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Order of Play, Forward Induction, and Presentation Effects in Two-Person Games*

R. ANDREW MULLER†
Department of Economics, McMaster University, Hamilton, Ontario, Canada
email: mullera@mcmaster.ca

ASHA SADANAND
Department of Economics, University of Guelph, Guelph, Ontario, Canada
email: asadanand@uoguelph.ca

Abstract

We investigate the effects of order-of-play (simultaneous, unobserved sequential and fully observed sequential play) and form of presentation (extensive vs. normal) in three simple two person games: battle-of-the-sexes with and without outside option and a three strategy game which differentiates between virtual observability (VO) and iterated elimination of dominated strategies as principles of equilibrium selection. VO predicts that knowledge of the order of play alone will affect the distribution of strategies chosen. We contrast this with the predictions of iterated elimination of dominated strategies. We report results from 1800 one-shot games conducted in 6 sessions with 120 subjects and analysed as panel data. The form of presentation strongly affects the distribution of outcomes and strategies. Information about order of play shifts the distribution of strategies away from the distribution in simultaneous play and towards the distribution in fully observed play, especially in the less complicated games presented in normal. Order-of-play effects are less evident as complexity of the game increases. Extensive form presentation appears to induce sequential thinking even in simultaneously played games.

Keywords: forward induction, virtual observability, order-of-play, presentation effects, battle of the sexes

JEL Classification: C72, C92

Introduction

The importance of order of play in different games having the same normal form was emphasized by Kreps (1990). Before then, it was frequently assumed that the knowledge of order of play without information about actual choices added nothing to the equivalent normal form of the game. However, a number of authors have considered how this might not be the case. Although there is no consensus on exactly how the order of play matters, there has been both theoretical work incorporating order of play and experimental evidence indicating that such effects do exist.

*On-line version: http://www.socsci.mcmaster.ca/mullera/recentpapers.htm.
†Author to whom correspondence should be addressed.

Order of play has figured significantly into many solution concepts that utilize forward induction. The general principle of forward induction is that in games of imperfect information, players at an information set deduce the beliefs that they can plausibly hold by using the information they have learned about how the game has evolved prior to the information set. Signalling games were the initial motivation for several forward induction equilibrium concepts (though some have more general application), such as the Intuitive Criterion (Cho and Kreps, 1987), Stable Equilibrium (Kohlberg and Mertens, 1986), or Perfect Sequential Equilibrium (Grossman and Perry, 1986). The salient feature in these solution concepts is that earlier players have private information that may be potentially inferred by later players who are able to observe some actions taken by the earlier players. Thus, an actual signal (or action) from the earlier player *must* be received (i.e. must be observable) to initiate the deductive reasoning used by later players to formulate their beliefs on their information sets.

A natural question that arises is whether, in the absence of any observable signal, the simple knowledge of the order of play that preceded him confers any advantage to a player who is not fully informed. Three distinct ways in which it might have been raised in the literature. The first is the notion that order of play may be used as a coordination device that allows players in a game with multiple equilibria to focus onto the equilibrium that is preferred by Player 1.[1] An obvious difficulty that emerges here is that in games with more than two players there is no significance attached to the order of play beyond the first player. A second approach is to argue that order of play information will compel players toward non-equilibrium outcomes that are preferred by Player 1.[2] If this approach is correct, order of play effects have to be extremely powerful so as to overwhelm the forces guiding players toward Nash equilibrium. A final approach is to argue that knowledge of the order of play, without any observable signal, still contains information that is useful in formulating beliefs on information sets, which then allow players to have best responses, which, finally, are essential in determining what constitutes an equilibrium.[3] This conflicts with the long-standing view that varying the order of play when no moves are observed is strategically irrelevant. Relating to the last hypothesis, we first describe some theoretical literature, which introduces an equilibrium concept that we will be studying in our experiments in this paper, and then turn to experimental work, in the literature, addressing the question of which of three approaches best depicts behaviour of subjects in laboratory experiments.

Some early theoretical work due to Amershi et al. (1985a, 1985b, 1985c, 1992) proposed a particular model of how order of play information enters into the behaviour of agents. The idea arose from the casual observation that when two players (especially players that are in an arms length context such as a business situation) are faced with two choices, one of which is superior to the other in payoffs but has an opposite effect on the other's payoffs, a player who knows he can choose first would naturally make the most advantageous choice. The less sensible equilibrium involves the first player to instead take the lower—paying because the follower player may want the better choice. We expect that the latter type of outcomes could occur if players were not at arms length, but in that instance it can be argued that the payoffs do not capture all the benefits for each choice.

The equilibrium concept developed by Amershi et al. is called Manipulated Nash equilibrium. It suggests that early players ask themselves what follower players would believe about unobservable actions that the leader players have taken and what the followers' best response would be. Earlier players would then choose the best course of action based on the anticipated behaviour that they deduced about the followers. Follower players would expect earlier players to act in this way and they would make the best choices they can, under the circumstances. Thus, it was believed that leader players could manipulate the follower players towards directions that were beneficial to the early players.[4] In many simple games, the equilibria predicted by Manipulated Nash equilibrium correspond to the same ones that are predicted by the other forward induction concepts. However, in general, Manipulated Nash equilibria are a subset (refinement) of the other forward induction solution concepts.

While computing the Manipulated Nash equilibrium in sequential games can in general be quite complicated, for simple two—player games with no moves by nature and where each player has exactly one move, an algorithm to find the Manipulated Nash equilibrium reduces simply to taking the intersection of the set of Nash equilibria of the original game with the subgame perfect. Nash equilibria of the game that results from removing the information sets. Camerer et al. (1996) have referred to this feature as Virtual Observability (VO). It is as if the follower player can observe the earlier player's move. We will adopt the VO terminology in the remainder of this paper.

Thus there are several equilibrium concepts in the literature that capture various aspects of forward induction and order of play. Another procedure often discussed in conjunction with forward induction is iterated elimination of dominated strategies (IEDS). This is less of an equilibrium concept than a computational procedure. It predates any of the equilibrium concepts discussed thus far and differs from them in not requiring any information about the order of play. In fact it is a normal form concept. However it has been aligned with forward induction because it frequently arrives at the forward induction equilibria in certain simple games with outside options (cf. Osborne and Rubinstein, 1994, p. 111). Of all the concepts discussed, VO is distinguished by emphasising the *pure* order of play effects within a clearly defined theory of equilibrium.

The experimental literature has investigated both order of play and forward induction with mixed results. The most widely accepted conclusion is that *some* subjects seem to utilize forward induction or order of play information or both in their behaviour. With respect to forward induction, Cooper et al. (1993) find mixed evidence in Battle-of-Sexes games with and without outside options. When these games are played sequentially, the VO principle finds the equilibrium preferred by Player 1 as the only equilibrium. The authors observe that the Player 1 preferred equilibrium significantly increases in frequency when the game is played sequentially in the presence of an outside option rather than simultaneously without the option. Interestingly, the Player 1 preferred equilibrium was consistently chosen in sequentially played games even when the option was irrelevant, a prediction supported by VO but conflicting with the other forward induction concepts. The results were not entirely consistent with VO, however, because the outside option was actually chosen in many cases, contrary to the predictions of VO. Another test of forward induction is provided by Brandts and Holt (1992), who report an experiment involving five games of imperfect information. The results show that subjects tend to avoid equilibria ruled out by forward induction arguments, even when these cannot be eliminated by other principles such as iterated dominance, and to select equilibria consistent with forward induction when these are not identified by other principles.

There is substantial confirmation of order of play effects in the experimental literature. Camerer et al. (1996) review a number of studies indicating that the timing of moves in sequential games can affect outcomes, even when the remaining players cannot observe earlier moves. They focus on two of the alternative explanations of this phenomenon that we have discussed above: first mover advantage and VO. In their experimental work, they consider three person weak link games such as the stag hunt, where VO will select equilibria which are preferred by both players rather than just those that yield advantage to the first player. The authors search for evidence of VO in these games conducted under three informational conditions: simultaneous play, sequential but unobserved play, and fully observed play. Their results suggest that the VO prediction, that outcomes in the sequential unobserved condition should be closer to those in the fully observed condition than the simultaneous condition, is true in the later part of their sessions.

Rapoport (1997) investigates order of play effects in three different games played in two or more of the three information conditions, in a within subject design. The three games were resource dilemmas (also studied in Budescu et al. (1995), where similar results are obtained), provision of public goods and a three-person symmetric coordination game. In each case Rapoport finds sufficient evidence to indicate that order-of-play effects exist, but there is not enough evidence to claim that all subjects are sensitive to variation in the order of play. He concludes that either order of play serves as a coordination device or that it has more profound effects on behaviour.[5] The experimental results found in the papers are unable to determine which interpretation should be selected.

In an interesting recent paper, Guth et al. (1998) investigate whether knowledge of order of play will cause subjects to deviate away from equilibrium in favour of disequilibrium outcomes preferred by Player 1. They find little support for this hypothesis. They interpret this to mean that there are limitations of the positional order effect. However, they do not consider the possibility that order of play can influence subject behaviour from within Nash equilibrium. Indeed for one of the games that they study there is no VO equilibrium, and in that case VO predicts that players' thought processes will cycle indefinitely among a certain set of their possible actions. However, real player are at some point decisive, and so VO predicts that they would stop at some arbitrary point and just choose. This appears to be consistent with their observations.

A somewhat neglected feature in these investigations is the possibility that the manner in which a game is presented to subjects may systematically alter the selection criteria they employ. Schotter et al. (1994) demonstrate the potential importance of this feature while investigating backward induction and IEDS as solution concepts in certain two-person games. They conjecture that normal form presentations will encourage IEDS outcome (because dominance relations are more prominent) and that extensive form presentations will encourage subgame perfect equilibria (because they emphasize the sequential nature of decision making. Their work is incomplete from our perspective because (with one exception) they always present their sequential games in extensive form and their simultaneous games in normal form. This confounds presentation and information effects. Nevertheless their work strongly suggests that the form of presentation of a game will affect the principles used by subjects in determining their actions and raises the question of whether other aspects presentation might also systematically affect results.

Although the experiments in the literature suggest that VO has power in predicting equilibria in sequential games of imperfect information, none of them directly contrasts VO with alternative procedures which yield alternative predictions. In this paper we replicate and extend the earlier experiments by examining the relative power of VO and IEDS principles in explaining strategies and outcomes in simple two-person games. Our intention is to identify cases in which the two principles seem most relevant. We examine both information about order-of-play and two aspects of presentation: the effect of extensive vs. normal form presentation and the ordering of payoffs and strategies within the game tree or payoff matrix. We create an environment in which groups of subjects play three games: one with three strategies per person in which VO and IEDS predict different solutions (2P3S), one Battle-of-Sexes game (BOS), and one Battle-of-Sexes with outside option (BOSO). The BOSO game is important because it is an instance of when the iterated elimination outcome coincides with the prediction of VO, as well as other forward induction concepts. BOS is important because many forms of forward induction (as well as the iterated elimination procedure) will be unable to make a clear prediction, since there is no signal to be observed. VO, on the other hand, predicts the Player 1 preferred equilibrium. Finally the 2P3S game has the property that in the sequential unobserved condition, VO and IEDS make different and non-overlapping predictions. Thus each game is important in our investigation.

Like Camerer, Knez and Weber we present the games in three information conditions: simultaneous moves, sequential unobserved moves, and sequential fully observed moves. Like Schotter, Weigelt and Wilson we present the games in both normal and extensive form. However our factorial design allows us to separate information effects from presentation effects. We also control for presentation effects by mixing the order of presentation of the games and their mirror images within sessions and by changing the presentation from normal form to extensive form between sessions. We employ a within-subject design so that each subject can act as his own control for changes in information and image reversals. As the form of presentation varies only between sessions it is investigated as an across-subjects effect.

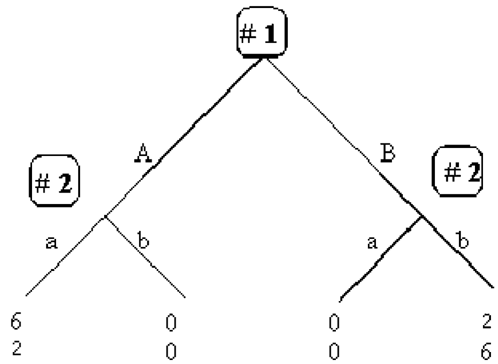
Our central question is whether knowledge of the order of play affects individual choice of strategy. Under the hypothesis of VO the distribution of strategies in sequential unobserved play should be shifted away from the strategies in simultaneous unobserved play and towards the distribution of strategies in fully observed play. Our subsidiary questions relate essentially to framing. We investigate whether outcomes and choice of strategy are influenced by the form of presentation (extensive or normal form) and by positioning (the ordering of alternatives within the payoff structure).

Experimental design

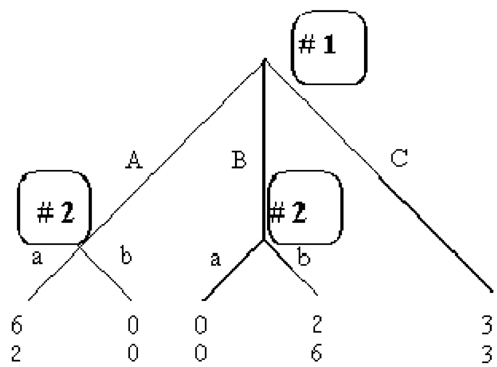
We conducted 12 experimental sessions with 10 subjects in each session. Subjects played three practice and either 18 or 36 regular rounds during which they were presented with one or more of the three games shown in Table 1.[6] The first two games, denoted BOS and BOSO, are standard Battle-of-the-Sexes and Battle-of-the-Sexes-with-outside-option games similar to those used by Cooper et al. The third game, denoted 2P3S, is a two-person, three-strategy game designed to discriminate between IEDS and VO as principles of forward induction.

Table 1. The three games in normal and extensive form.

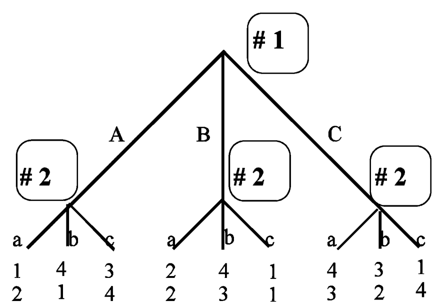
BOS	Player 2	
Player 1	**a**	**b**
A	6, 2	0, 0
B	0, 0	**2, 6**



BOSO	**Player 2**	
Player 1	**a**	**b**
A	**6, 2**	**0, 0**
B	**0, 0**	**2, 6**
C	**3, 3**	**3, 3**



2P3S	**Player 2**		
Player 1	**a**	**b**	**c**
A	**1, 2**	**4, 1**	**3, 4**
B	**2, 2**	**4, 3**	**1, 1**
C	**4, 3**	**3, 2**	**1, 4**



The equilibria of these games are presented in Table 2 and the rationalizable strategies for each game are presented in Table 3. In this section we describe variation in treatments within and across sessions. The predictions and results for each game will be discussed in individual sections below.

Each session consisted of 3 practice decision periods followed by either one or two sequences of 18 real decision periods. During each of these 18-period sequences we presented

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Table 2. Equilibrium sets by game and information treatment under three principles of equilibrium selection.

Game and information treatment	Principle		
	Conventional	VO	IEDS
BOS			
Simultaneous (**S**)	(**A**, **a**), (**B**, **b**), m	(**A**, **a**), (**B**, **b**), m	(**A**, **a**), (**B**, **b**), m
Unobserved (**U**)	(**A**, **a**), (**B**, **b**), m	(**A**, **a**)	(**A**, **a**), (**B**, **b**), m
Observed (**O**)	(**A**, **a**)	(**A**, **a**)	(**A**, **a**)
BOSO			
Simultaneous (**S**)	(**A**, **a**), (**C**, **b**)	(**A**, **a**), (**C**, **b**)	(**A**, **a**)
Unobserved (**U**)	(**A**, **a**), (**C**, **b**)	(**A**, **a**)	(**A**, **a**)
Observed (**O**)	(**A**, **a**)	(**A**, **a**)	(**A**, **a**)
2P3S			
Simultaneous (**S**)	(**A**, **c**), (**B**, **b**), M	(**A**, **c**), (**B**, **b**), M	(**A**, **c**)
Unobserved (**U**)	(**A**, **c**), (**B**, **b**), M	(**B**, **b**)	(**A**, **c**)
Observed (**O**)	(**B**, **b**)	(**B**, **b**)	(**B**, **b**)

Notes: Equilibria are denoted by ordered pairs (x, y), where x and y denote the strategies of Players 1 and 2 respectively.
m denotes a mixed with probabilities P(A) = 3/4, P(B) = 1/4, P(a) = 1/4, and P(b) = 3/4.
M denotes a mixed strategy for 2P3S. M denotes a mixed strategy with probabilities P(A) = 0, P(B) = 1/2, P(C) = 1/2, P(a) = 2/7, P(b) = 4/7, and P(c) = 1/7.

Table 3. Possible strategies rationalized by alternative equilibrium concepts.

	Simultaneous (**S**)			Unobserved sequential (**U**)			Observed sequential (**O**)		
	Std. theory	VO	IEDS	Std. theory	VO	IEDS	Std. theory	VO	IEDS
BOS									
Player 1	**A**, **B**	**A**, **B**	**A**, **B**	**A**, **B**	**A**	**A**, **B**	**A**	**A**	**A**
Player 2	**a**, **b**	**a**, **b**	**a**, **b**	**a**, **b**	**a**	**a**, **b**	**a**	**a**	**a**
BOSO									
Player 1	**A**, **C**	**A**, **C**	**A**	**A**, **C**	**A**	**A**	**A**	**A**	**A**
Player 2	**a**, **b**	**a**, **b**	**a**	**a**, **b**	**a**	**a**	**a**	**a**	**a**
2P3S									
Player 1	**A**, **B**, **C**	**A**, **B**, **C**	**A**	**A**, **B**, **C**	**B**	**A**	**B**	**B**	**B**
Player 2	**a**, **b**, **c**	**a**, **b**, **c**	**c**	**a**, **b**, **c**	**b**	**c**	**b**	**b**	**b**

either 9 periods of BOS intermixed with 9 periods of BOSO or 18 periods of 2SPS. Each game was presented in three information conditions. In the Simultaneous Condition (S) the two players made their decisions at the same point in time. In the Unobserved Sequential Condition (U) Player 1 made his decision first but Player 2 was not informed of Player 1's choice. Both players were informed of their position in the sequence and of the fact that the second player would decide without knowing the decision of the first player. Finally, in the Observed Sequential Condition (O), Player 1 made his decision first and Player 2 was informed of Player 1's decision before making his own decision.

In six sessions all games were presented in extensive form. In the remaining six sessions all games were presented in normal form, thus each group of subjects saw only one form. There were some variations in presentation across games. In the extensive form representations of BOS and BOSO Player 1's strategies were labelled L (for Left), R (for Right) and O (for outside option). Similarly Player 2's strategies were labelled 1 and r. In the remaining games strategies were labelled with the symbols A, B, C and a, b, c. In the Extensive Form games the agents were labelled Player 1 and Player 2. In the normal form games the players were labelled BLUE and RED and the payoffs were colour-coded to match. To further aid comprehension, the payoff tables and colours were transposed as necessary so that regardless of their logical role in the game (Player 1 or Player 2) all subjects were designated as BLUE and their strategies were listed as the rows of the payoff matrices they faced.

It is possible that subjects might cue their behaviour from the position of a strategy, either from left to right in the extensive form presentations or from top to bottom in the normal form. We controlled for this effect by presenting each game in its basic form (as presented in Table 1) and in an altered form. For BOS and BOSO we interchanged the payoffs for Strategies **A** and **B** and for Strategies **a** and **b**. Similarly we interchanged payoffs for Strategies **A** and **C** and for Strategies **a** and **c** in 2P3S. These transformations were carried out for both normal and extensive form games. We refer to original and transformed versions of each game as "left" and "right" respectively and the distinction between the two as the "handedness" of the game. In all the results presented in this paper the choice of strategies in "right" games has been re-labelled to conform to the "left" version of the game.

At the beginning of each session subjects were seated at individual carrels and given written instructions (Appendices C and D, available on the EE website). Questions were posed and answered orally by the experimenter. Subsequently a series of extensive form or normal form games was presented on the computer screens. Messages on the computer screen informed subjects of their role, whether the other player would decide before, at the same time, or after they had made their decision and whether the other player would know their decision. Subjects entered their choices using a keyboard. Choices were confirmed by a computer prompt. As noted above, subjects played three practice rounds, followed either by 18 rounds of BOS intermixed with BOSO or 18 rounds of 2P3S. In eight of our twelve sessions subjects then played a second set of 18 rounds of a different game (either 9 rounds each of BOS and BOSO or 18 rounds of 2P3S). At the end of the session payoffs were converted from laboratory currency to Canadian dollars and paid privately in cash, together with a \$5 show-up fee. The organization of each of the six sessions is presented in Table 4.

There were ten subjects in each session. Each subject played some games in the role of Player 1 and some in the role of Player 2. Roles, partners, handedness and information conditions were scrambled as much as possible within each 18-period sequence of games. The 18 periods were subdivided into six bands of three rounds each. Within each band, one round was played in each of the three information conditions in varying orders. In each round the ten subjects were divided into five pairs, three receiving one version (left or right)

Table 4. Experimental design: Number of sessions by session type and presentation.

Session type	Extensive form	Normal form
18 rounds 2P3S	2	2
18 rounds BOS/BOSO followed by 18 rounds 2P3S	2	2
18 rounds 2P3S followed by 18 rounds BOS/BOSO	2	2

Notes: All sessions began with 3 practice rounds of BOS, once in each information condition. Information treatments. Information treatments S, U, and O appeared 6 times in each set of 18 rounds.

of the game and the two receiving the other version. Subjects were told that they would never know the partners with whom they were paired, and that they would meet each other individual at least twice and never more than three times (within each subsession of 18 games). In addition we ensured that no one subject met any other subject twice in the same role in any game. The mixing of pairs and roles was adjusted on an ad hoc basis to achieve this. One consequence was that although each subject played each role approximately the same number of times, some subjects experienced long runs of one role or the other. On average, each subject played each other subject twice in each sequence of 18 periods, once in each role.

Given the large number of framing variables for which we were controlling, we have effectively created a split-plot $2 \times (3 \times 2 \times 2)$ factorial design. We analyse one factor (presentation) across sessions and 3 factors (information treatment, handedness, and sequence) within session. As a result of the manipulations described in previous paragraphs all factors (role, information treatment, handedness and sequence in session) are perfectly orthogonal within BOS, BOSO, and (with one exception) the 2P3S games. Consequently the main effect of each factor can generally be inferred by simple comparisons of mean values.

Subjects were recruited from the available undergraduate population of McMaster University. Salient earnings (before the $5.00 show-up fee) ranged from $9.50 to $18.25 (mean $14.50) for the shorter (18 period) sessions and from $21.50 to $37.25 (mean $28.56) for the longer (36 period) sessions. Short sessions lasted about one hour; long sessions lasted about one and a half hours.

Statistical model and procedures

Our within-subject design implies that we have many repeated observations on the same subjects. Although we observed the outcome of 360 games for each of BOS and BOSO and 1080 games of 2P3S we have only 120 subjects. On average each subject played 9 rounds of 2P3S in each of the two roles and either 4 or 5 rounds of each of BOS and BOSO in each of the two roles. In general these observations cannot be considered independent because each subject may have deviated from average behaviour either because of a subject-specific effect on all his choices or because of a learning effect arising from his experience in the session. Because of this lack of independence conventionally estimated standard errors may be biased and statistical tests misleading.

We deal with this difficultly by treating our observations as cross-section time-series (panel) data, in which decision periods correspond to time and the cross-section is across individual subjects. We shall adopt the following procedure. For each game we hypothesize an effect of the treatment variables on the frequency of play of a particular strategy, generally the one expected under the virtual observability hypothesis. We cross-tabulate this outcome variable with respect to the treatment variables of interest and present the results in graphical format. To formally test the hypotheses we estimated cross-section time-series probit equations with dummy variables for presentation (extensive or normal), information (S, U, or O), handedness (left or right) and sequence in session (first or second). We also included the interactions of presentation with all the remaining variables. The model is estimated using the Liang and Zellner GEE algorithm as implemented in Stata (1999). We applied the Huber/White/sandwich algorithm to obtain robust estimators of the standard errors of the coefficients.[7] We conducted a specification search by testing the joint significance of handedness and sequence. If these were jointly significant at the 10% level, we tested handedness and sequence individually. If necessary we reestimated the equation, discarding factors which were not significant at the 10% level. We then conducted chi-square tests on the restrictions on the coefficients implied by our various hypotheses, discussed below.[8]

BOS games

Predictions

The BOS game was presented in Table 1. In simultaneous play (Condition **S**) standard theory identifies two pure strategy equilibria, (**A**, **a**) and (**B**, **b**). A mixed strategy equilibrium is also possible (see Table 2). Neither pure strategy can be eliminated by iterated dominance arguments and, of course, virtual observability does not restrict the outcomes in this condition. Thus in Condition **S** all Strategies (**A**, **B**, **a** and **B**) are rationalizable as best responses to an equilibrium play of the opponent. In the fully observed condition (Condition **O**), all three theories select (**A**, **a**) as the unique subgame perfect equilibrium, so only Strategies **A** and **a** are rationalizable. The theories diverge under unobserved sequential play (Condition **U**). In this case VO selects (**A**, **a**) while the other theories cannot discriminate between (**A**, **a**) and (**B**, **b**). Thus in Condition **U** all strategies are rationalizable according to standard theory and IEDS, but only Strategies **A** and **a** are rationalizable according to VO. These sets of rationalizable strategies are summarized in Table 3.

To derive testable predictions, we adopt two auxiliary hypotheses:

> *Hypothesis A1*: Rationalizable strategies are played with higher probabilities than those of non-rationalizable strategies.

> *Hypothesis A2*: If the sets of rationalizable strategies are the same under two information conditions, then the probability of play of each strategy is independent of information condition.

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If all players apply VO reasoning we have two strong predictions. First, all players will choose the VO-consistent Strategies **A** or **a** in Condition **U** and secondly, the observed frequency of Strategies **A** and **a** will be the same in Conditions **U** and **O**. We call these predictions "Strong VO" and test them as null hypotheses. Rejection of the null will be interpreted as support for Standard Theory and IEDS, under which both Strategies **B** and **b** are rationalizable in Condition **U** but not in Condition **O**.

Under Standard Theory or IEDS the sets of rationalizable equilibria under Conditions **S** and **U** are identical, consequently Hypothesis A2 implies that the probability of observing Strategies **A** and **a** are the same under both conditions. If no players follow VO reasoning, then we have a strong prediction that the observed frequencies of play of Strategy **A** and of Strategy **a** will be the same (but not necessarily equal to each other) in Conditions **S** and **U**. On the other hand, the pure-order-of-play (VO) effect predicts an increase in the frequencies of Strategies **A** and **a** under Condition **U** compared with Condition **S**, unless the frequency in Condition **S** is already 100%. We call this prediction "weak VO" and test it as a research hypothesis against the null of equal frequencies. Rejection of the null will be taken as support for the proposition that at least some subjects are applying VO reasoning and consequently that standard theory and IEDS are not sufficient explanators of individual behaviour.[9]

Results

Table 5 presents the distribution of outcomes and the observed frequencies of Strategies A, by information condition and by form of presentation. The first two columns of Table 6 present p-values for a number of hypothesis tests. The key results are readily apparent in the bar graphs presented as figure 1.

First note from Table 5 that Strategy **A** is more likely to be chosen when BOS is played in the second part of the experiment than when it is the first game presented (93% vs. 83%).[10] A similar result holds for Player 2's Strategy **a** (79% vs. 67%). This effect is significant for both players (see Table 6, row 1B). Player 1 is also more likely to choose his high-payoff Strategy **A** in the left-handed form of normal games than in the right (89% vs. 75%). This is not the case for extensive form games, where the frequencies of play are essentially equal. Overall we reject the hypothesis of no handedness effects ($p = 0.0311$). On other hand, Player 2 is not significantly affected by the handedness of the game.

Second, note that choice of extensive or normal form presentation has a clear effect. Subjects in the Player 1 role are significantly more likely to choose the VO-consistent strategy in extensive form games (93%) than in normal form games (82%). Overall, we decisively reject the null that the coefficients of presentation and its interactions with information condition are collectively zero. Similar results hold for Player 2 (86% vs. 60%). Inspection of figure 1 shows, however, that the effect of information is largely restricted to Normal form games. In Extensive games, Player 1 plays Strategy **A** almost exclusively, regardless of information condition. In normal form games, Player 1 plays Strategy **A** 63% of the time in Condition **S** but 88% and 95% of the time in Conditions **U** and **O** respectively. The results for Player 2 are similar. The effect of information varies dramatically according to the form of presentation. In extensive form games the frequency of Strategy **a** rises gradually

Table 5. Frequency of VO-consistent Strategies A and a, BOS games.

		Strategy and information condition							
		Player 1 Strategy **A**				Player two Strategy **a**			
Form	Treatment	**S**	**U**	**O**	Total	**S**	**U**	**O**	Total
Extensive	Left	0.97	0.91	0.94	0.94	0.78	0.88	0.88	0.84
	Right	0.93	0.86	1.00	0.93	0.86	0.86	0.93	0.88
	First	0.90	0.83	0.93	0.89	0.77	0.83	0.83	0.81
	Second	1.00	0.93	1.00	0.98	0.87	0.90	0.97	0.91
	Total	0.95	0.88	0.97	0.93	0.82	0.87	0.90	0.86
Normal	Left	0.75	0.91	1.00	0.89	0.28	0.72	0.88	0.62
	Right	0.50	0.86	0.89	0.75	0.18	0.79	0.75	0.57
	First	0.60	0.80	0.90	0.77	0.13	0.70	0.73	0.52
	Second	0.67	0.97	1.00	0.88	0.33	0.80	0.90	0.68
	Total	0.63	0.88	0.95	0.82	0.23	0.75	0.82	0.60
Total	Left	0.86	0.91	0.97	0.91	0.53	0.80	0.88	0.73
	Right	0.71	0.86	0.95	0.84	0.52	0.82	0.84	0.73
	First	0.75	0.82	0.92	0.83	0.45	0.77	0.78	0.67
	Second	0.83	0.95	1.00	0.93	0.60	0.85	0.93	0.79
	Total	0.79	0.88	0.96	0.88	0.52	0.81	0.86	0.73

from 82% to 87% to 90% as Information Condition changes from **S** to **U** to **O**, while in normal form games frequency of Strategy **a** rises sharply from 23% in Condition **S** to 75% in Condition **U**.

Let us turn now to our key hypotheses. We see very little difference between play in Condition **U** and play in Condition **O**. We easily retain the null of equal frequencies for Player 1 in extensive form games and for Player 2 in both normal and extensive form games. Although we reject equality for Player 1 in normal form games, we do so with relatively low confidence ($p = 0.08$). These results support the strong VO prediction. Most subjects are playing the unobserved sequential games in the same way as they are playing fully observed games.

Equally importantly, the results for both players provides strong evidence for a pure order-of-play effect in Normal Form games. Subjects in the role of Player 1 chose the VO-consistent Strategy A much more frequently in the unobserved sequential condition (88%) than in the true simultaneous condition (63%). As noted above, Player 2 demonstrates an even greater increase. This rejects the strong predictions of Standard Theory and IEDS in favour of weak VO. The result is significant strongly significant for both players ($p = 0.0001$ and $p = 0.0000$). The results are different for Player 1 in extensive games, where the frequency of Strategy **A** is higher (95%) in Condition **S** than in Condition **U** (88%). This is not inconsistent with VO, but rather represents a surprisingly high frequency of Strategy **A** in the true simultaneous Condition **S**. Player 2 also plays Strategy **a** very frequently

Table 6. *P*-values for hypothesis tests.

Game Number and null hypothesis	Play in BOS		Play in BOSO		Play in 2P3S			
					Player 1		Player 2	
	Player 1 **A**	Player 2 **a**	Player 1 **A**	Player 2 **a**	**A**	**B**	**b**	**c**
1: No handedness or sequence effects	0.0157	0.0311	0.0926	0.7384	0.105	0.214	0.726	0.933
1A: No handedness effects	0.0311	0.3657	0.1117	n.a.				
1B: No sequence effects	0.0259	0.0239	0.1535	n.a.				
2: No presentation effects	0.0000	0.0000	0.0000	0.0000	0.000	0.001	0.000	0.000
3: No information condition effects	0.0000	0.0000	0.0000	0.0000	0.000	0.000	0.000	0.000
4: Condition **O** = Condition **U**								
4N: Normal form	0.0801	0.3709	0.0000	0.0208	0.000	0.000	0.000	0.000
4: Extensive form	0.2270	0.5373	0.0024	0.9533	0.000	0.000	0.000	0.000
5: Condition **S** = Condition **U**								
5N: Normal form	0.0001	0.0000	0.0368	0.0000	0.019	0.595	0.086	0.008
5E: Extensive form	0.0925	0.4705	0.1459	0.1126	0.912	0.553	0.036	0.968

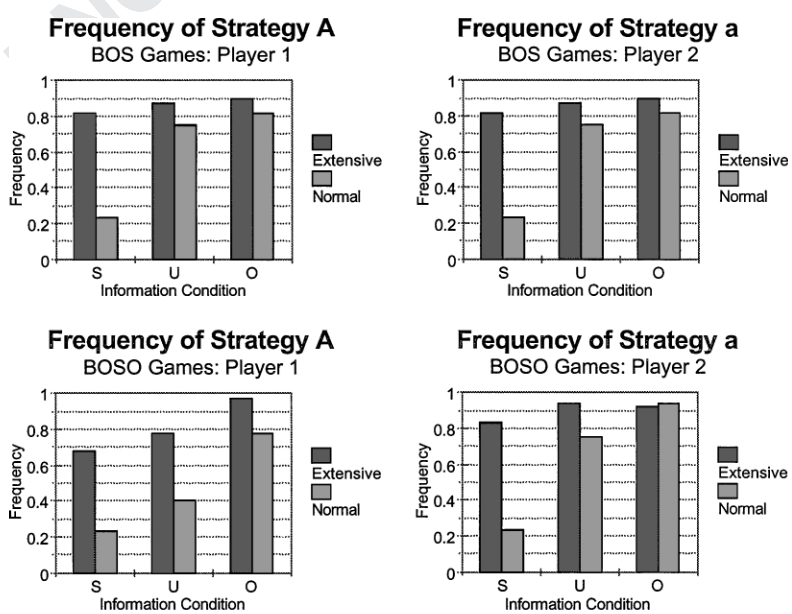

Figure 1. Frequency of Strategies in BOS and BOSO games.

in Condition **S** of extensive games, but here there is a slight increase in the frequency of Strategy **a** in Condition **U** (87% vs. 82%) and we weakly reject the null of no effect of information ($p = 0.0925$).

To summarize, knowledge of the order of play has a strong effect on strategies and outcomes chosen in normal form BOS games. This is entirely consistent with the VO concept as introduced by Amershi et al. The effect is harder to detect in extensive form games because the distribution of outcomes and strategies in extensive form simultaneous games is already close to indistinguishable from the distribution under Conditions **S** and **U**. This strong effect of extensive form presentation confirms the findings of Schotter et al. It also appears to suppress any effect of handedness in the presentation of this simple game. On the other hand subjects playing the role of Player 1 appeared to be affected by handedness in the only slightly more opaque normal form.

BOSO games

The extensive and normal forms of the BOSO game were presented in Table 1. In Conditions **S** there are two pure strategy Nash equilibria: (**A**, **a**) and (**C**, **b**). Thus Strategies **A**, **C**, **a** and **b** are rationalizable under standard theory, but Strategy **B** is not. Pure order-of-play effects cannot exist in Condition **S**, so the VO principle selects the same equilibria as standard theory. IEDS selects (**A**, **a**). Note that the outside option, C, is not rationalizable under IEDS. In the fully observed Condition **O** there is a unique sub-game perfect equilibrium at (**A**, **a**), so **A** and **a** are the rationalizable strategies under all three principles of equilibrium selection. In the Unobserved Sequential Condition **U** neither Standard theory nor IEDS can reduce the sets of rationalizable strategies, but VO selects (**A**, **a**) because it is the unique sub-game perfect equilibrium of the fully observed game. This equilibrium is also consistent with signalling-based concepts of forward induction. Loosely speaking, the fact that Player 2 is allowed a choice reveals that Player 1 has rejected the outside option, Strategy **C**. Because Player 1 receives a higher payoff from **C** than from **B**, Player 2 must infer that Player 1 has rejected **B** and therefore chosen **A**. This leads to (**A**, **a**) as the unique forward induction equilibrium.

Our predictions for BOSO are essentially the same as for BOS. If all players apply VO reasoning all players will choose the VO-consistent Strategies **A** or **a** in Condition **U** and the observed frequency of Strategies **A** and **a** will be the same in Conditions **U** and **O**. If no players follow VO reasoning, then the observed frequencies of play of Strategy **A** and of Strategy **a** will be the same in Conditions **S** and **U**. Both forms of forward induction (pure-order-of-play and signalling) predict an increase in the frequencies of Strategies **A** and **a** under Condition **U** compared with Condition **S**, unless the frequency in Condition **S** is already 100%.

Results

Table 7 presents the distribution of outcomes and displays the relative frequencies with the VO consistent strategies **A** and **a** were chosen. Notice that under Conditions **U** and **O**, Player 2 had no decision to make if Player 1 chose the outside option **C**. For Player 2

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Table 7. Frequency of play of VO consistent Strategies, BOSO games (excluding cases in which Player 2 had no option).[a]

		Player 1				Player 2			
Form	Sequence	**S**	**U**	**O**	Total	**S**	**U**	**O**	Total
Extensive	First	0.70	0.70	0.93	0.78	0.83	0.86	0.86	0.85
	Second	0.67	0.87	1.00	0.84	0.83	1.00	0.97	0.93
	Total	0.68	0.78	0.97	0.81	0.83	0.94	0.92	0.89
Normal	First	0.33	0.50	0.77	0.53	0.27	0.80	0.87	0.59
	Second	0.13	0.30	0.80	0.41	0.20	0.67	1.00	0.57
	Total	0.23	0.40	0.78	0.47	0.23	0.75	0.94	0.58
Total	First	0.52	0.60	0.85	0.66	0.55	0.83	0.87	0.73
	Second	0.40	0.58	0.90	0.63	0.52	0.91	0.98	0.78
	Total	0.46	0.59	0.88	0.64	0.53	0.87	0.92	0.75

[a]The breakdown of the frequency of play consistent with VO in BOSO games for handedness has also been tabulated, and the table is available at the *EE* website.

these frequencies exclude the cases in which Player 2 had no opportunity to make a choice. Table 6 (columns 3 and 4) presents p-values for a number of hypothesis tests. The key results are readily apparent in the bar graphs presented in figure 1.

The results for BOSO provide strong support for order-of-play effects and for the importance of form of presentation and less support for sequence or handedness effects. Considering the last first, we see from Table 6 that experience and handedness makes very little difference to Player 1's choices. Although the two effects considered jointly are marginally significant ($p = 0.0926$), considered individually neither handedness nor sequence in session are statistically significant at the 10% level ($p = 0.1117$ and $p = 0.1535$ respectively).[11] The null of no joint effect is easily retained for Player 2. Unlike the BOS results, the BOSO results show a clear effect of information in both extensive and normal form games, with a steady increase in the frequency of Strategy **A** as the information condition changes from **S** to **U** to **O**. Presentation has a very clear effect, with Strategy **A** distinctly more frequent in extensive games in all three information conditions. The main effects of information and presentation are highly significant ($p = 0.0000$ for each).

Comparing Conditions **U** and **O** we find less evidence for the strong VO hypothesis than we did in the BOS games. Play in the two conditions is indistinguishable for Player 2 in extensive form games, but in the other three cases (Player 2 in normal form, and both Players in extensive form) the frequencies of VO consistent Strategies **A** and **a** are significantly less in Condition **U** than in Condition **O**. In comparing Conditions **S** and **U**, however, we find evidence of order-of-play effects, particularly for Player 2 in normal form games. In normal form games both players play their VO consistent strategies more frequently in Condition **U** than in Condition **S** (40% vs. 23% for Player 1, $p = 0.0368$; 75% vs. 23% for Player 2, $p = 0.000$). Although the effect is in the same direction for extensive form games (78% vs. 68% for Player 1 and 94% vs. 83% for Player 2), neither effect is statistically significant. Once again, the results are not so much a failure of VO to predict correctly in

Condition **U** as an unexpectedly high frequencies of Strategy **A** and **a** in the simultaneous play Condition **S**. This strongly suggests that the extensive form encouraged subjects to analyse the simultaneous games as if they were sequential.

2P3S games

The third game, denoted 2P3S, is a two-person, three-strategy game designed to discriminate between IEDS and VO as principles of forward induction. It is the simplest game under which these principles rationalize different unique strategies in Condition **U**. Under Condition **S** (simultaneous play), 2P3S has two pure strategy Nash equilibria, (**A**, **c**) and (**B**, **b**), and a mixed-strategy equilibrium. Neither conventional theory nor VO can refine this set, but IEDS selects the (**A**, **c**) equilibrium.[12] By the same reasoning, IEDS also selects (**A**, **c**) in Condition **U**, so only Strategies **A** and **c** are rationalizable in this case. Under fully observed play (Condition **O**), all theories select (**B**, **b**) as the unique subgame perfect equilibrium. Consequently (**B**, **b**) is also the predicted equilibrium and **B** and **b** are the unique strategies rationalizable under VO. These predictions on rationalizable actions were given in Table 3.

If all players follow VO reasoning, we have two strong predictions. First, all players will choose the VO consistent strategies **B** and **b** in Condition **U** and secondly, there will be no difference between Conditions **U** and **O** in the frequency of Strategies **B** and **b**. We test these strong predictions as null hypotheses and interpret rejection of the null as rejection of the hypothesis that all players are applying VO reasoning. If only some players are following VO reasoning we have a weaker prediction. In this case the observed frequency of Strategies **B** and **b** should be higher in Condition **U** than in Condition **S**. Both standard theory and IEDS predict that these frequencies should be the same in both Conditions. We test the prediction of standard theory as a null hypothesis and interpret rejection as evidence that some players are applying VO reasoning.

Finally, if all players are following IEDS reasoning, we have the strong prediction that all players will choose Strategies **A** and **c** both in Condition **S** and Condition **U**.

Results

Table 8 reports the distribution of outcomes by information condition. Figure 2 graphs the relative frequency of Strategies **A** and **B** for Player 1 and of Strategies **c** and **b** for Player 2. These are the strategies rationalizable under IEDS and VO respectively. P-values for a range of null hypotheses appear in Table 6, columns 5 to 8.

This game exhibits strong presentation effects, but there is very little evidence of pure order-of-play effects. We retain the null of no handedness or sequence effects for both Player 1 and Player 2 and for both the IEDS consistent Strategies **A** and **c** and the VO consistent Strategies **B** and **b**. Presentation has a strong effect, with VO consistent play substantially more likely in extensive form games than in normal games, both for Player 1 (53% vs. 35%) and Player 2 (47% vs. 28%). These effects are strongly significant.

Information has an effect on both players, but it is concentrated in the contrast between the fully observed Condition **O** and the other two Conditions. Both players play the subgame perfect equilibrium Strategies **B** and **b** more frequently and the IEDS consistent Strategies

Table 8. Frequency of Strategies, by role and information condition, 2P3S games.

Information condition	Player 1's Strategy	Player 2's Strategy 1	2	3	Total
S	1	35	34	132	201
	2	19	22	62	103
	3	14	8	34	56
	Total	68	64	228	360
U	1	35	41	105	181
	2	13	28	59	100
	3	14	25	40	79
	Total	62	94	204	360
O	1	0	1	47	48
	2	7	246	21	274
	3	7	2	29	38
	Total	14	249	97	360

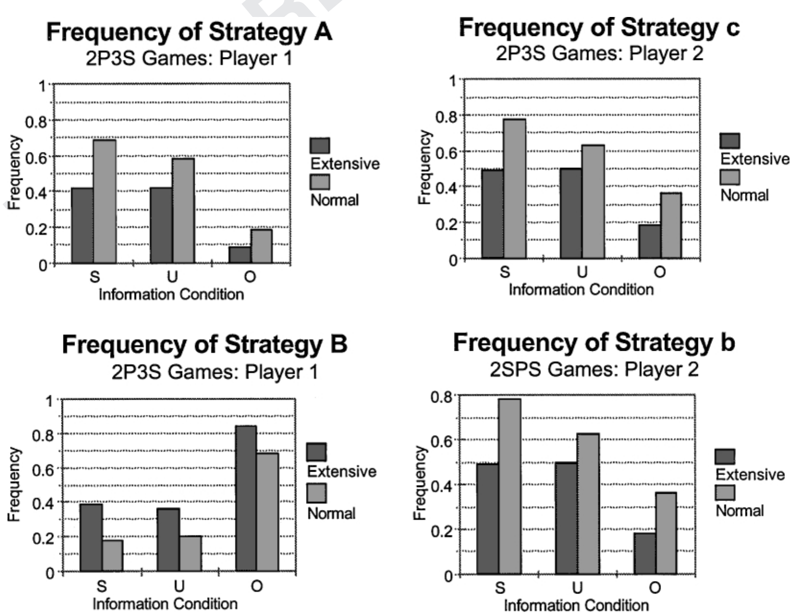

Figure 2. Frequency of Strategies in 2P3S games.

A and **c** less frequently in Condition **O** than in the other two conditions. We easily reject the null of no information effect on the choice of Strategy **B** or Strategy **A** ($p = 0.0000$).

Comparing Conditions **U** and **O** we clearly reject the strong VO predictions that all subjects will play **B** and **b** in both conditions. Comparing Conditions **S** and **U** we find

Table 9. Frequency of equilibrium consistent Strategies VO consistent Strategies **B** and **b**.[a]

		Role and Information Condition							
		Player 1 plays **B**				Player 2 play **b**			
Form	Sequence	**S**	**U**	**O**	Total	**S**	**U**	**O**	Total
Extensive	First	0.33	0.32	0.83	0.5	0.24	0.32	0.81	0.46
	Second	0.52	0.42	0.85	0.59	0.28	0.43	0.77	0.49
	Total	0.39	0.36	0.84	0.53	0.26	0.36	0.79	0.47
Normal	First	0.17	0.16	0.66	0.33	0.09	0.19	0.59	0.29
	Second	0.20	0.28	0.73	0.41	0.12	0.1	0.58	0.27
	Total	0.18	0.20	0.68	0.35	0.10	0.16	0.59	0
Total	First	0.25	0.24	0.75	0.41	0.17	0.26	0.70	0.38
	Second	0.36	0.35	0.79	0.50	0.20	0.27	0.68	0.38
	Total	0.29	0.28	0.76	0.44	0.18	0.26	0.69	0.38

IEDS Consistent Strategies **A** and **c**[b]

		Player, Strategy and Information Condition							
		Player 1 Strategy **A**				Player 2 Strategy **c**			
Form	Treatment	**S**	**U**	**O**	Total	**S**	**U**	**O**	Total
Extensive	First	0.49	0.45	0.08	0.34	0.17	0.22	0.08	0.16
	Second	0.28	0.37	0.10	0.25	0.20	0.22	0.05	0.16
	Total	0.42	0.42	0.09	0.31	0.18	0.22	0.07	0.16
Normal	First	0.68	0.59	0.22	0.50	0.15	0.25	0.12	0.17
	Second	0.72	0.57	0.10	0.46	0.08	0.15	0.17	0.13
	Total	0.69	0.58	0.18	0.49	0.13	0.22	0.14	0.16
Total	First	0.59	0.52	0.15	0.42	0.16	0.24	0.1	0.17
	Second	0.50	0.47	0.10	0.36	0.14	0.18	0.11	0.14
	Total	0.56	0.50	0.13	0.4	0.16	0.22	0.11	0.16

[a]The breakdown of the frequency of VO consistent Strategies **B** and **b** for handedness has also been tabulated, and the table is available at the *EE* website.

[b]The breakdown of the frequency of VO consistent Strategies **B** and **b** for handedness has also been tabulated, and the table is available at the *EE* website.

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only very slight support for a pure order-of-play effect. Player 1 chooses the VO consistent Strategy **B** about as frequently in Condition **U** (20% and 36% for normal and extensive form games respectively) as in Condition **S** (18% and 39%) respectively and neither difference is significant. Player 2 does choose the VO-consistent Strategy **b** more frequently in Condition **U** (16% and 36% for normal and extensive forms, respectively). This effect is statistically significant at the 5% level for Extensive games and at the 10% level for Normal games (two tailed chi-square tests). Moreover, in normal form games there is a statistically significant *decline* in the frequency of the IEDS consistent Strategies **A** and **c** in Condition **U** compared

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to Condition **S**. This indirectly supports a pure order-of-play effect. Nevertheless, in all cases the IEDS Strategies **A** and **c** are played more frequently than the VO consistent Strategies **B** and **b**, even though the strong IEDS prediction that all players choose Strategies **A** and **c** cannot be maintained.

Discussion

Our results strongly confirm that knowledge of the order of play can affect subjects's actions in simple two-person co-ordination games. The effect seems much stronger in relatively simple games such as BOS and BOSO compared to less transparent games such as 2P3S. It is also strongly dependent on the form of presentation. VO-consistent play and outcomes are consistently more frequent in extensive form games that in normal form games. However the *differential* effect of knowing the order of play (relative to simultaneous play) is generally most marked in normal form games. This is because the VO-consistent equilibrium is frequently observed in extensive form games even in the simultaneous information condition. Thus the contrast between the simultaneous and unobserved sequential conditions is less dramatic.

The evidence of VO behaviour in normal form BOS games is particularly interesting because it suggests that at least some subjects engage in forward induction of the type modelled by Amershi et al. Neither IEDS nor forward induction theories based on limited observation of previous moves is capable of predicting this behaviour. There were slight indications of the application of VO reasoning among subjects when they are playing 2SPS in the role of Player 2. However it is clear that VO reasoning is far from dominant in this game, where the IEDS equilibrium emerged much more frequently.

Our investigation of handedness shows that apparently innocuous changes in the ordering of payoffs within a matrix (handedness) can occasionally have significant effects on outcomes and play. However, there seems to be little pattern to the rejections of handedness and it may be that the rejections we found were essentially random events. There is also evidence of sequence effects in some games, so that VO play generally becomes more common as subjects become more familiar with the games. Again this is a relatively minor effect.

Our results complement and extend the existing literature on order-of-play effects in games. We have extended the class of games found by other authors (notably Rapoport and Camerer, Knez, and Weber) to exhibit order-of-play effects generally and we detect in BOS games strong evidence of pure order of play effects of the sort studied by Amershi et al. Like Rapoport but unlike most other studies we utilize a within subject design that allows subjects to serve as their own controls for the examination of information and handedness effects. We have clear evidence that the success of VO reasoning in predicting actual choices diminishes rapidly as games become more complex. Most strikingly we have confirmed the Schotter et al. finding that extensive form presentations promote sequential thinking, in a somewhat different design that permits a clear distinction between information and presentation effects. This should serve as a clear indication that experimentalists generally should investigate whether their results are robust to strategically inessential alterations in the presentation of games.

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Notes

1. Rapoport (1997) interprets the results of his experiments to indicate either that order of play serves as a coordination device or that it has a more serious consequence, but he does not have sufficient experimental evidence to resolve which is the correct interpretation.
2. Guth et al. (1998) test, among many other things, whether sequential games with unobserved moves will result in players choosing non-equilibrium outcomes preferred by Player 1. Quite expectedly they find that there is no support for Player 1 preferred out of equilibrium outcomes.
3. Camerer et al. (1996) conduct some experiments designed to distinguish between the first and third possible ways in which order of play influences outcomes, and they find support for the third.
4. However, leadership has its drawbacks: once the leader has moved he can no longer influence the game. For example, in a game with more than two players, if the first player has played a move which is consistent with a Nash equilibrium, after he has moved the remaining players *need not adhere* to that Nash equilibrium to the extent that they no longer have to worry about whether the first mover's choice is a best response to what they are choosing, since that move is now a *fait accompli* and there is no taking it back. Consequently, in such games the Manipulated Nash equilibrium need not result in Player 1 receiving his highest Nash equilibrium payoff. This differentiates the Manipulated Nash Equilibrium from concepts which simply focus on the outcome preferred by the first player.
5. Rapoport (1997) describes this second interpretation as 'damaging'.
6. As will be discussed below, subjects were mixed after every round. Subjects knew they were being mixed and that on average they would played each other twice in each game, once in each role. The computer interface provided no clue about the identity of a subject's partner in any round.
7. Specifically, we used the following Stata command: **`xi: xtgee s1 i.pcode i.rvcode i.hand i.seqno i.pcode*i.hand i.pcode*i.seqno, family(binomial) link(probit) robust`** where xi is a meta-command which creates dummy variables, xtgee is the general estimation command, sl is a dummy variable indicating that the relevant strategy was played, i. pcode, i.rvcode, i.hand and i.seqno designate dummy variables for presentation, information, handedness and sequence respectively. and terms such as i.pcode*i.hand generate dummy variables for all interactions of presentation and handedness.
8. Although our procedures deal with statistical dependencies across observations *within* subjects, we have not dealt with any remaining dependencies generated by the subjects' interactions with each other.
9. In interpreting the tests of strong and weak VO readers should remember this switch in null hypotheses.
10. This result pertains to the averages across both forms of presentation and all three information conditions presented in the lower third of the table.
11. Nevertheless, we retained handedness, sequence and all interactions in the xtprobit regression.
12. Player 2's Strategy **a** is dominated by **b** and **c**, that is, **a** is never a best response to any of Player 1's actions. With Player 2's Strategy **A** eliminated, Player 1's Strategies **B** and **C** are dominated by his own Strategy **A**. With Player 1's Strategies **B** and **C** eliminated, Player 2 plays his own Strategy **c**.

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