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Investigating Sense of Agency in Multi-Agent Action-Effect Causality Perception

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Abstract

By action-outcome causality learning people are able to gain a sense of agency which motivates people to take goal-directed actions. However, people' sensation of agency can be influenced by the multi-agent context where the causation between agents and outcome are complex. The present study examine how people judge the sense of agency of themselves and others when presented with different contingencies of the outcome controlled by the individual and another agent. The results shows that People can learn action-outcome causation from action-effect causal perception in multi-agent context, gain sense of agency when they do have control on the outcome and learn the agency of other agent when other agent has the causal power on the outcome. The present study is an step forward to understand how individuals work and perceive sense of agency with a external agent, which may give a hint to further inquiry of computational modeling and analysis of brain activities in the development of agency.

Keywords

Agency, Causal learning, Contingency learning, Multi-agent context.

1. Introduction

Individuals become agents when they carry out behaviors that are appropriate to achieve their goals. For example, people (agents) may cook (behavior) because they need food to alleviate hunger (goal). Once the actions lead to the expected outcome, a perception of a sense of agency may develop, "I did it". In addition to the adaptive function of agency, there is evidence that the disruption in perception of these relations is a marker for psychopathology including depression (e.g., Murphy et al., 2017) [1]. Goal-directed learning is a type of instrumental learning, where the action-outcome association has to be controlled, not by the predictive association between stimuli and outcome as in Pavlovian learning, but by the perceived causal relationship between actions and their outcome. Both forms of learning have been shown to be sensitive to the temporal contiguity between either actions and outcome or stimulus and outcome in Pavlovian learning (e.g., Mackintosh, 1975) [2]. That action learning is based on empirical cues is suggested by the idea that people have to learn about causation between their actions and the outcome and make action selection choices to reach an expected outcome. Moreover, Karsh and Eitam (2015) found that manipulating one's objective control over the condition influences the speed and the frequency of performing an action associated with that control[3]. These results indicate that learning about the causal relativity between action and outcome (i.e., their ability to control the outcome) is rewarding to the agent, and consequently improves action performance, which infers a positive change on the sense of agency.

The real-world application of this ability is complicated by the fact that a person is never the only agent in a given context. The multi-agent environment people experience can influence or impede the learning of the causal relationship between actions and various outcomes. However, there is a paradox, namely the Agent's Paradox, which suggests that the environment is multi-causal, many different events may cause any outcome, so how is it that, people are found to

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perform rational actions, and at other time act irrationally. The discussion of Agent's Paradox is a fundamental problem for the understanding of people's behavior. Previous studies have reported experimental analysis of causation learning in terms of action-outcome (A-O) contingency (Allan, 1980; Dickinson, Shanks, & Evenden, 1984; Wasserman, Elek, Chatlosh, & Baker, 1993)[4-6]. A-O Contingency refers to the relative probability of the outcome's occurrence in the presence of a goal-directed action minus its probability in the absence of the action. Learning about the sense of agency in different action-outcome contingencies is crucial for people to take appropriate action in a dynamic environment. This study's overall aim is to examine how people judge the sense of agency of themselves and others, as a prior experiment of probing into Agent's Paradox.

The present study adopts a contingency manipulation as methods to investigate Agent's Paradox. Rescorla (1968) found that rats were sensitive to CS-US correlation[7]. However as suggested by the paradox, in many even complex situations, people are able to learn the consequences of their actions. Chapman and Chapman (1967) found a tendency to overestimate the casual relativity between symptoms and diagnoses in zero or low contingencies due to the high outcome density[8]. The same bias is also shown in A-O contingency judgment: though people rate a high control of actions over outcome in high A-O contingency conditions and rate a low control in low A-O contingency conditions, they also have strong tendency to evaluate a higher degree of control in high-density zero contingency condition (Dickinson, Shanks, & Evenden, 1984; Msetfi, Murphy, Simpson, & Kornbrot, 2005; Blanco & Matute, 2015; Alloy & Abramson, 1979; Byrom, Msetfi, & Murphy, 2015; Morris, Cyrzon, Green, Le Pelley, & Balleine, 2018)[5,9-13]. Together, these studies highlight a bias of control judgment based on specific A-O contingency information. One of the explanations of this bias is that people make control judgment to the contingency information but also to their own expectation of action-outcome association (Alloy & Tabachnik 1984; Alloy, Abramson, & Kossman, 1985; Msetfi, Murphy, Simpson, & Kornbrot, 2005)[9,14-15], which may imply the mechanism behind Agent's Paradox.

However, the existing studies measured the judgment of control with only one agent involved, whereas the investigation of Agent's Paradox needs a multi-agent context to examine the other agent's effect on one's sensation of the agency. This study aims to explore how individuals judge the degree of control of themselves, a simulated agent and other factors when presented with different contingencies of the outcome controlled by the individual and the simulated agent. Additionally, in order to explore the effect of temporal contiguity on judgments, I varied the time limit for individuals to act during each trial (750, 1200 and 2000 ms between the action occurrence and the outcome). The present study hypothesizes that there is a significant interaction between the judgment of control (control of human, simulation and other factors) and contingencies (6 Conditions: no control, positive human, negative human, positive simulation, negative simulation, equally positive) where higher contingency conditions (positive conditions) result in a judgment of stronger control and lower contingency conditions (negative conditions) results in a judgment of weaker control on both individual and simulated agent, while the zero contingency condition (no control condition) leads to a judgment of stronger control on context (other factors). For the manipulated time limit, it is expected that individuals might be more likely to generate a sense of control with more time to contrast the effectiveness of own behavior with the effectiveness of the competitive agent. The present study is an attempt to understanding how a single agent works with a simulated agent, which may give a hint to further inquiry of computational modeling and analysis of brain activities in the development of agency.

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2. Methods

2.1. Participants

Twenty university students participated in the present study (8 males, 12 females, Mean age = 22.2, SD = 1.40). One of them was excluded in the final data set for not correctly understanding the task instruction. Participants were run individually at home with their own PC.

2.2. Materials

Apparatus. An adapted version of the 'light bulb task' described by Msetfi, Murphy, Simpson, and Kornbrot (2005) was used for this experiment[9]. The experimental program was coded, sent to participants and displayed though Gorilla.sc. All participants complete the task on their personal computer.

Stimuli. The stimuli comprised of images of a chick in an eggshell, a chick out of an eggshell and a hand, which represent the initial situation, the outcome and the response of simulated agent respectively.

2.3. Procedure

This experiment involved participants learning each of 6 conditions at one of two times intervals between the start and end of trials. The design therefore was a 6(Condition) x 3(Control Rating) x 2(Bin length) within-subject design. Participants were asked to play a 15-min game on their own PC. The game consisted of 12 blocks and each block contained 40 trials. In each block, there was a chick hidden in its eggshells, and the goal of participants was to try to get the chick out of the shell as many times as possible. Participants could control the chick by pressing the "B" button on the keyboard. In each trial, a stimulus of a chick hidden in an eggshell was presented for 750 or 1200 ms (depending on different blocks) with the question: 'Press B or NOT?', which indicated that they had the opportunity to press B to control the chicks or do nothing about it. During this period, the second player (computer) was also trying to control the chicks at the same time as the participants. Every time the computer pressed the key, a hand would appear on the screen. Subsequently, the chicks either came out for 250 ms (i.e., outcome-present trial) or, alternatively, stayed in the shell for 250 ms (i.e., outcome-absent trial). After a series of 40 trials, the participants were asked to rate how much control they (Human), the computer (Simulation) and other factors (Other) exerted over the chick coming out of the shell (i.e., a judgment of control: "To what extent did you control the getting out of the chick?") by clicking on a scale ranging from −10 to +10 (-10 meaning negative control, +10 meaning full control).

Table 1. The contingency conditions in the experiment

Contingency patterns	Probability of outcome occurrence following participant responses	Probability of outcome occurrence when the simulation responded
No Control (nC)	.5	.5
Positive Human (PH)	1	.5
Positive Simulation (PS)	0	.5
Negative Human (NH)	.5	1
Negative Simulation (NS)	.5	0
Equally Positive (Eq)	The outcome occurs only if both human and the computer response	

There were 2 within-participant manipulations in the task. One was the contingency of the outcome (i.e., chick emerging from the egg) when participants and the computer made the key responses, and the other is the time bin that in which participants were allowed to response. There were six different contingency conditions coded: no control (nC), positive human (PH), negative human (NH), positive simulation (PS), negative simulation (NS) and equally positive

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(Eq), and each Condition was tested twice in 2 different blocks with different binlength (750 ms and 1200 ms). The specific contingency patterns are shown in Table 1. The sequences of trials and blocks are randomly determined by the program.

2.4. Data Analysis

All statistical analysis was performed on IBM SPSS version 26.0. There were three independent variables: Condition (nC, PH, NH, PS, NS, Eq), Control (hum, sim, oth) and Binlength (750 ms, 1200 ms). The dependent variables were ratings of participant control, simulation control and other control.

To assess the effect of contingency conditions and different control factors on the rating of control, a 3 x 6 repeated-measures analysis of variance (rmANOVA) was conducted with Condition (nC, PH, NH, PS, NS, Eq) as a between-subjects factor and Control Rating (hum, sim, oth) as a within-subjects factor. Paired-sample t-tests were also conducted to compare the Control Ratings (hum, sim, oth) in each Condition (nC, PH, NH, PS, NS, Eq). To test the Bin Length effect on rating of control, a 2 (750 ms, 1200 ms) x 6 (nC, PH, NH, PS, NS, Eq) rmANOVA and a 2 (750 ms, 1200 ms) x 3 (hum, sim, oth) rmANOVA were conducted. Also, the rating of each control in each condition with different time bin lengths were compared through paired-sample t tests.

3. Results

Ratings of control and the behavioral responses are displayed in Figure 1 and 2. Figure 1 summarizes the mean rating of three kinds of control in six conditions with different bin length. It is shown that individuals rate a high degree of control of themselves in PH condition and rate a low control of themselves in NH condition. For the control judgment of external agent, individuals report a higher control of simulated agent in PS condition and lower control in NS condition. In nC condition, individuals rate approximately no control of the three factors. In the Eq condition, individuals rate a negative control on both themselves and the computer while rate a much higher and positive control on other factors. The significance of these results are supported by the statistical analysis. It was found using rmANOVA that there was a significant effect of Control ($F(2, 37) = 9.86, p < .001, \eta p^2 = .043$) and Condition ($F(5, 37) = 20.51, p < .001, \eta p^2 = .316$) on the ratings. An effect of Condition-Control interaction was also observed ($F(10, 37) = 52.39, p < .001, \eta p^2 = .541$). To explore the interactions paired-sample t tests were conducted to compare the control ratings between conditions. Table 2 shows the results of the t tests. In the two conditions in which the participant had control (PH and NH) participants correctly judged their control as stronger than the Simulation or Other for positive ($t_{hum\text{-}sim}(37) = 15.32, p < .001$; $t_{hum\text{-}oth}(37) = 17.76, p < .001$) and negative ($t_{hum\text{-}sim}(37) = -6.21, p < .001$; $t_{hum\text{-}oth}(37) = -9.37, p < .001$). In the two conditions in which the simulation had control (PS and NS) participants correctly judged the control of Simulation as stronger than the Human or Other for positive ($t_{sim\text{-}hum}(37) = 8.78, p < .001$; $t_{sim\text{-}oth}(37) = 7.98, p < .001$) and negative ($t_{sim\text{-}hum}(37) = -8.76, p < .001$; $t_{sim\text{-}oth}(37) = -8.49, p < .001$). In Eq, the rating of other control is significantly higher than human control ($t_{oth\text{-}hum}(37) = 7.20, p < .001$) and simulation control ($t_{oth\text{-}sim}(37) = 6.15, p < .001$), but no significant difference between the rating of human and simulation control is found. In nC, only the rating of human and other factors are found significantly different ($t_{hum\text{-}oth}(37) = 2.31, p = .026$).

Figure 1(b) illustrates the rating of control in two different time bins. The patterns of mean ratings seem not differ. To evaluate the effect of bin length on rating, an rm-ANOVA and paired-sample t test was also conducted. However, no significant bin length effect is found and the ratings in each condition in two time bins were not differ ($F(1, 37) = .20, p = .653, \eta p^2 = .002$), and the same type of control ratings in two time bins were not differ according to paired-sample t tests.

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The results of behavioral responses show tendencies corresponding to the results of control rating, which are shown in Figure 2. Generally, participants responded more frequently in PH and less frequently in NH than other conditions in which they have no absolute control over the chick. From Figure 2(b) and (c) it can be observed that in PH and NH the data shows a growing occurrence of outcome event and corresponding trends of key response. The Eq condition also shows an increasing number of outcome occurrence. In other conditions, no significant tendency of human responding was found.

Table 2. Results of Paired-sample t tests comparing different Control Ratings in 6 Conditions

Condition	Control Types	M	SE	t	p value
nC	hum - sim	-3.289	7.324	-0.449	.656
	sim - oth	-17.816	9.226	-1.931	.061
	oth - hum	21.105	9.122	2.314	.026
PH	hum - sim	105.895	6.913	15.318	.000
	sim - oth	-12.447	8.008	-1.554	.129
	oth - hum	-93.447	5.263	-17.756	.000
PS	hum - sim	-94.974	10.813	-8.783	.000
	sim - oth	78.737	9.866	7.981	.000
	oth - hum	16.237	7.941	2.045	.048
NH	hum - sim	-87.316	14.057	-6.212	.000
	sim - oth	-2.184	12.103	-0.180	.858
	oth - hum	89.5	9.549	9.373	.000
NS	hum - sim	105.605	12.059	8.758	.000
	sim - oth	-81.368	9.586	-8.488	.000
	oth - hum	-24.237	12.298	-1.971	.056
Eq	hum - sim	-5.553	9.268	-0.599	.553
	sim - oth	-66.789	10.867	-6.146	.000
	oth - hum	72.342	10.049	7.199	.000

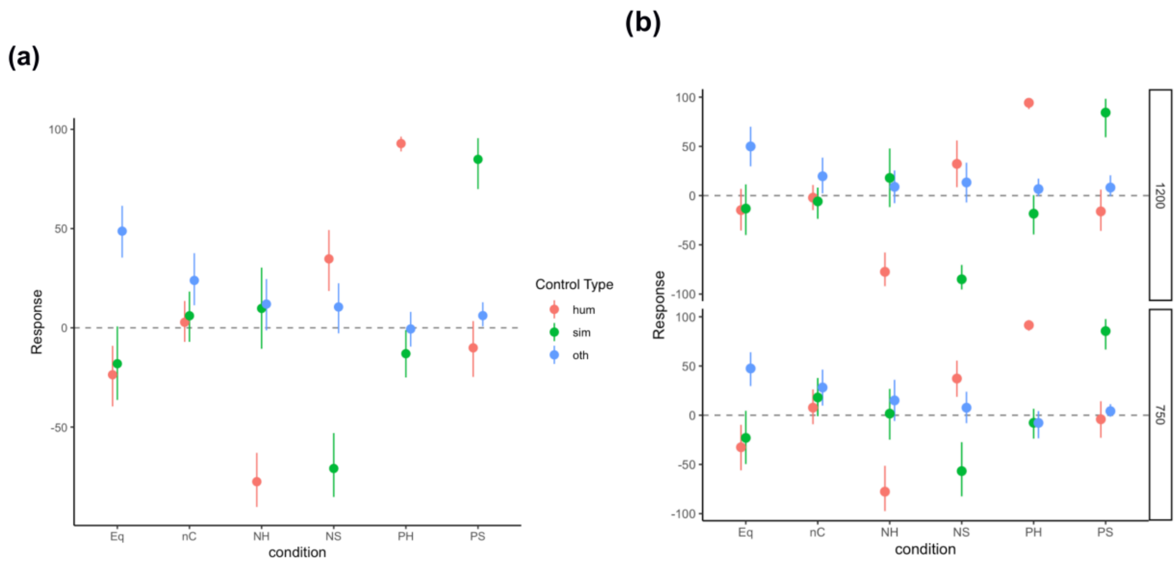

Figure 1. Mean rating of control. (a) shows overall mean ratings in 6 conditions, (b) compares mean ratings of each condition in different time bin manipulations

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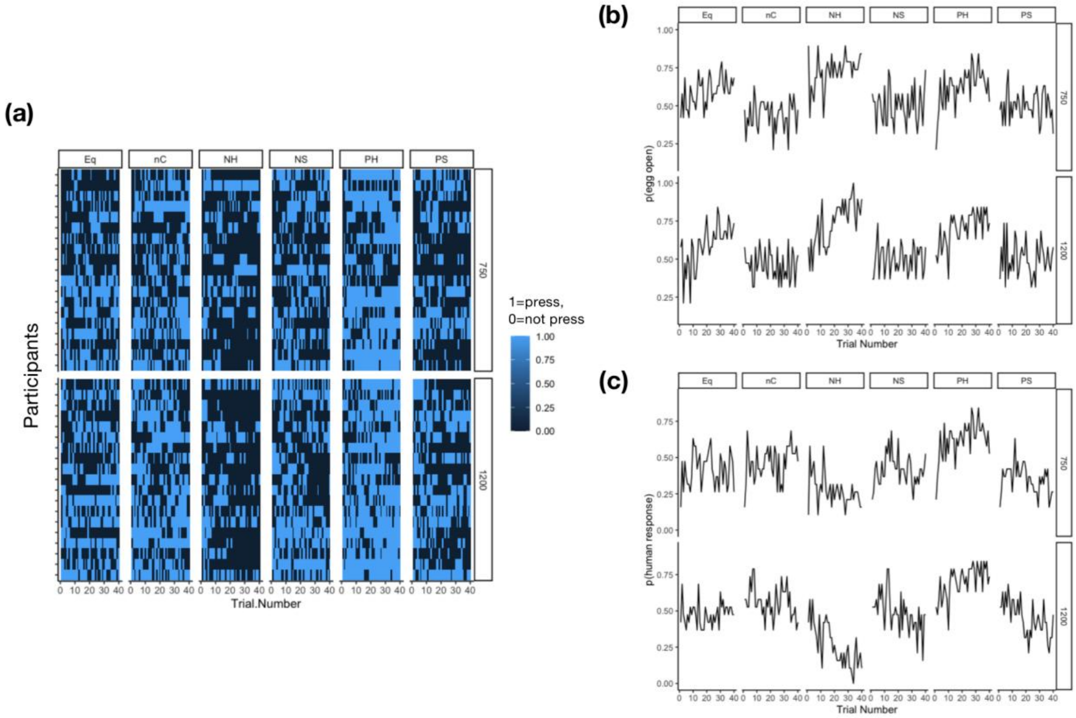

Figure 2. Data of behavioral response. (a) All participants' response in each trial. Correct = 1 means that they made a key response. (b) The variation of proportion of egg open in each block. (c) The variation of proportion of human response in each block

4. Discussion

The primary objective of the current study was to determine the effect of other agent and A-O contingency on individual's judgment of control. The results show that individuals are sensitive to their own agency: they rate a high degree of control in a condition in which the objective contingency implies their control(PH) and rate a low control in one in which their behavior stops the outcome (NH). These finding are consistent with those of Dickinson et al. (1984) and Blanco & Matute (2014) in the single-agent context. It was also found that individuals report a higher control of external agent (PS) condition and lower control in NS condition. These results indicate that in the situation where the effect is caused by another agent, people also can perceive the relation between the cause and the effect. Notably, it is implied in Figure 1 that in NS situation individuals have a tendency to regard themselves having a positive control on the outcome. This indicates an illusion of control which may somehow explain the Agent' Paradox that people are likely to gain a sense of agency towards a change when they learn another agent's negative control on that change, even though they actually have no control over it. The ratings in conditions where no control is made by neither of the agent all approximately equal to zero, which matches the zero contingency condition. However, the ratings in the condition where both individuals' and the external agent's responses cause the outcome, individuals tends to rate a negative control on both themselves and the external agent while rate a positive control on other factors. This imply that individuals will associate the context with the outcome when neither of themselves nor the other agent can independently contribute to the outcome. Together, these results support the assumption that people can learn their own control and other agent's control over an outcome in the process of making the outcome occur in a multi-agent context, but their sensation of control can be influenced by the information of other agent and context they learned in the process.

The bin length effect on rating was not significant in the current experiment. Temporal contiguity is a variable that supports normative learning. Nevertheless, there was a tendency

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in the 1200ms situation, that the ratings of negative control are more accurate and have a more centralized distribution in NH and NS condition. This tendency calls to a further investigation on the same task with a longer time bin.

The behavioral response has some implication about what individuals learn about the sense of control. A possible explanation for the tendencies found in behavioral response is that people have learned how they can make control to the outcome in the conditions that they do have certain influence on the outcome (PH, NH, Eq). Interestingly, though people learned cooperating with external agent to make the effect in Eq condition, they still judged their control as a negative one and attributed the effect to the context. It needs further investigation why cooperating with another agent will produce much less sense of agency than being the only cause of it.

5. Conclusion

Based on these findings and implication, the present study is a step forward to explore the Agent's Paradox. It demonstrates that people can learn A-O causation from action-effect causal perception with another agent also causing the effect, and gain sense of agency when they do have positive control on the outcome and learn the agency of other agents when other agents have the causal power on the outcome. The behavioral response shows corresponding tendencies. On the basis of the current findings, future research can probe into the mechanism behind Agent's Paradox by conducting computational modeling and analysis of brain activities in the development of agency.

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