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An Experiment on Behavior, Learning, and Forgetfulness in Inductive Game Theory

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Abstract

We conduct an experimental study on behavior and cognition in various 2×2 games with/without role-switching from the perspective of inductive game theory (IGT). Here, subjects have no prior knowledge about payoffs and can only learn them by playing the game. Without role-switching, subjects can, and many do, successfully learn their own payoffs. To learn the payoffs of the other, role-switching is required. While this gives more information about the whole structure, subjects do not learn all payoffs successfully. This partial learning allows us to study interactions between behavior and cognition. We find that role-switching has both behavioral and cognitive effects. On the behavioral side, without role-switching, many subject pairs converged to a Nash eq. With role-switching, a significant number of subject pairs converged to either Nash or ICE (intrapersonal coordination eq.) maximizing the average payoffs, as predicted by IGT. On the cognitive side, correct recall of payoffs is positively correlated with the number of experiences but is negatively correlated with convergence to some action pair. Here, some forms of forgetfulness are involved. In particular, when convergence occurs, the other action pairs do not appear and the memories about those payoffs once learned decay and disappear.

JEL Classification Numbers: C72, C79, C91

Key words: Inductive game theory, Knowledge of payoffs, Nash equilibrium, Intrapersonal coordination equilibrium, Off-equilibrium forgetfulness

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1 Introduction

This paper presents an experimental study on behavior and cognition of players from the perspective of *inductive game theory* (IGT). Theoretical structures on IGT have been developed

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in Kaneko-Kline [17], [18], [19], and Akiyama *et al.* [1][1]. Here, in particular, the theory developed in [19] is experimentally tested. We have various new findings, some of which are neither addressed nor noticed in [19]. Also, our experimental study differs from the literature of experimental game theory (economics) in many ways. We start by listing important features of our study, then mention related works, and finally, we give a summary of our experimental results.

1.1 Salient features and related works

Our study has five salient features:
(*i*) no-(prior) knowledge assumption on payoff values;
(*ii*) two types of role-switching;
(*iii*) emergence of Nash eq. (NE) and (cooperative) intrapersonal coordination eq. (ICE);
(*iv*) cognitive limitations and slow learning; and
(*v*) interactions between cognition and behavior.

By role-switching, we mean that two subjects take the positions of the row and column players in some alternating manner. The assumption in (*i*) is basic to IGT and the role-switching in (*ii*) is essential for possible learning about the entire structure of a game. These two are bases for the other features.

The emergence of NE or ICE in (*iii*) depends on the type of role-switching. In (*iv*), we presume, in accordance with IGT, that subjects are boundedly rational. Under (*iv*) together with (*i*) and (*ii*), feature (*v*) becomes relevant. By studying these features, we find some new aspects that were not previously considered in IGT such as the relationship between convergence and memory decay. All five features are closely related and new to the game theory and experimental game theory literature. We use them to explain our experimental analysis and results.

The standard experimental game theory starts with a well specified description of the game structure explained to experimental subjects. This description includes the available actions and monetary payoffs as well as some information structure (cf., Camerer [7], Holt [16]). Typically, one studies how subjects behave together with the other players in such an experimental environment. As a consequence, (*i*) is not an issue, except for a few studies to be mentioned below. Under (*i*), however, it becomes relevant to discuss a subject's learning not only of behavior but also of his and the other's payoffs. This differs from the standard literature where learning is typically about behavioral adjustments and convergence to some equilibrium (cf., Camerer [7], Chap.6). In our approach, interactions between behavior and cognition are central. The role-switching in (*ii*) gives a new source for learning the payoffs of both players. IGT suggests that the emerging behavior described in (*iii*) is influenced by role-switching. Our experiment allows us to test this prediction of IGT.

A few papers in the literature deal with ignorance about payoffs. For example, Shubik [32], McCabe-Rassenti-Smith [23], Oechssler-Schipper [27] reported some experimental studies dealing with the case where each subject knows only his own payoffs but not the other's payoffs. These correspond to the behavior of subjects in late periods of our experiment without role-switching where they have learned their own payoffs already. In [27], each subject again observes only his own payoffs and has to guess the other's preferences from a given small list of possible preferences. Apesteguia [3] and Erev-Greiner [9] studied learning of one's own payoffs, but did not consider role-switching as a source for learning the other's payoffs. They obtained

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[1] A seminal form of inductive game theory was given in Kaneko-Matsui [21].

experimental results, behaviorally quite consistent with our experiment without role-switching.

It is known (cf., Selten-Stoecker [31], Andreoni-Miller [2]) that a strong tendency of cooperative behavior was supported by trigger-strategies in Prisoner's Dilemmas without role-switching. This tendency critically depends upon the end-game effect, which requires the subjects to know when the experiment stops. Contrary to this, we avoid the possibility of the subjects knowing which round they are playing and when the experiment will stop (Section 2). Our results are behaviorally very different from this known tendency. We observe convergence to the NE in the case without role-switching, but more cooperative behavior with role-switching, which is supported in a different way from trigger-strategies.

There are some papers, appearing to be related to our study, on "playing both roles" in the literature of experimental game theory (cf., Weg-Smith [33], Burks *et al* [6], and their references). These intend to study social reciprocity/fairness and social preferences (cf., Fehr-Schimidt [10], Charness-Rabin [8]), and in [6], it is studied whether prior knowledge on "playing both roles" affects reciprocity/fairness. However, these studies did not address interactions between learning of the game structure and behavior. The social preferences in those studies are taken as given and brought to the experiment by the individuals. The experimenter tries to detect evidence of social preferences. We are interested in the emergence of social preferences in an experiment with role-switching. We touch this issue again in Section 7.

1.2 Summary of our experiment and results

We adopt five different 2-person 2×2 games: three Prisoner's Dilemmas (QS1, QS2, T), another game with a unique mixed Nash equilibrium (MS), and a Stag-Hunt (SH). For each game, we consider two types of role-switching: No role-switching (NRS) and Alternate role-switching (ARS). In total, we have 10 treatments. In each, the subjects play the same game 50 times, and at the end of the experiment, they answer a questionnaire about their understanding of observed payoffs. We explain the experimental design in Section 2. Here, we use behavioral and cognitive outcomes, to discuss (*i*) - (*v*), from two subject pairs in NRS and ARS for game T.

Table 1.1: Game T

	c	d
c	(5,4)	(2,10)^{ICE}
d	(6,1)	(3,2)^{NE}

Table 1.2: Average payoffs

	c	d
c	(5+4)/2	(2+10)/2
d		(3+2)/2

The *twisted* Prisoner's Dilemma T is given as Table 1.1; it can be regarded as a Prisoner's Dilemma though the payoffs are asymmetric and twisted. The action pair dd is the unique NE[2]. The pair cd is the unique ICE, which maximizes the average of the payoffs for each action pair over unilateral deviations. The concept of ICE was introduced in Kaneko-Kline [19] in order to describe subjects' behavior with role-switching. Table 1.2 gives the average payoff of 6 to cd, which is larger than the average 2.5 obtained from a unilateral (but coordinated) deviation to dd and also the average 4.5 obtained from cc. The concept of an ICE is discussed in Section 3.

Both NE and ICE are interpreted from the perspective of IGT as possible stationary states subject to some trials/errors. IGT presumes that in the beginning, each behaves more or less

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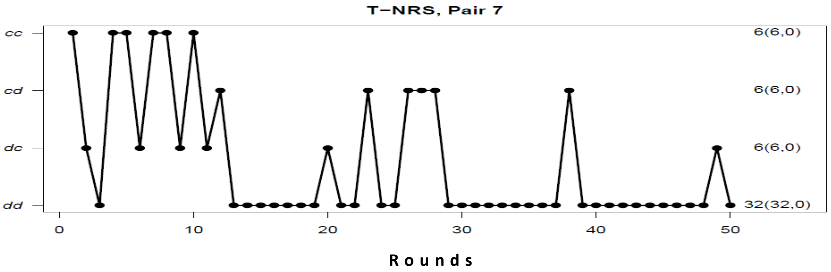
[2] Mathematically speaking, this is a dominant strategy equilibrium. Nevertheless, since IGT implies the NE logic, dd should be a Nash equilibrium in accordance with IGT.



Game T

	c	*d*
c	5 , 4	2 ,10
d	6 , 1	3 , 2

1's view

	c	*d*
c	5 ,	2 ,
d	6 ,	3 ,

2's view

	c	*d*
c	, 4	, 10
d	, 1	, 2

Figure 1: Game T in NRS

randomly in an effort to learn the payoffs. In NRS, a subject can learn only the payoffs of one role, while in ARS, he can learn the payoffs of both roles, but learning may be slower because of role-switching. By the cognitive limitations (*iv*), we expect the learning, memory retention, and behavior to differ between NRS and ARS. Kaneko-Kline [19] made theoretical predictions: For NRS, a possible stationary state is a NE, and for ARS, it is either a NE or an ICE[3].

Here, we illustrate the above difference using the experimental results of two subject pairs: one for NRS and one for ARS. In NRS, the game is played 50 times without role-switching, and a subject is either a row or a column player for all the rounds. In Fig.1, the subject pair 7 playing game T in NRS showed some learning at the beginning, but finally converged to NE, *dd*. The numbers $(6, 0)$ in the top right margin describe that subject 1 experienced *cc* 6 times as a row player and 0 times as a column player. In ARS, each subject played the row player and column player 25 times alternately. The 11(4,7) in the bottom right margin of Fig.2 indicates that this subject experienced *cd* 11 times, 4 of which he experienced as the row player. By role-switching, each subject may learn the payoffs of both row and column players. Fig.2 describes the trajectory of action pairs taken by the subject pair 14; after round 35, the subjects played ICE, *cd*, constantly to the end, except for round 40. Those figures illustrate well some predicted behavioral differences of IGT between NRS and ARS.

To study the behavioral data from the viewpoints of (descriptive/mathematical) statistics as well as of IGT, we introduce two concepts: *temporal phases* and 8-*convergence*. The first concept is used to divide the 50 rounds into 5 sub-periods in each of which each subject's behavior is regarded as stochastically constant. The concept of 8-convergence captures stationary behavior of subjects over a temporal phase. In general, however, we do not necessarily have convergence for all subject pairs. We analyze convergence (and non-convergence) in different treatments. These are discussed in Sections 3 and 4.

With respect to cognitive aspects, NRS and ARS are very different. After the 50 rounds of play, each subject is given a questionnaire about his understanding of the payoffs. Although

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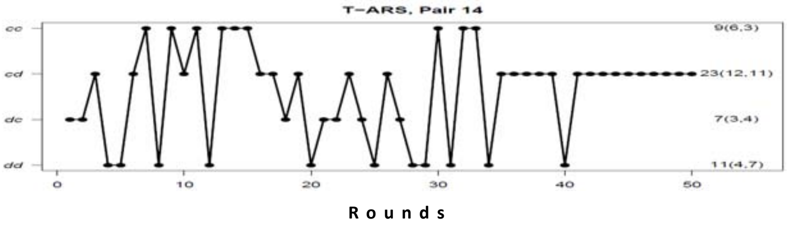
[3] Binmore [5] divided the possible interpretations of NE into two extremes: eductive and evolutive. Our interpretation of NE (and ICE) is closer to the latter. The concept of ICE seems also related to Bachrach's [4] emergence of cooperation from team reasoning. However, his approach is eductive, and the underlying source for team reasoning is not in the scope. The main development of IGT in [19] is to uncover the experiential source for cooperative behavior.



Game T

	c	*d*
c	5, 4	2, 10
d	6, 1	3, 2

1's view

	c	*d*
c	[4], [3]	2, 10
d	[5], [8]	3, 2

2's view

	c	*d*
c	[6], 4	2, 10
d	[8], [8]	3, [6]

Figure 2: Game T in ARS

subjects have bounded memory abilities, as mentioned in (*iv*), each possibly needs to learn only 4 payoff values in NRS, and is quite successful at retaining correct memories of all payoff values. On the other hand, in ARS, he faced possibly 8 payoff values, and had large difficulties in recalling the payoffs. The first rows of Tables 1.3 and 1.4 show the average numbers, in NRS and ARS, of payoffs experienced *at least once* in the 50 rounds, which are out of 4 and 8. The second rows show the average numbers of correct memories, out of 4 and 8, again. These were quite accurate in the NRS cases, but accuracy almost halves in the ARS cases[4].

Table 1.3: NRS, out of 4

	QS1	QS2	T	MS	SH
#exp.	3.93	3.93	4	4	3.57
#cor.	3.39	3.39	3.82	3.68	3.00

Table 1.4: ARS, out of 8

	QS1	QS2	T	MS	SH
#exp.	7.36	7.07	7.71	8	6.86
#cor.	4.36	2.86	3.64	4.79	2.39

Features (*iv*) and (*v*) are interactively related. Because of cognitive limitations of (*iv*), each subject needs repeated experiences in order to successfully learn payoffs and obtain a subjective view. Once he has a view, which may be partial and include incorrect elements, he adjusts his behavior based on his view, which is one direction in (*v*). He now plays the action suggested by his view more frequently and the other actions less frequently. Consequently, his memories about the payoffs from the other actions decay. Thus, convergence to some action requires experiences and learning, but once convergence happens, decay of other memories sets in. This decay is a new type of bounded memory not discussed in the papers on IGT, e.g., in [19] and [1].

In Section 5, we focus on the cognitive data in the ARS cases, and show a positive correlation between the number of experiences of a payoff value and the correctness of the answer given to the questionnaire. When the experiment shows convergence, we find a decay of memories of off-equilibrium action pairs. In Fig.2, the understandings by the two subjects involve a lot of incorrect recall marked with [ ]. Both subjects experienced all payoffs, but both gave 4 incorrect answers. Since the subjects did not play any action pairs other than *dc* after round 35 with the exception of *dd* at round 40, forgetfulness is involved in their incorrect answers.

From the perspective of IGT, the NE and ICE are defined relative to each individual subjective understanding. In Section 6, we look at those concepts in the subjects' subjective un-

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[4] This is reminiscent of Miller's [24] "the magic number 7", which is the observation that 7 digits are a typical limit for short-term memorization.

derstandings. The subject pairs showing convergence behaved consistently with their subjective views with some exceptions. Those will be discussed in Section 6.

In sum, we found that behavior and cognition interactively evolved. Cognitive aspects allow behavior to converge to an equilibrium. Conversely, convergence may cause memory once acquired to decay over time. This is observed in the ARS treatments but is not observed in the NRS cases, since keeping 4 payoffs is easy for each subject. In this respect, the ARS cases are very different from the NRS cases. We summarize and discuss our findings in Section 7.

The paper is organized as follows: Section 2 summarizes the experimental design. Section 3 describes behavioral data from our experiment, and prepares some concepts such as 8-convergence, NE and ICE from the perspective of IGT. Section 4 gives some statistical tests on the behavioral data. Section 5 analyzes the cognitive data mainly for ARS. We consider interactions between cognition and behavior in Section 6. In Section 7, we give a summary, discussions and future problems.

2 Experimental Design and the Resulting Data

Our experiment, conducted in 2009 and 2012, is designed to fit the no-knowledge assumption and role-switching. Here, we describe the experimental design[5].

Treatments: In addition to the game T given in Section 1, we use two Quasi-symmetric prisoner's dilemmas (QS1 and QS2), a game MS with a unique mixed NE, and a Stag-Hunt SH. The payoff functions of a game are denoted by h_b and h_g for roles b (row player) and g (column player). We discuss these games together with the concepts of NE and ICE in Section 3.

Table 2.1: game QS1

	c	d
c	$(5,4)^{ICE}$	$(2,5)$
d	$(6,1)$	$(3,2)^{NE}$

Table 2.2: game QS2

	c	d
c	$(8,7)^{ICE}$	$(2,8)$
d	$(9,1)$	$(3,2)^{NE}$

Table 2.3: game MS

	c	d
c	$(9,3)^{ICE}$	$(1,6)$
d	$(3,5)$	$(2,4)$

Table 2.4: game SH

	c	d
c	$(8,7)^{ICE,NE}$	$(2,6)$
d	$(7,1)$	$(4,3)^{NE}$

In each experiment, one of these games is played repeatedly 50 times by the same subjects. We consider two types of role-switching, NRS and ARS. In NRS, each subject plays the same role for all 50 periods, and in ARS, each subject plays each role 25 times alternately. A treatment τ is expressed by a vector in the set $\Upsilon := \{\text{NRS,ARS}\} \times \{\text{QS1,QS2,T,MS,SH}\}$. The experiment was conducted in the between-subject design, i.e., each subject participated in only one treatment.

Subjects: Each treatment has 14 pairs of subjects; the total number of subjects is $280 = 10$ (treatments) $\times$ 14 (pairs) $\times$ 2 (subjects)[6]. We chose those subjects from the undergraduate students of Waseda University, a comprehensive private university with about $45,000$ undergraduates. They were chosen from all majors, except economics to avoid subjects familiar with

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[5] Experimental materials and analyzed data are available at:
http://aitakeuchi.web.fc2.com/materials/igt_experiment.html

[6] The number of subject pairs for treatment (ARS,QS2) is 15, due to some recruiting reason. In the following calculations, we use this number for (ARS,QS2), but we ignore this difference unless it matters.

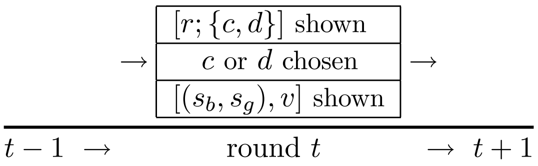
economics and game theory.

Laboratory Setting: The laboratory was set up to prohibit direct interactions between the subjects: The two subjects of each pair had interactions only through the computer system to keep anonymity. The subjects were assembled and given a computer based instructional tutorial. The tutorial took 30 minutes, including an understanding test and a small rehearsal[7], where all payoffs were specified to be 1.

The instructions included a statement that the experiment would stop at some round between 40 to 60. This was to avoid the end-game effect. Actually, we stopped all experimental runs at the end of round 50. After the experiment, each subject was given a questionnaire, which took about 10 minutes to complete, and then the rewards to the subjects were paid. The entire duration of each experiment was about 70 minutes from the start of the instructions through the questionnaire and payment to subjects.

Basic Information: In the tutorial, each subject was told that he would play a 2-person game with a fixed opponent and had 2 available actions for his choice in each round. Also, he was told that role-switching might happen and his role would be specified in the beginning of each round. He would notice the pattern of role-switching only during the experimental run. His own payoff values, but not those for the other subject, were experienced in the experimental run, and they could be memorized only in his mind (no devices for taking notes were allowed). Subjects were informed that the payoff structure would be constant over all rounds.

The information flow to each subject in each round is as follows:



In the beginning of round t, two pieces of information $[r;\{c,d\}]$ appear on the monitor screen: role r (blue b (row) or green g (column) player) and available actions c,d. Then, a subject chooses c or d within 10 seconds[8]. After the choices are made, the screen shows the feedback information, $[r;(s_b,s_g),v]$, including his role r, the choices, s_b,s_g, and his own payoff value v. This screen lasts for 10 seconds before the experiment goes to the next round. During the experimental run, subjects were not told which round they were in.

We call the subject having role b at round 1 as 1 and the other as 2.

Payoffs (Rewards) to Subjects: It is also stated that the total reward to each subject will be paid in cash and calculated as: (the sum of payoffs from the 50 rounds) × 5yen + 500yen (participation fee). Hence, in QS1, if (c,c) is played for 50 rounds, the total payment for subject 1 becomes $1,750$yen. The average payment over all the subjects was $1,484$yen.

Questionnaire: Three types of questions were given to each subject: (1) payoff structure; (2) behavioral criteria (in ordinary language); and (3) free writing comments about his and the opponent's behavior. For (1), we asked each subject about the 8 payoff values. Each answer should be given as a natural number, or a "?" in the case he cannot recall. In this paper, we focus on the data for (1), and use (2), (3) only as auxiliary data.

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[7] We use the Z-tree program by Fischbacher [11] for our experiment.

[8] In the instructions, each subject was informed that if he fails to make a choice in a round, his payoff for that round will be 0. In this case, the payoff to the other player is 5, but the subjects were not informed of this fact. The failures to make choices were less than 0.05% of the actions to be taken in the entire experiment.

The subjects were not informed about the questionnaire before the experiment and no monetary rewards were given for correct answers. Our objective is to study interactions between behavior and cognition. Cognition helps to obtain a better reward from better behavior. If subjects would be paid for correct answers, this might distort those objectives and cause subjects to concentrate on memorizing payoffs to increase payments for correct answers[9].

Symbol Neutrality: In writing up the experimental results, we use the roles as the row and column players, and available actions c and d. In the actual laboratory setting, we used "blue" and "green" for the two roles, and "N" and "S" ("W" and "E") for c and d. To ensure neutrality of the action symbols, the 14 pairs of subjects for each treatment τ were divided into two sessions where the payoffs from the action pair NW were interchanged with those from SE, and those from NE were interchanged with those from SW. These treatments were adopted to avoid framing effects and to keep symbol neutrality. Our experimental results do not indicate much difference in the behaviors of subjects between those different sessions.

Behavioral Data: Let $\tau \in \Upsilon$ be a treatment, and let $\pi = 1, ..., 14$ be a pair of subjects. The behavioral data for τ and π are described as the form:

$$\langle \widehat{s}_1^{\tau,\pi}, \cdots, \widehat{s}_{50}^{\tau,\pi} \rangle, \text{ where } \widehat{s}_t^{\tau,\pi} = (\widehat{s}_{t,1}^{\tau,\pi}, \widehat{s}_{t,2}^{\tau,\pi}) \text{ for } t = 1, ..., 50. \tag{1}$$

Each $\widehat{s}_t^{\tau,\pi} = (\widehat{s}_{t,1}^{\tau,\pi}, \widehat{s}_{t,2}^{\tau,\pi})$ describes the action pair taken by subjects 1 and 2 of pair π in round t in treatment τ. In Fig.1, $\tau =$ (NRS,T), $\pi = 7$, and if $t = 2$, then $\widehat{s}_t^{\tau,\pi} = dc$.

Cognitive (Payoff) Data: The payoff question itself is the same for all the treatments. Recall that a subject experienced (at most) 4 payoffs in NRS, but 8 in ARS. We focus only on the four payoffs in NRS, and the 8 payoffs in ARS[10,11].

3 Behavioral Data, NE and ICE in IGT

To analyze the behavioral data, the evolutionary processes from random behavior to stationary or patterned behavior (equilibrium) are crucial. In Section 3.1, we introduce the notion of temporal phases to examine this evolution. We find a tendency for behavior to converge to specific action pairs in later temporal phases in both NRS and ARS. However, the behavior is not the same for NRS and ARS. In Section 3.2, we use the theoretical results in IGT to explain these differences. In Section 3.3, we explain the background of IGT for further considerations.

3.1 Temporal phases

The experiment starts with the no-knowledge assumption (feature (i)). A subject can only learn payoff values by taking various actions in early rounds. Once a subject has experienced enough payoff values, he may take a specific action which he deems to work well and sticks to for some

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[9] Stated answers without monetary incentives may have higher error than ones with monetary incentives (cf. Rustrom-Wilcox [29]).

[10] Each subject was asked to report all 8 payoff values in NRS even though the reports on the payoffs for the other role must have been guesses. These guesses were not very accurate, so we ignored them. The average correct rates vary from 1% to 7% for the 5 treatments, and the entire average is about 3%.

[11] Incidentally, Oechssler-Schipper [27] gave a questionnaire after 15 rounds of play where subjects were asked to guess about the relative values of the other subject's payoffs. The subjects in their experiment were not very successful at guessing either.

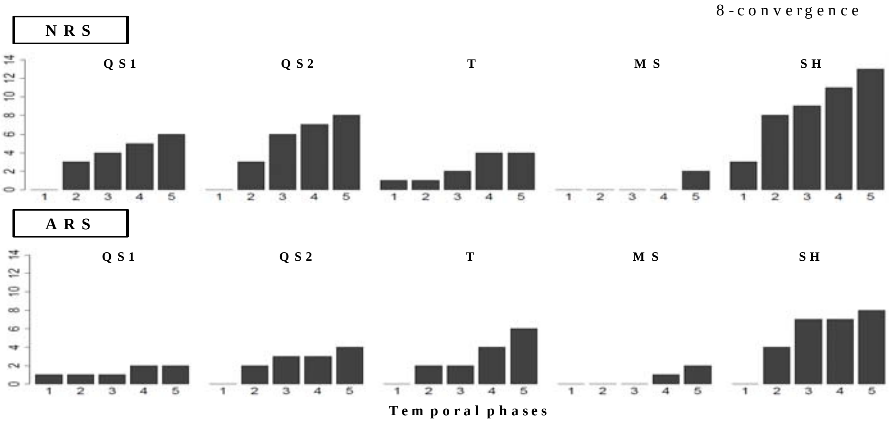

Figure 3: 8-convergence

time. In IGT, these actions form stationary states, which are either NE or ICE. Nevertheless, the transition from the trials/errors to stationary actions is gradual.

To examine this gradual transition, we introduce the concept of a temporal phase in which a subject is assumed to keep his behavior and view constant while still making occasional trials/errors. A subject needs time to change his behavior consciously, which is based on his bounded cognitive ability. For an analytic purpose, this allows us to compare behavioral changes over the course of play.

We divide the entire 50 rounds simply into 5 temporal phases[12], i.e., $1-10, 11-20, 21-30, 31-40$, and $41-50$. These are called *temporal phases* $1, ..., 5$. Phase k consists of rounds $10(k-1)+t$, $t = 1, ..., 10$.

We use the concept of convergence to express stationarity within a temporal phase. We say that $\langle \widehat{s}^{\tau,\pi}_{10(k-1)+1}, ..., \widehat{s}^{\tau,\pi}_{10k} \rangle$ for phase k is 8-*convergent to* action pair $s \in S$ iff

$$\left| \{ t : \widehat{s}^{\tau,\pi}_{10(k-1)+t} = s \text{ and } t = 1, ..., 10 \} \right| \geq 8. \tag{2}$$

This states that s occurred at least 8 time for temporal phase k. Such an action pair s is called a *cluster pair*. Since trials/errors involve some stochastic process, we consider statistical aspects for 8-convergence in Section 4.2. The subject pair depicted in Fig.1 shows 8-convergence in phases 4 and 5, and the subject pair in Fig.2 shows 8-convergence only in phase 5. We can change 8-convergence to 7-, 9- and even 10-convergence simply by replacing 8 in (2) by $7, 9$ and 10. In general, the results change in an expected manner with a higher requirement for convergence reducing the number of subject pairs showing convergence.

The bar chart in Fig.3 describes the number of subject pairs, out of 14 subject pairs, exhibiting 8-convergence for each treatment τ and each of the five temporal phases. As a temporal phase proceeded, more convergences appeared. For example, in phase 5 for (NRS,SH), all the subject pairs showed 8-convergence to two cluster action pairs, *cc* and *dd*. Contrary to this, MS shows smaller numbers of 8-convergence even in phase 5. In Fig.3, however, we cannot see

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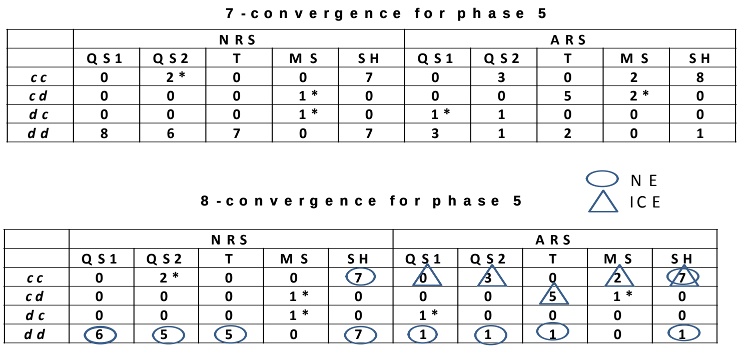
[12] We made the choice to use 5 phases of equal length, but other choices, e.g., fewer or more phases of different lengths, are possible and open for future study.



7-convergence for phase 5

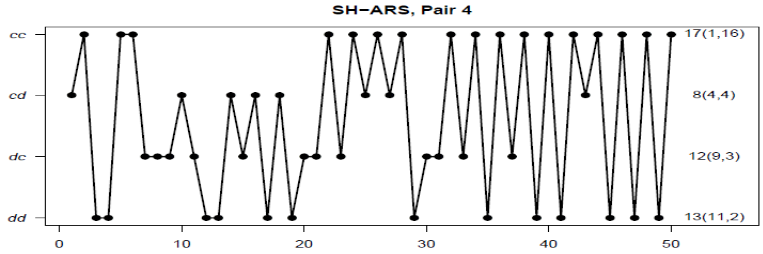
	NRS					ARS				
	QS1	QS2	T	MS	SH	QS1	QS2	T	MS	SH
cc	0	2*	0	0	7	0	3	0	2	8
cd	0	0	0	1*	0	0	0	5	2*	0
dc	0	0	0	1*	0	1*	1	0	0	0
dd	8	6	7	0	7	3	1	2	0	1

○ NE
△ ICE

8-convergence for phase 5

	NRS					ARS				
	QS1	QS2	T	MS	SH	QS1	QS2	T	MS	SH
cc	0	2*	0	0	7	0	3	0	2	7
cd	0	0	0	1*	0	0	0	5	1*	0
dc	0	0	0	1*	0	1*	0	0	0	0
dd	6	5	5	0	7	1	1	1	0	1

Figure 4: 7- and 8-convergence for phase 5



Game SH

	c	*d*
c	ICE, NE 8, 7	2, 6
d	7, 1	NE 4, 3

1's view

	c	*d*
c	ICE, NE 8, 7	2, 6
d	7, 1	NE 4, 3

2's view

	c	*d*
c	ICE, NE 8, [8]	[?], [?]
d	[?], [?]	ICE, NE [3], 3

Figure 5: Role-dependent behavior of the ICE-type

detailed cluster pairs for convergence. Therefore, for the remainder of this paper, we restrict our attention to 8-convergence in phase 5, forgetting the dynamics described in Fig.3.

Fig.4 lists the number of subject pairs converging to each action pair for each treatment in phase 5. We focus on 8-convergence, but sometimes look at the data for 7-, 9- and 10-convergence.

The above data reveal clear differences between ARS and NRS. For example, in (NRS,T), all five convergent subject pairs converged to the action pair *dd*. In (ARS,T), five out of the six convergent subject pairs converged to a different action pair *cd*. In Sections 3.2 and 3.3, we use IGT to explain these observations on convergence.

Role-dependent behavior: A number of pairs both in NRS and ARS show some patterned, but non-convergent, behaviors. In ARS specifically, the additional information of the assigned role is available. It is possible for subjects to behave taking assigned roles into account. Such a behavior is seen in Fig.5. Indeed, for phase 5, *dd* and *cc* are alternately played; this is confirmed by looking at the number of plays of those action pairs listed in the right margin. The development of such role-dependent behavior may help to expand the scope of IGT. We discuss this and some other examples in Section 6.2.

3.2 Behavioral Predictions from IGT

In IGT, we have two candidates for possible stationary states to which the behaviors of subject pairs might converge. They are the Nash eq. (NE) and the Intrapersonal Coordination Eq. (ICE)[13]. In IGT, we interpret NE as a stationary state from which neither player has an incentive to deviate. Since in the NRS treatment, each subject can know payoffs for only his role, the stationary state inherited from previous plays supports him choosing the Nash type behavior[14].

In ARS, on the other hand, each subject learns payoffs of both roles as well as the behavior of the other subject across roles. It is still possible for a subject to follow the Nash type behavior to maximize his payoff against his observed behavior of the opponent. In ARS, new behavior becomes possible; in particular, ICE behavior emerges in ARS. In Kaneko-Kline [19], the ICE behavior of each subject is defined within his acquired subjective view. In this section, however, we focus on the ICE behavior in the objective game with correct payoffs. We return to this in Section 6 after we explore the cognitive data in Section 5. We refer to the following definition for ICE, which was derived from more basic concepts in [19] for cases with sufficient role-switching.

We say that a pair (s_b^*, s_g^*) is an *ICE* iff for $s_b \neq s_b^*$ and $s_g \neq s_g^*$,

$$\begin{aligned} \frac{1}{2}h_b(s_b^*, s_g^*) + \frac{1}{2}h_g(s_b^*, s_g^*) &> \frac{1}{2}h_b(s_b, s_g^*) + \frac{1}{2}h_g(s_b, s_g^*) \qquad (3)\\ \frac{1}{2}h_b(s_b^*, s_g^*) + \frac{1}{2}h_g(s_b^*, s_g^*) &> \frac{1}{2}h_b(s_b^*, s_g) + \frac{1}{2}h_g(s_b^*, s_g), \end{aligned}$$

Recall that h_b and h_g are the payoff functions for the roles b (row player) and g (column player). The first inequality in (3) corresponds to deviations by the two subjects when each is at role b, supposing that the other subject follows the same deviation when he is at role b. If this happens, each subject experiences the payoffs derived by such deviations at both roles. Since the subjects alternately switch roles in ARS, each cares about the simple average payoff. The second inequality corresponds to deviations at role g. Notice that when a subject considers a deviation at a role, he supposes that the other subject would deviate in the same way. This behavioral assumption is called the *role-model behavior*. Since this involves some initial sacrifices (risk/cost), we discuss the underlying assumptions in more detail in Section 3.3[15].

We now look at the data of 8-convergence in Fig.4 in terms of NE and ICE, where NE and ICE are marked with a circle and a triangle. We start with the three games: T, QS2, and QS1, and then go to MS and SH.

In (NRS,T), all convergent subject pairs went to the NE *dd*. In (ARS,T), five of the six convergent subject pairs went to the unique ICE *cd*, and the remaining pair went to the NE. Thus, these show a tendency to move from NE to ICE when going from NRS to ARS.

In (NRS,QS2), five out of seven convergent subject pairs went to the NE *dd*. In (ARS,QS2), three out of the four convergent subject pairs converged to the ICE *cc*, with the other subject pair converging to the NE *dd*. The results for QS2 are also supportive of the predictions of

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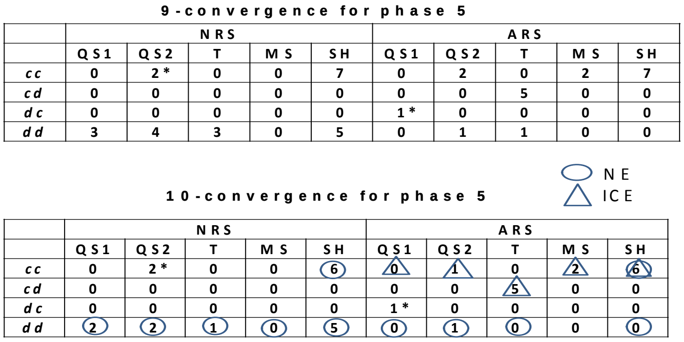
[13] Exactly speaking, ICE covers NE also. ICE, as we use it in this experimental paper, is derived theoretically in Kaneko-Kline [19] for cases with sufficient role-switching. Without role-switching, on the other hand, ICE is shown to reduce to NE.

[14] In this sense, we refer to this as NE behavior, not as dominant strategy behavior.

[15] The choice of the strict inequality or weak inequality in (3) does not matter for the games considered here But it matters in general (see Kaneko-Kline [19]). Here, we adopt the strict inequalities for the definitions of ICE and NE even for subjective views in Section 6.



9-convergence for phase 5

	NRS					ARS				
	QS1	QS2	T	MS	SH	QS1	QS2	T	MS	SH
cc	0	2*	0	0	7	0	2	0	2	7
cd	0	0	0	0	0	0	0	5	0	0
dc	0	0	0	0	0	1*	0	0	0	0
dd	3	4	3	0	5	0	1	1	0	0

◯ NE
△ ICE

10-convergence for phase 5

	NRS					ARS				
	QS1	QS2	T	MS	SH	QS1	QS2	T	MS	SH
cc	0	2*	0	0	6	0	1	0	2	6
cd	0	0	0	0	0	0	0	5	0	0
dc	0	0	0	0	0	1*	0	0	0	0
dd	2	2	1	0	5	0	1	0	0	0

Figure 6: 9- and 10-convergence for phase 5

IGT. In (NRS,QS2), however, we have two subject pairs exhibiting convergence to *cc*, which are outliers of IGT, and some other treatments have such outliers, which appear with asterisks, *, in Fig.4. Those pairs with asterisks will be briefly discussed in the end of this subsection.

The results for QS1 show more limited support for the predictions of IGT. In NRS, all six convergent subject pairs converged to the NE *dd*. In ARS, however, only one of two convergent pairs went to the NE with the other going to an outlier *dc*. The ARS case showed a clear movement away from NE, but not much of a movement towards ICE. The concept of ICE is based on the role-model behavior, which has some associated risk/cost. In Section 3.3, we will discuss this in more detail and show how this consideration might explain the low level of ICE behavior in (ARS,QS1).

The MS game has no NE, so IGT does not predict any convergent behavior in NRS. Nevertheless, we find two subject pairs converging to non-NE's. In ARS, MS has a unique ICE, *cc*, and two of the three convergent subject pairs went to the ICE *cc*. Here, we have three outliers in NRS and ARS. However, Fig.6 shows that these outliers would disappear if we look at 9-convergence.

The game SH has two NE: *dd* and *cc*. In the NRS case, 7 subject pairs showed 8-convergence to *dd* and the remaining 7 pairs converged to *cc*. These findings are consistent with IGT for NRS since we have convergence to a NE for each of the 14 subject pairs. Though both *cc* and *dd* are NE, only *cc* is an ICE. For ARS we expect more instances of the ICE *cc*. This is what we see: 7 of the 8 convergent pairs went to the ICE *cc*[16].

In the entire table of 8-convergence, we have 6 outliers, not directly compatible with the IGT prediction. However, in the tables of 9- or 10-convergence in Fig.10, the number of action pairs with asterisks is reduced to three. Tightening the convergence requirement results in a tighter fit between the behavioral data and IGT.

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[16] Incidentally, the theory of equilibrium selection (cf., Harsanyi-Selten [15], Myerson [25], p.119) can also be used to separate *cc* from *dd*. The former, *cc*, is payoff dominant and the latter, *dd*, is risk dominant. Some experimental literature (cf. Schmidt, *et al.* [30]) has shown that payoff values and differences in SH games impact on whether *cc* or *dd* is chosen. Our finding is that that the type of role-switching also affects this choice.

3.3 Role-model behavior and associated risk/cost

In IGT, the two concepts, NE and ICE, are based on subjects' understandings acquired from experiences. This is the cognitive part of our experimental study, but in particular, ICE requires a specific form of interactive reasoning, though its resulting mathematical definition is simply given in (3). For a better understanding of the cognitive study given in Section 5, here we give a background of the ICE concept. We emphasize some associated risk/cost involved in ICE, which differentiates ICE from NE.

The motivation for ICE comes with the behavioral and cognitive interactions caused by role-switching. These interactions are summarized as follows:

(a): each subject develops some beliefs on the other subject's payoffs derived from his own experiences.

In particular, after sufficient repetitions of role-switching, each subject develops the belief that the other subject develops, more or less, the same understanding. Although those subjects are mentally and cognitively independent, alternate role-switching gives each subject a reason, at least from his own perspective, to believe that the other reaches essentially the same beliefs about payoffs. It will be seen in Sections 5 and 6 that the actual beliefs may differ quite lot.

Once a subject reaches this state of mind, he may recognize some alternative action pair with a higher average payoff than the current action pair. For example, in game T, *cd* gives a higher average payoff, $(2 + 10)/2 = 6$, than *dd*, $(3 + 2)/2 = 2.5$, for both subjects. How might these subjects initiate a move from *dd* to *cd* since they are behaviorally independent and no communication is allowed? Here we postulate:

(b): one subject takes the *role-model behavior* to reach an ICE pair.

After recognizing a mutually beneficial deviation, one subject, say 1, acts as a role-model, and takes the initiative to change his behavior, hoping that the other will follow his lead. In the game T, subject 1 initiates a switch to *cd* from *dd* when he is the row player. This change involves a *sacrifice* by subject 1 of his immediate payoff which drops from 3 to 2. If subject 2 follows 1's lead by switching to c in the next round, then subject 1 would get 10. If they move to the stationary action pair *cd*, the resulting average payoff increases from 2.5 to 6. We call this type of behavior for subject 1 "role-model behavior" since 1 plays the role of a "leader".

In our behavioral data shown in Fig.4 and Fig.6, we have positive tendencies of emergence of ICE, except for the game QS1. To understand what could happen in (ARS,QS1), we should notice that the role-model behavior requires a cost of sacrificing the immediate payoff as well as a risk of ending in failure. In ARS, we can expect (a) to hold, but (b) holds only if the cost and risk are smaller than a gain relative to an alternative behavior.

Let us look at QS1. Consider the corresponding version of Table 1.2 for it, which allows us to compare the average payoff gains and associated sacrifice:

Table 3.1: NE in QS1

	c	d
c	$(5,4)^{ICE}$	(2,5)
d	(6,1)	$(3,2)^{NE}$

Table 3.2: average payoffs

	c	d
c	(5+4)/2	(2+5)/2
d	(6+1)/2	(3+2)/2

In QS1, *dd* is a NE but not an ICE. One possible mutually beneficial deviation from *dd* is to *cd*. This will increase the average payoff from 2.5 to 3.5, which is only an average gain of 1. The immediate sacrifice to the role-model in moving from d to c is also 1. Similarly, the deviation from cd to cc increases the average payoff by 1 but again induces the sacrifice 1 to subject 2. Arguably, in both deviations, the average gain is not large enough relative to the sacrifice to induce the risky behavior of a role-model.

It is an empirical question as to how large average gains need to be relative to the immediate sacrifices in order to generate role-model behavior. It is our observation that in the case of QS1 where these differences were notably small, ICE behavior was not emerging much in (ARS,QS1).

The ICE concept has a similarity to some traditional moral principles such as the golden rule and/or other proverbs: *"Do unto others as you would have them do unto you"* (Christianity), *"What you do not want done to yourself, do not do to others"* (Confucian). The first is particularly similar to the role model behavior, and the second is its negative form. However, we do not regard the ICE concept as a moral principle, but as spontaneously emerging with enough role-switching. These have been developed in each experimental run[17].

4 Statistical Analysis of the Behavioral Data

Here, we look at the behavioral data in terms of mathematical statistics. We conduct a *convergence test* for each treatment $\tau \in \Upsilon$ formulating 8-convergence as a statistic. We make one stringent assumption that for temporal phase 5, the behavior can be represented by independent and identically distributed random variables over the subject pairs for each treatment. This assumption is statistically violated in all the cases other than (NRS,QS1). We study, for each treatment, in what manners and how far our behavioral data deviate from the assumption.

4.1 Statistical model

Let $\tau \in \Upsilon$ be a treatment and $\pi \in \Pi(\tau)$ a subject pair playing in τ. Each trajectory $\langle \widehat{s}_1^{\tau,\pi}, ..., \widehat{s}_{50}^{\tau,\pi} \rangle$ in (1), where $\widehat{s}_t^{\tau,\pi} = (\widehat{s}_{t,1}^{\tau,\pi}, \widehat{s}_{t,2}^{\tau,\pi})$ for $t = 1, ..., 50$, is regarded as the realization of some stochastic process:

$$\langle X_1^{\tau,\pi}, ..., X_{50}^{\tau,\pi} \rangle. \tag{4}$$

We assume that all stochastic moves are based on a probability space $(\Omega, \mathcal{B}, \Pr)$. Each $X_t^{\tau,\pi}$ is a random variable defined over Ω taking an action pair $s \in S := \{c, d\}^2$ as its value, i.e., $X_t^{\tau,\pi} : \Omega \to \{c, d\}^2$. Although $X_t^{\tau,\pi}$ consists of the two components $X_{t,1}^{\tau,\pi}$ and $X_{t,2}^{\tau,\pi}$, we treat $X_t^{\tau,\pi}$ as one variable at the level of subject pair π. For an action pair $s \in \{c, d\}^2$, we use $p_t^{\tau,\pi}(s)$ to denote the probability that the random variable $X_t^{\tau,\pi}$ takes the value s, i.e., $p_t^{\tau,\pi}(s) = \Pr(X_t^{\tau,\pi} = s)$.

We focus on the temporal phase $k = 5$ for convergence results. First, we make:

Assumption ID1 (Pair-wise independence): for any treatment $\tau \in \Upsilon$, subject pairs $\pi, \pi' \in \Pi(\tau)$ and rounds $t, t' = 41, ..., 50$, if $\pi \neq \pi'$, then $X_t^{\tau,\pi}$ and $X_{t'}^{\tau,\pi'}$ are independent;

ID2 (Time independence for each subject pair): For any $\tau \in \Upsilon$ and $\pi \in \Pi(\tau)$, the random

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[17] This looks to be related to the literature of "social preferences" (cf., Fehr-Schmidt [10], Charness-Rabin [8]). The basic idea is that people in the society have some utility functions including preferences over the other's state. In this literature, it is typically discussed that such extended utility functions may explain people's reciprocity/fairness better. However, the source for such "social preferences" is not discussed. In IGT, we seek a source in subjects' experiences with role-switching.

variables $X_{41}^{\tau,\pi}, ..., X_{50}^{\tau,\pi}$ are independent.

The first part is ensured by the experimental design. If we drop $\pi \neq \pi'$, ID2 is included in ID1. However, ID2 is essential and is separately written. The role-dependent behavior mentioned in Section 3.1 violates ID2. We find a few subject pairs showing this kind of role-dependent behaviors, but we include them in the data for our testing.

We further assume the following: for each $\tau \in \Upsilon$, $\pi, \pi' \in \Pi(\tau)$ and $s \in S = \{c, d\}^2$,

Assumption IB1 (Identical behavior over the temporal phase): $p_{41}^{\tau,\pi}(s) = ... = p_{50}^{\tau,\pi}(s)$;

IB2 (Identical behavior over subject pairs): $p_t^{\tau,\pi}(s) = p_t^{\tau,\pi'}(s)$.

Assumption IB1 specifies that the stochastic behavior of each subject pair is time independent over the temporal phase 5. Assumption IB2 is more essential for our statistical testing. We hypothetically assume that the behaviors of subject pairs are governed by not only independently but also identically distributed variables. Statistical tests are applied to IB2 under the assumptions ID1, ID2 and IB1. The negative (rejection) results for our hypothesis testing could be expected. However, our main purpose is not to show rejection for IB2, but to study how differently the data for each treatment deviate from IB2.

Under ID and IB, the *maximum likelihood estimator* $\widehat{p}^{\tau}(s)$ for $p^{\tau}(s) = p_t^{\tau,\pi}(s)$ is given as the relative frequencies of occurrences of $s \in S$ over the subjects $\pi \in \Pi(\tau)$ and rounds $41, ..., 50$:

$$\widehat{p}^{\tau}(s) = \frac{\Sigma_{\pi=1}^{14} \left|\{t : \widehat{s}_{40+t}^{\tau,\pi} = s\}\right|}{14 \times 10} \quad \text{for } s \in S. \tag{5}$$

The numerator counts how many times an action pair s was taken by the subject pairs in treatment τ for phase 5, and is divided by 14 (subject pairs) ×10 (rounds)[18]. These are calculated from the behavioral data as Tables 4.1 and 4.2.

Table 4.1: $\widehat{p}^{\tau}(s)$ in NRS

$s \backslash G$	QS1	QS2	T	MS	SH
cc	.014	.252	.064	.164	.493
cd	.158	.115	.179	.214	.029
dc	.129	.108	.164	.286	.007
dd	.698	.525	.593	.334	.471

Table 4.2: $\widehat{p}^{\tau}(s)$ in ARS

$s \backslash G$	QS1	QS2	T	MS	SH
cc	.124	.380	.086	.293	.700
cd	.212	.187	.507	.314	.079
dc	.248	.180	.114	.107	.064
dd	.416	.253	.293	.286	.157

These tables are already quite informative. Look at the column for (NRS,SH) in Table 4.1. Under Assumptions ID and IB, it is very unlikely for these probabilities to generate 7 subject pairs exhibiting 8-convergence to either *cc* or *dd* such as in Fig.4; since each subject pair having *cc* (*dd*) in a round goes to *dd* (*cc*) in the next round with the probability 0.471 (0.493), the probability of 8-convergence to *cc* (or *dd*) must be very small. On the other hand, the column for (NRS,QS1) in Table 4.1 seems free from this difficulty. To see those observations more quantitatively, we conduct statistical tests in Section 4.2.

We can test various other hypotheses. Here, we give two remarks on such possible tests.

Separations between the NRS and ARS treatments: To test whether the type of role-switching matters for subjects' behaviors, we can strengthen Assumption IB2 that the probability $p_t^{\tau,\pi}(s)$ is identical over the two treatments for the same game. The maximum likelihood

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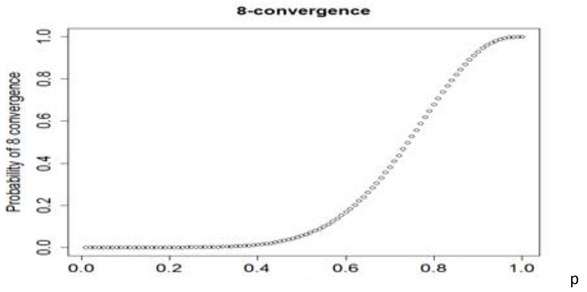
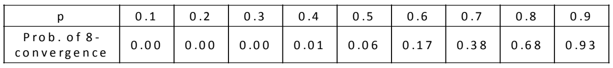
[18] For $\tau =$ (ARS,QS2), the denominator is $15 \times 10 = 150$, corresponding to Footnote 6.





p	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Prob. of 8-convergence	0.00	0.00	0.00	0.01	0.06	0.17	0.38	0.68	0.93

Figure 7: Probability of 8-convergence

estimator (5) is the relative frequency of an action taken by all the subjects for each game $g \in \{\text{QS1,QS2,T,MS,SH}\}$. Then the statistical hypothesis tests given in Section 4.2 can be repeated. We conducted this test and the test results show that for each game, the NRS case and ARS case are statistically separated with very low significance levels.

Decomposability into two subjects: In our analysis, we have treated the behavior of each subject pair as an entity. However, a random variable $X_t^{\tau,\pi}$ should consist of two random variables, $X_{t,1}^{\tau,\pi}$ and $X_{t,2}^{\tau,\pi}$, for the two subjects of π. It may be informative if $X_t^{\tau,\pi}$ can be decomposed into *independent* $X_{t,1}^{\tau,\pi}$ and $X_{t,2}^{\tau,\pi}$. Under ID and IB, we can test this decomposability tests. We have a positive result on decomposability only for treatment (NRS,QS1). The apparent violation of IB2 creates a problem for the decomposability in the other treatments.

4.2 Convergence tests on the action pairs for each treatment

To consider the probability of 8-convergence to an action pair s, we reformulate the random variable $X_t^{\tau,\pi}$: For each $s \in S = \{c,d\}^2$, we define random variable $Y_t^{\tau,\pi}(s)$ by $Y_t^{\tau,\pi}(s) = 1$ if $X_t^{\tau,\pi} = s$, i.e., π plays s, and $Y_t^{\tau,\pi}(s) = 0$ otherwise. Under ID and IB1 alone, we can write $p^{\tau,\pi}(s)$ for $p_t^{\tau,\pi}(s)$. The probability of pair π in treatment τ exhibiting 8-convergence to s is given as:

$$q^{\tau,\pi}(s) := \Pr(\Sigma_{t=41}^{50} Y_t^{\tau,\pi}(s) \geq 8 : p^{\tau,\pi}(s)) = \Sigma_{\nu=8}^{10} \binom{10}{\nu} (p^{\tau,\pi}(s))^{\nu} (1 - p^{\tau,\pi}(s))^{10-\nu}. \quad (6)$$

This probability value varies with $p^{\tau,\pi}(s)$ as depicted in Fig.7. It is relevant for the subsequent consideration that the curve is steep between $p^{\tau,\pi}(s) = 0.6$ and 0.8.

Suppose IB2 in addition to ID and IB1. Then, $q^{\tau,\pi}(s)$ can be written as $q^{\tau}(s)$. The probabilities, $\widehat{q}^{\tau}(s) := \Pr(\Sigma_{t=41}^{50} Y_t^{\tau,\pi}(s) \geq 8 : \widehat{p}^{\tau}(s))$, of 8-convergence to $s \in S$ with the estimator $\widehat{p}^{\tau}(s)$ of (5) are given in Tables 4.3 and 4.4, where the values of 0.000 are positive but very small. Now, we confirm the comment on (NRS,SH) given after Table 4.1. The expected number of pairs showing 8-convergence to *cc* and *dd* for (NRS,SH) are $14 \times 0.050 = 0.70$ and $14 \times 0.037 \doteqdot 0.52$, respectively, which are far less than the observed 7 occurrences of each in Fig.4. On the other hand, the expected number of subject pairs showing 8-convergence to *dd* in (NRS,QS1) is $14 \times 0.377 \doteqdot 5.28$, which is quite close to the observed number 6 in Fig.4.

Table 4.3: $\widehat{q}^{\tau}(s)$ in NRS

	QS1	QS2	T	MS	SH
cc	.000	.000	.000	.000	.050
cd	.000	.000	.000	.000	.000
dc	.000	.000	.000	.001	.000
dd	.377	.075	.156	.004	.037

Table 4.4: $\widehat{q}^{\tau}(s)$ in ARS

	QS1	QS2	T	MS	SH
cc	.000	.009	.000	.001	.383
cd	.000	.000	.060	.002	.000
dc	.000	.000	.000	.000	.000
dd	.016	.000	.001	.001	.000

The other cases are not as clear-cut. For example, the probabilities of cc, cd and dc in the column for (ARS,SH) in Table 4.4 look consistent with the corresponding number of occurrences $7, 0, 0$ in the lower table of Fig.4, but the probability 0.000 seems inconsistent with the 1 occurrence of dd. In order to analyze those cases, we evaluate the observed occurrences in terms of the probabilities given in Tables 4.1 and 4.2. Specifically, using 8-convergence as the statistic, we evaluate the behavioral data for each treatment. In the following, we denote each entry of the lower table of Fig.4 by $\gamma^{\tau}(s)$, e.g., if $\tau =$ (NRS,QS1), then $\gamma^{\tau}(dd) = 6$ is given in the southwest corner of Fig.4.

We consider the following null hypothesis:

$\mathrm{H}_0 : q^{\tau}(s) = \widehat{q}^{\tau}(s)$.

Assumption IB2 is stated in terms of $p^{\tau,\pi}(s)$, while H_0 is in terms of the statistic of 8-convergence and the maximum likelihood estimator $\widehat{p}^{\tau}(s)$ under ID and IB. Nevertheless, IB2 is the central part of our tests of H_0.

Supposing that the alternative hypothesis is $q^{\tau}(s) \neq \widehat{q}^{\tau}(s)$, we conduct the 2-sided binomial test for H_0 for each $s \in S$. Thus, for each treatment $\tau \in \Upsilon$, we have 4 binomial tests (cf., Lehmann [22] and Gibbons-Chakraborti [13] for binomial tests). Our aim is to consider implications from the size of the p-value for H_0.

Let $\tau \in \Upsilon$, $\pi \in \Pi(\tau)$, and $s \in \{c, d\}^2$ be fixed. We define the random variables $Z_s^{\tau,\pi}$ for 8-convergence of a subject pair π to action pair s in treatment τ by:

$$Z^{\tau,\pi}(s) = \begin{cases} 1 & \text{if } \Sigma_{t=41}^{50} Y_t^{\tau,\pi}(s) \geq 8 \\ 0 & \text{otherwise.} \end{cases}$$

Using the random variables $Z^{\tau,\pi}(s)$, we evaluate the probability of the event $\gamma^{\tau}(s)$ (the observed number of 8-convergences to s) under the null hypothesis H_0. The p-value for H_0 is given as the sum of the left-hand sides over $k_s = 0, ..., 14$ satisfying the following inequality:

$$\Pr(\Sigma_{\pi=1}^{14} Z^{\tau,\pi}(s) = k_s : \widehat{p}^{\tau}(s)) \leq \Pr(\Sigma_{\pi=1}^{14} Z^{\tau,\pi}(s) = \gamma^{\tau}(s) : \widehat{p}^{\tau}(s)). \tag{7}$$

That is, it sums over all cases that are less than or equally as likely as the observed event $\gamma^{\tau}(s)$. A low p-value suggests that the observed event $\gamma^{\tau}(s)$ is unlikely to have happened under the null hypothesis H_0. This provides evidence to reject H_0.

The p-value is given for each $\tau \in \Upsilon$ and each $s \in S$ in Tables 4.5 and 4.6.

Table 4.5: p-values in NRS

	QS1	QS2	T	MS	SH
cc	1	.000***	1	1	.000***
cd	1	1	1	.002***	1
dc	1	1	1	.015**	1
dd	.784	.003***	.054*	1	.000***

Table 4.6: p-values in ARS

	QS1	QS2	T	MS	SH
cc	1	.000***	1	.000***	.415
cd	1	1	.000***	.031**	1
dc	.005***	1	1	1	1
dd	.203	.007***	.019**	1	.000***

where *, **, *** mean that the p-value is less than 10%, 5% and 1%. The case of cc in (NRS,QS1) has a p-value of 1. Since $\widehat{q}^{\tau}(cc)$ is almost 0, the event that the number of 8-convergence to cc is $\gamma^{\tau}(cc) = 0$ is more likely than any other 8-convergence numbers $k_c = 1, ..., 14$, which implies that the sum of the left hand side of (7) is exactly 1. The entry value 1 in those tables is obtained for the same reason. On the other hand, the entries 0.000 are very small.

At the 1% significance level, we reject at least one null hypothesis for each treatment except for the treatments (NRS,QS1) and (NRS,T). In (NRS,QS1), each p-value is very large, the lowest being 0.784. This means that the observed numbers, (0,0,0,6), of 8-convergence to the action pairs (cc, cd, dc, dd) are very compatible with $\widehat{q}^{\tau}(s)$'s listed in Table 4.3. In (NRS,T), only the null hypothesis for dd is almost rejected at the 5% significance level, since the p-value is 0.054. Hence, these results as a whole are interpreted as meaning that the null hypothesis H_0 (identical behavior over the subjects) is rejected for each treatment except for (NRS,QS1).

How should we interpret the results of the four tests all together for each treatment? As stated, under ID and IB1, the null hypothesis H_0 can be regarded as a test of IB2. IB2 states that $p^{\tau,\pi}(s)$ is identical over the subject pairs π for each treatment τ. A violation of IB2 suggests various forms of heterogeneities on $p^{\tau,\pi}(s)$'s. First, consider the following:

CD1: convergence to different action pairs by different subject pairs;

We can find evidence of CD1 by simply looking at the table for 8-convergence in Fig.4 for more than one cluster point. In (NRS,SH), half the subject pairs converged to cc while the other half converged to dd. Every other treatment except for (NRS,QS1) and (NRS,T) show evidence of CD1 in terms of having more than one cluster point.

Let us look at the two remaining treatments. For (NRS,QS1), all the p-values are very high, which suggests that the entire assumptions ID and IB are statistically consistent with the data. While (NRS,T) does not show evidence of CD1, it differs from (NRS,QS1) since it has one small p-value 0.054, which is for the pair dd. This violation of IB2 may be caused by a different type of heterogeneity. We may consider:

CD2: convergence of different speeds by different subject pairs.

This means that the probability $\widehat{p}^{\tau,\pi}(dd)$ is not uniform over the subject pairs π, even though these probabilities lead to convergence to dd. Unfortunately, we do not find a clear-cut difference between (NRS,QS1) and (NRS,T), to provide evidence for CD2, in the numbers of 7-, 8-, 9- and 10-convergence in Fig.4 and Fig.6.

Our results in Tables 4.5 and 4.6 suggest that the behavioral data show various forms of heterogeneity. Some enjoy the assumptions ID and IB, but many other show heterogeneities such as CD1. We speculated about another possible heterogeneity CD2. To check and/or separate the effects of CD1 and CD2, however, will require further and perhaps different experiments.

5 Analyses of the Cognitive Data

The NRS and ARS treatments are very different from the cognitive point of view, too. As seen in Tables 1.3 and 1.4, subjects successfully learned the relevant payoffs in NRS, while subjects showed slow learning and/or forgetfulness about payoffs in ARS. The latter manifests cognitive limitations of feature (*iv*). Since the incorrectness and forgetfulness are more salient in the ARS treatments, we focus on these treatments in Sections 5 and 6.

Here, we discuss two aspects of forgetfulness. The correct recall rate of a payoff:

(a) increases with the number of experiences of that payoff;

(b) decreases with the time lag from the last experience of the payoff to the time of the questionnaire.

Aspect (a) means that a memory needs some repetition to become fixed, and (b) that a memory once fixed would decay unless it is reinforced from time to time[19]. Aspects (a) and (b) are conceptually independent, but they are not statistically independent. The forms of experiences involved in them are negatively correlated: If the number of experiences is large, then the time lag is small, and *vice versa*. Indeed, the data show a strong (negative) correlation between the two. Since these features are more salient for convergent subject pairs, and since (b) is observed for non-cluster action pairs, we call those general phenomena the *off-equilibrium forgetfulness*.

In Section 5.1, we consider how to capture aspects (a) and (b) with our data and the degree of correlation between the two. In Section 5.2, we conduct a logit regression analysis for (b) (and (a)).

5.1 Correct answers and experiences in ARS

Now, let us look at the behavioral and cognitive data for each treatment $\tau \in \{\text{ARS}\} \times \{\text{QS1,QS2,T, MS,SH}\}$. We first consider aspect (a) and relate correct payoff answers to the numbers of experiences. Let $\xi_i^\tau(r,s)$ be the number of experiences of action pair s in the 25 rounds with role r by subject i. We also define $\xi_i^{\tau,C}(r,s) = 1$ if if subject i's answer to $h_r(s)$ is correct, and $\xi_i^{\tau,C}(r,s) = 0$ otherwise. We formulate the recall rate $rec_\xi^\tau(x)$ for a treatment τ:

$$rec_\xi^\tau(x) = \frac{\Sigma_{(r,s)} \left|\{i : \xi_i^\tau(r;s) = x \ \& \ \xi_i^{\tau,C}(r;s) = 1\}\right|}{\Sigma_{(r,s)} \left|\{i : \xi_i^\tau(r;s) = x\}\right|}, \text{ where } (r;s) \text{ varies over } \{b,g\} \times S. \quad (8)$$

For the experience number x ($0 \leq x \leq 25$), the denominator is the number of subjects having exactly x experiences of action pair s at role r, while the numerator is the number of the subjects, among those in the denominator, who also gave correct answers[20]. Note that this $rec_\xi^\tau(x)$ is undefined (no dots in Fig.8 and Fig.9) when no subjects have exactly x experiences for a payoff.

Fig.8 shows a high positive correlation between the number of experiences and correct recall rates of payoffs, which is consistent with the basic assumption for IGT. In QS1 and MS, the slopes look quite constant, and SH flattens out quickly.

To consider aspect (b), let $\eta_i^\tau(r;s)$ denote the time lag from 50 to the last experience of s at role r for subject i, e.g., in Fig.2, $\eta_1^\tau(b;dd) = \eta_2^\tau(g;dd) = 50 - 31 = 19$. In the parallel manner as (8), we define $rec_\eta^\tau(x)$ by substituting $\eta_i^\tau(r;s)$ for $\xi_i^\tau(r;s)$. Then, we have Fig.9. We find a clear negative effect of time lag on recall rate in SH and a smaller negative effect in MS. For the other games, the effects are less clear.

The two recall rates $rec_\xi^\tau(x)$ and $rec_\eta^\tau(x)$ are conceptually independent concepts. It is aspect (a) that the recall rate $rec_\xi^\tau(x)$ is increasing with the number of experiences x, and (b)

---

[19] In the theoretical development of IGT (Kaneko-Kline [17], [19], Akiyama *et al.* [1]), only the former was explicitly taken into account.

[20] A subject may be counted more than once in the denominator and numerator.

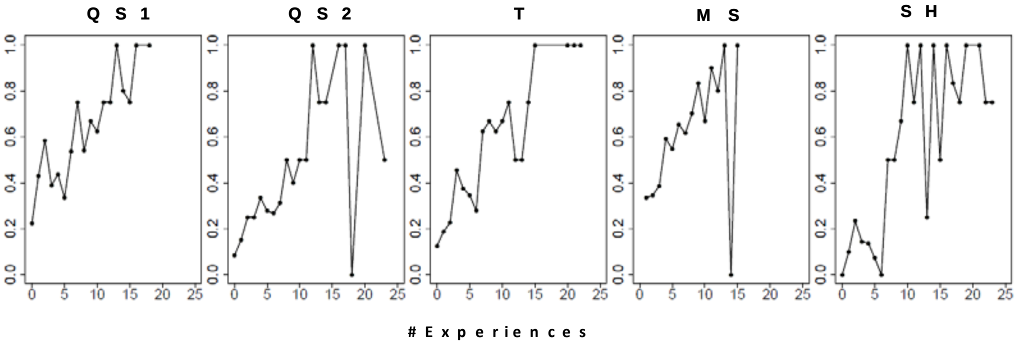


Figure 8: #experiences x and correct recall rate $rec^{\tau}_{\xi}(x)$

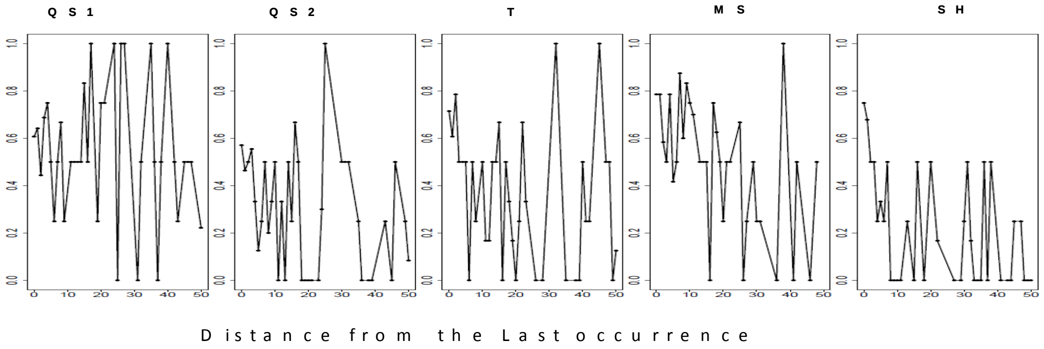


Figure 9: Time lag x and correct recall rate $rec^{\tau}_{\eta}(x)$

that $rec^{\tau}_{\eta}(x)$ is decreasing with the time lag x. However, these depend, respectively, upon the number of experiences $\xi^{\tau}_{i}(r;s)$ and the time lag $\eta^{\tau}_{i}(r;s)$, and these are statistically correlated; in particular, when a subject pair shows convergence, those are heavily correlated. Consider a subject pair showing 8-convergence to an action pair s in phase 5. Then, the lag $\eta^{\tau}_{i}(r;s)$ is quite small and $\xi^{\tau}_{i}(r;s)$ is typically much larger than 5 for each role. This suggests a strong negative correlation between $\xi^{\tau}_{i}(r;s)$ and $\eta^{\tau}_{i}(r;s)$. At the same time, non-cluster action pairs $s' \neq s$ are not played much in phase 5, which implies that $\xi^{\tau}_{i}(r;s)$ is not large but $\eta^{\tau}_{i}(r;s')$ are typically larger than 10. This suggests still some negative correlation between $\xi^{\tau}_{i}(r;s')$ and $\eta^{\tau}_{i}(r;s')$ for the non-cluster action pairs s'.

Only the latter part is applied to the subject pairs not showing 8-convergence. Hence, it may be expected that we see stronger correlations between $\xi^{\tau}_{i}(r;s)$ and $\eta^{\tau}_{i}(r;s)$ on the group of subject pairs showing 8-convergence than on the group of others.

The *coefficient of correlation* between $\xi^{\tau}_{i}(r;s)$ and $\eta^{\tau}_{i}(r;s)$ over the subjects showing 8-convergence over all action pairs is

$$CC^{\tau}_{8}(g) = \frac{\Sigma_{(i,r;s)}(\xi^{\tau}_{i}(r;s) - \overline{\xi}^{\tau})(\eta^{\tau}_{i}(r;s) - \overline{\eta}^{\tau})}{\sqrt{\Sigma_{(i,r;s)}(\xi^{\tau}_{i}(r;s) - \overline{\xi}^{\tau})^2}\sqrt{\Sigma_{(i,r;s)}(\eta^{\tau}_{i}(r;s) - \overline{\eta}^{\tau})^2}}, \tag{9}$$

where i varies over the subject pairs showing 8-convergence for each game in ARS and the averages $\overline{\xi}^{\tau}$ and $\overline{\eta}^{\tau}$ are taken over those subjects over all (r, s). The coefficient of correlation for the non-convergent subject pairs $CC^{\tau}_{-8}(g)$ is defined analogously. The coefficients $CC^{\tau}_{8}(g)$ and $CC^{\tau}_{-8}(g)$ for each game g in ARS are described as Table 5.1. For subject pairs showing 8-convergence, $\xi^{\tau}_i(r; s)$ and $\eta^{\tau}_i(r; s)$ are highly and negatively correlated. As expected, the non-convergent subject pairs show weaker negative correlation.

In the experiment, aspects (a) and (b) are not well separated statistically, though we find evidence of both. After all, having too few experiences to fix a memory and forgetting by not having enough experiences to reinforce the memory are the two sides of the same coin. Since, as discussed, this feature is most saliently observed in the non-cluster action pairs, by focussing on forgetfulness, we call the general phenomena the *off-equilibrium forgetfulness.*

Table 5.1; Coefficients of correlation

	QS1	QS2	T	MS	SH
$CC^{\tau}_{8}(g)$	-.940	-.738	-.786	-.860	-.876
$CC^{\tau}_{-8}(g)$	-.609	-.598	-.661	-.536	-.687

5.2 Logit analyses

A logit analysis (cf., Freedman [12]) may be applied to study forgetfulness and slow learning. Since we have observed different tendencies between the subject pairs showing 8-convergence and the others, we conduct separate logit analyses for the two groups. Also, since $\xi^{\tau}_i(r; s)$ and $\eta^{\tau}_i(r; s)$ are highly correlated, we use only one of them; here, we use the time lag variable $\eta^{\tau}_i(r; s)$. We can conduct a parallel analysis with $\xi^{\tau}_i(r; s)$, which is briefly mentioned in the end of this section.

Let a treatment $\tau \in \Upsilon$ in ARS be fixed. First we focus on the subject pairs showing 8-convergence. Our logit regression model is given as

$$y_i = \alpha_0 + \alpha_1 \eta^{\tau}_i(r; s); \text{ and } F(y_i) = \frac{1}{1 + e^{-y_i}}, \tag{10}$$

where $F(y_i)$ is the logistic function assigning the probability of a correct recall of the payoff to s at role r when subject i had the time lag $\eta^{\tau}_i(r; s)$. The parameters α_0, α_1 are estimated by the maximum likelihood method. That is, using the formulae in (10), we can calculate the probability of the given data of payoff answers being correct, which is a function of two parameters α_0, α_1. Then, we maximize this probability by controlling α_0, α_1, and obtain the estimates $\widehat{\alpha}_0, \widehat{\alpha}_1$, which are summarized in Table 5.2.

Table 5.2; convergent subjects

	QS1	QS2	T	MS	SH
$\widehat{\alpha}_0$	3.59	.460	.903	1.19	1.04
std.error	1.45	.403	.357	.553	.360
$\widehat{\alpha}_1$	-.087	-.042	-.047	-.075	-.102
std.eror	.034	.016	.013	.027	.017
p-value	.000	.006	.000	.002	.000
N	32	64	96	48	128

Table 5.3; non-convergent subjects

	QS1	QS2	T	MS	SH
$\widehat{\alpha}_0$	.275	-.244	.290	.881	-.137
std.error	.190	.218	.254	.218	.276
$\widehat{\alpha}_1$	-.014	-.045	-.072	-.038	-.037
std.eror	.010	.017	.028	.015	.016
p-value	.165	.002	.003	.012	.000
N	192	160	128	176	96

Here, it is important that $\widehat{\alpha}_1$ is significantly negative for each game, which means that a correct recall is negatively correlated with the gap $\eta_i^\tau(r;s)$. This is confirmed by looking at the p-value for the null hypothesis that the corresponding coefficient is 0; actually, the p-values described in the second lowest row are all very small. This fact is interpreted as meaning the off-equilibrium forgetfulness: the correct recall rate is high for a cluster pair (equilibrium) s, but it is low for a non-cluster pair (off-equilibrium) s.

We expect a weaker tendency of the off-equilibrium forgetfulness for the subjects not showing 8-convergence, since the values of $\eta_i^\tau(r;s)$ are not separated in a clear-cut manner between a cluster action pair and the others. We conduct a logit analysis for those subjects, and obtain the estimates given in Table 5.3.

We check whether the aspect (b) is stronger in Table 5.2 (convergent subjects) than in Table 5.3 (non-convergent subjects)[21]. This is confirmed for QS1, MS, and SH with respect to the value $\widehat{\alpha}_1$ as well as the p-value. For QS2, the values $\widehat{\alpha}_1$ and p-value are, more or less, the same, and for T, our expectation does not hold. This needs further experiments to have a more conclusive result on off-equilibrium forgetfulness.

Finally, we mention what would happen if we take the number of experiences $\xi_i^\tau(r;s)$ as an independent variable instead of the lag $\eta_i^\tau(r;s)$. We have the parallel conclusion that $\xi_i^\tau(r;s)$ leads to higher recall rates. Here, the results are stronger for the convergent subjects than for non-convergent subjects, except for game SH.

6 Interactions between Behavior and Cognition

We have considered NE and ICE relative to each of the five, objectively given, games. In IGT, however, each subject makes behavioral adjustments according to his own understanding of the game. Here, we consider behavior and cognition from this subjective perspective[22]. We still restrict our attention to the ARS treatments. In Section 6.1, we make comparisons between objective and subjective NE and ICE for 8-convergent subjects. In Section 6.2, we look at some special cases of non-convergent behavior and its relationship to subject views.

6.1 s-NE and s-ICE

We use o-NE and s-NE to distinguish between NE for the objective game and that for the subjective view, and o-ICE and s-ICE in the parallel manner. We stipulate that the incorrect answer $[k]$ is compared with k directly and [?] is smaller than the correct and incorrect numeric payoffs. The concepts of NE and ICE for a subjective view are defined using strict inequalities, since this assumption makes their interpretations clear-cut.

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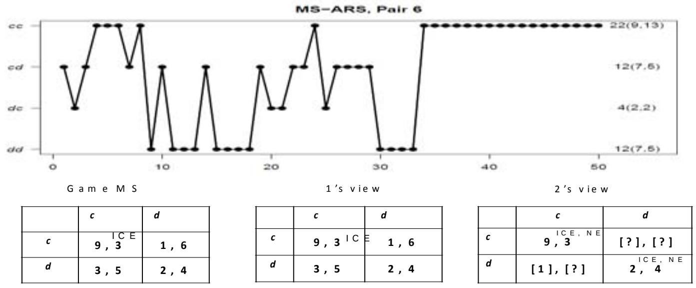
[21] In Footnote 6, we mentioned that the number of subject pairs for (ARS,QS2) was 15, but with respect to the cognitive data, it is 14 since the data for one pair are missing.

[22] The theory of subjective equilibrium of Kalai-Lehrer [20] may look related to the ICE concept in IGT. This theory treats the no-knowledge assumption (i) as uncertainty (subjective probability over the pre-specified possibilities) together with the Bayesian updating with information. The only incorrectness could involve subjective beliefs of a player about strategies of the others. In IGT, the no-knowledge assumption does not presume possibilities as explained in Section 1. The point of ICE is to consider interactions, together with/without. role-switching, between an endogenous formation of each individual's subjective view and its effects on behavior and *vice versa.* Here, it allows incorrectness about structural aspects of the game, including his own payoffs.



Game MS

	c	d
c	9 , 3 ICE	1 , 6
d	3 , 5	2 , 4

1's view

	c	d
c	9 , 3 ICE	1 , 6
d	3 , 5	2 , 4

2's view

	c	d
c	9 , 3 ICE, NE	[?], [?]
d	[1], [?]	2 , 4 ICE, NE

Figure 10: s-NE and s-ICE (1)

We exemplify s-NE and s-ICE in Fig.10. Subject 1's view is entirely correct showing s-ICE as the same as in the objective game MS. In 2's view, he got the correct payoffs for both roles at *cc* and *dd*, but gave incorrect answers to the other payoffs. In his view, *cc* and *dd* are both s-NE and s-ICE. The pair *cc* to be an s-NE and an s-ICE is confirmed, respectively by:

$$9 > [1] \text{ for role } b, \text{ and } 3 > [?] \text{ for role } g; \tag{11}$$

$$(9+3)/2 > ([1]+[?])/2 \text{ for role } b, \text{ and } (9+3)/2 > ([?]+[?])/2 \text{ for role } g. \tag{12}$$

Thus, *cc* is an s-ICE in both 1's and 2's views, and *dd* is both an s-NE and an s-ICE in 2's view.

Table 6.1: s-NE & s-ICE

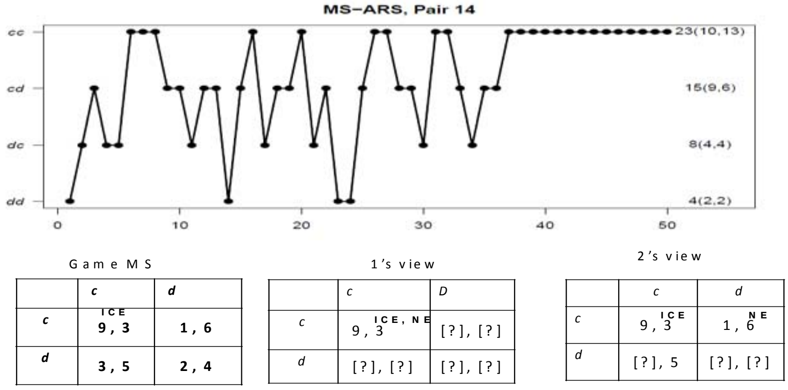
		QS1	QS2	T	MS	SH
8-convergence to o-NE		2	2	2		2
o-NE & s-NE		1	2	2		2
o-NE & s-ICE		0	0	0		0
8-convergence to o-ICE		0	6	10	4	14
o-ICE & s-ICE		0	5	9	4	14
o-ICE & s-NE		0	2	4	2	14

Table 6.1 summarizes s-NE and s-ICE for the five games in ARS. The upper part lists, for each game, the number of subjects showing 8-convergence to the o-NE. We count each subject in each subject pair showing 8-covergence. We find that all the o-NE's are supported as s-NE's, except for 1 in QS1. In QS1, only one subject's view shows o-NE & s-NE. The lower part is described from the viewpoint of o-ICE. In almost all cases, o-ICE remains to be s-ICE, but some become s-NE, too.

The lower table of Fig.4 has two more convergences to *dc* in (ARS,QS1) and *cd* in (ARS,MS), which are neither o-NE nor o-ICE. Each of these will be discussed in details in Section 6.2.

The 2nd lowest row of Table 6.1 means that the o-ICE almost remains to be an s-ICE in their subjective views. On the other hand, interestingly, the lowest row means that the o-ICE that is not an o-NE becomes an s-NE for some subjects. In Fig.10, both subjects treated *cc* as an s-ICE, and *cc* becomes an s-NE for subject 2. We should consider two questions on these newly appearing s-NE.

One question is how these appeared. Perhaps, the subjective views are much more simplified than the objective games, which is closely related to the off-equilibrium forgetfulness discussed



Game MS

	c	*d*
c	ICE 9 , 3	1 , 6
d	3 , 5	2 , 4

1's view

	c	*D*
c	ICE, NE 9 , 3	[?], [?]
d	[?], [?]	[?], [?]

2's view

	c	*d*
c	ICE 9 , 3	NE 1 , 6
d	[?], 5	[?], [?]

Figure 11: s-NE and s-ICE (2)

in Section 5. In Fig.11, for example, subject 1's view simplifies all payoffs, other than those for *cc*, to the same [?]. For a similar reason, *cd* became an s-NE in 2's view. Thus, these s-NE can be generated by simplified understanding of the payoffs.

The other question is the behavioral effects of these newly generated s-NE. First, we emphasize that almost all o-ICE's remain as s-ICE's. Hence, it would be natural to regard these o-ICE's as resulting from the interactions between the two subjects of each subject pair; some subjective views have s-NE, but they were generated by simplified views and, perhaps, not directly related to the behavioral consequences.

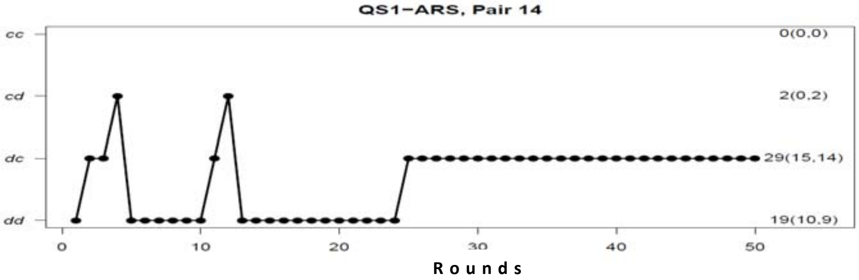
6.2 Interactions in other forms

Overall, we found that the subjective views are quite consistent with the observed behaviors for the subjects showing 8-convergence. It is relevant to look at other subject pairs. Here, we look at one pair showing 8-convergence but to neither the o-NE nor the o-ICE, two pairs showing role-dependent behavior, and finally, a pair showing some inconsistency between subjective views and behavior.

Two subject pairs in ARS exhibited 8-convergence to a cluster action pair that is neither an o-NE nor an o-ICE. They are pair 14 in QS1 and pair 5 in MS appearing as an asterisk * in Fig.4. Each has a specific feature: the first pair is considered in (1), and the second in (4).

(1): "No experiences" creates an s-ICE: Pair 14 for QS1 in Fig.12 shows 9- and even 10-convergence to action pair *dc*. However, *dc* is neither an o-NE nor an o-ICE. It is, however, an s-ICE in each subject's view and not an s-NE in either view! These views contain incorrect payoffs, which are created by "no experiences" of *cc*, and this incorrectness allows *dc* to be an s-ICE. Incidentally, the payoff value 5 for *cc* in 1's view is, accidentally, correct.

(2): Role-dependent behavior of the ICE type: Fig.5 shows a role-dependent behavior. Here, *cc* and *dd* were mainly played at even and odd rounds. In this trajectory, subjects 1 and 2 enjoyed the average payoffs $(7+4)/2$ and $(8+3)/2$. Also, each may believe that the other enjoyed such an average, e.g., in subject 1's view, 2 enjoys $(8+3)/2$, and in subject 2's view, 1 enjoys $([8]+[3])/2$. Even in the subjective views, these behaviors are dominated by *cc* with alternate role-switching. However, the trajectory showed that subject 1 tried to move to *cc*



QS1

	c	*d*
c	5 , 4	2 , 5
d	6 , 1	3 , 2

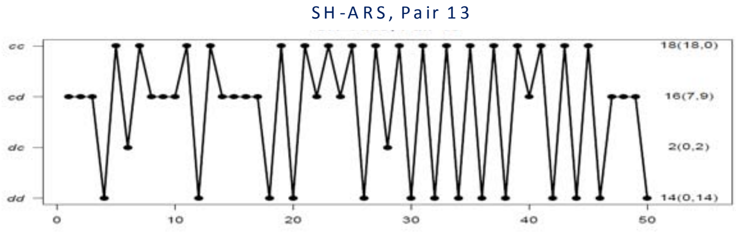
1' view

	c	*d*
c	5 , [1]	[1] , 5
d	6 , 1	3 , 2

2's view

	c	*d*
c	[1], [2]	2 , [1]
d	6 , 1	3 , 2

Figure 12: ICE only in the subjective views



Game SH

	c	***d***
c	**8, 7**$^{\text{ICE, NE}}$	**2,6**
d	**7,1**	**4, 3**

1's view

	c	*d*
c	8, [?]	2, 6$^{\text{NE}}$
d	[?], [?]	[?], 3

2's view

	c	*d*
c	[?], 7	2, 6
d	7, [?]	4, [?]

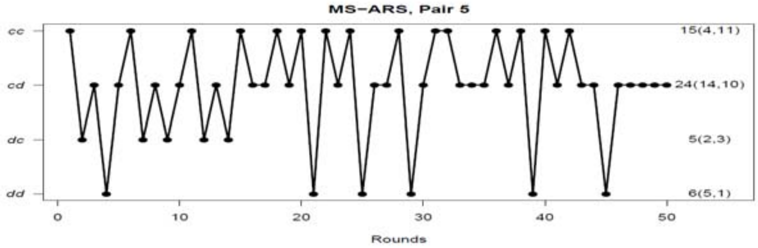
Figure 13: Role-dependent behavior of the NE-type

from the alternate role-dependent behavior from round 24 to 28 but failed. Here, the role-model behavior failed.

(3): Role-dependent behavior of the NE type: Fig.13 also shows role-dependent behavior, but it differs from Fig.5 in that neither subject considers the other's payoff. Subjects 1 and 2 enjoyed the average payoffs $(8+3)/2$ and $(7+4)/2$, respectively, but subject 1 answers [?] to the payoff values to *cc* with role *g* and to *dd* with role *b*. Subject 2's answers are the same. This is interpreted as meaning that they did not consider the other's average payoffs. In this sense, the role-dependent behaviors of this pair are based on the Nash type behavioral assumption rather than the ICE type.

While the role-dependent behavior observed in the experiment goes beyond the arguments for NE and ICE given in Kaneko-Kline [19], it's emergence is worthy of being discussed more and suggests a further theoretical analysis.

(4): Anomalous cases: Consider subject pair 5 in MS in Fig.14, which showed 8-convergence to *cd*. Neither subjective view allows *cd* to be an s-NE or an s-ICE. From the subjective views, we can find no hints to induce 8-convergence to *cd*. Those views include many incorrect payoffs even for the payoffs experienced many times. This may be interpreted as meaning that the



Game MS

	c	d
c	9 , 3	1 , 6
d	3 , 5	2 , 4

1's view

	c	d
c	9 , 3	[?], [1]
d	[?], [?]	[3], [1]

2's view

	c	d
c	9 , [6]	1 , [3]
d	[4], [4]	[3], [3]

Figure 14: Anomalous case

subjects were simply confused or not serious. This pair disappears for 9- and 10-convergence. One possible explanation is that they are still in a process of making trials/errors.

In addition to the above four subject pairs, we find some non-convergent subject pairs showing inconsistent behaviors with their subjective views. Perhaps, if they played more rounds, these inconsistencies would disappear.

7 Conclusions and Remaining Problems

We presented an experimental study of behavior and cognition in repeated situations of the five games with/without role-switching from the perspective of IGT. For the 10 treatments, we obtained the behavioral data directly from the experiments and the cognitive data from the payoff questionnaire. For NRS, the exhibited behavior is largely consistent with the NE concept in both objective and subjective senses. The cognitive data are also conclusive: recall is quite perfect as seen in Table 1.3. On the other hand, for ARS, the behavioral results are less conclusive, and the payoff answers are diverse as in Table 1.4. However, the data for ARS have two salient features. Behavioral-wise, there are some convergences to the ICE and NE, and precisely speaking, we find a tendency to go to ICE more than NE. Cognitive-wise, recall of payoffs was more varied while exhibiting off-equilibrium forgetfulness for convergent pairs.

Interactions between behavior and cognition are found in various ways. Adjustments of behavior based on subjective views show effects from cognition to behavior. We observed effects of the behavior to cognition in Section 5.2; in particular, convergence leads to forgetfulness of the action pairs other than the cluster action pair, which is off-equilibrium forgetfulness. In Section 6, we observed how cognition and behavior interact through subjective views.

We obtained a lot of findings, but these generate more questions, which may require possible extensions of the experimental design and some modifications of the concepts used in this paper. We found new types of behavior like role-dependent behavior and new cognitive aspects like memory decay. Here, we mention only some possible extensions and modifications:

(A): the total duration of the experiment is extended into 70 or 80 rounds.

By this change, we may see whether the treatments lead to more convergences. If the answer is affirmative, the present duration of 50 rounds could be regarded as an intermediate step to convergence.

Extending the duration of the experiment could also aid in the study off-equilibrium forgetfulness and more complicated role-dependent behaviors like those mentioned in Section 3.1. Then,

(B): the concepts of temporal phase and convergence may be generalized to capture such complicated patterns of behavior.

Such generalization should be constrained to make them consistent with the cognitive limitations stated in feature (*iv*). Then, we need to think about a rationale for general patterned behavior.

Finally, we address some questions of how to distinguish our IGT explanations of ICE behavior from alternative theoretical explanations. One may ask whether the observed ICE behavior is due to the learning by experience and endogenously emerging as explained by IGT, or it would happen with descriptive learning, which is where the subjects are told the payoffs before playing. To answer this, we could design a new treatment where the payoffs of both roles are described to the subjects before the experiment in either NRS or ARS. Then, we can see if there are any significant differences between descriptive and experiential treatments.[23]

The same design can also be used to answer the related question of whether the observed ICE behavior is merely an expression of social preferences as described by Fehr-Schimdt [10] and Charness-Rabin [8]. As discussed in the introduction, the theory of social preferences presumes that the subjects bring their social preferences to the experiment, and the experimenter tries to measure them. In IGT, on the other hand, the social preferences, e.g., utilitarian preferences, are emerging in the experiment with role-switching. We hope to answer these questions by making more experiments.

In general, to study problems from experimental points of view must enrich the entire IGT as a theory. This paper has paved the way for further development of IGT, by providing a sound framework for analysis of experimental data on behavior and cognitive learning.

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