腹外側前頭前皮質 (vlPFC) が得られ、dACC からの抑制を受けることが示唆された。最終的に、dACC が vlPFC を介して 扁桃体を抑制 し、「嫌気」を抑えて不公平な提案を受諾するという作業仮説と矛盾しない結果が得られた。論文の前半ではDDM によりUltimatum Gameの反応時間もDIの係数で説明した点が新規性を持ち、すでに Neuroscience Research 誌に発表済みである。後半では、不公平な受諾における dACC による vlPFC の抑制 の役割を明確化した。本研究は、現実の社会では頻繁に見られる不公平な分配を「嫌々」受諾する際の意思決定メカニズムを解明する社会神経科学の重要な成果であり、博士の学位を授与するに値するものと認める。なお、チェックツール “iThenticate 2.0” を使用し、剽窃、引用漏れ、二重投稿等のチェックを終えていることを申し添える。