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Learning transfer in small group coordination

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Abstract

This work tests the adaptation of groups from two generalizations of the multiple-player stag hunt to a difficult third version, the notorious weakest-link game. The two training conditions either encouraged or discouraged the development of stable subgroups. Theories of modularization predict that stable subgroups will facilitate coordination in larger groups by helping them "scale up." However, internal structure may also cause "overfitting," or adaptation to only spurious features of training. In this experiment, experience with internal structure prevented coordination at larger scales, while experience in environments that discourage internal structure led to performance at least as high as in the control environments. I offer the analogy from individual learning transfer, that distracting details from superficially-similar domains may transfer and interfere with coordination. This work has implications for the development and adaptability of small coordinating groups. In particular, it demonstrates that coordination is not a monolith, and experience with one sense may impair performance under others.

Keywords: stag hunt; learning transfer; n-player games; coordination games; group structure.

Introduction

Adaptability and transfer have been a focus of group research since its inception (Bavelas, 1950; Guetzkow & Simon, 1955). The research in "endogenous" groups applies modern experimental methods and game theoretic approaches to understanding adaptability and learning during group formation.

Traditional group experiments impose groups by design, and they use careful matching procedures and information conditions to minimize interaction and reputation effects, and to maintain the independence of individual reasoners. Investigations of *endogenous* group formation encourage interactions and attend to the processes of group formation within an experiment. Endogenous group experiments permit the study of internal (often "network") structure. In groups, *internal structure* describes the heterogeneous but systematic pattern of coordinated behavior between subgroups. Internal structure can be measured by observing the behavior of group members over time. As the demands on a group change, these internal patterns should also change. For large networks, group structures can be compared along innumerable dimensions, but for the small groups featured in this study it is possible to meaningfully quantify structure with fewer variables.

Ahn, Isaac, & Salmon (2008) documented segregation processes as a result of reputation formation and individual choice. Camerer and Weber elicited unprecedented coordination in the weakest-link game by starting with successful groups of two and "growing" them slowly up to the standard 7-person case (Camerer & Weber, 2008). Their work shows that coordination can be attained if the learning process occurs in parallel with the group formation process. Across a diversity of paradigms, many other experiments have found conditions in which the internal structure created by local information improves group-level outcomes (Ahn, Esarey, & Scholz, 2009; Goldstone, Roberts, Mason, & Gureckis, 2010; Kearns, Suri, & Montfort, 2006; Mullen, Johnson, & Salas, 1991; Mason, Jones, & Goldstone, 2008).

There is also conflicting evidence that internal structure interferes with coordination among endogenous groups. Weber & Camerer (2003), complementing their "slow growth" result above, showed that combining two successful medium-sized groups can induce coordination failure in the large merged group. Rick, Weber, & Camerer (2006) hypothesized that decentralization would promote adaptability. After their result failed to materialize, they reframed the experiment in terms of learning transfer (Rick, Weber, & Camerer, 2007). Frey & Goldstone (2010) show the simultaneous emergence of internal structure and coordination failure in a multiple-player stag hunt. Participants in groups of many sizes could coordinate on equilibria that required larger quora for larger payoffs. Despite many trials and large groups, coordination failure was common, and the successes were most typical for the smallest subgroups of pairs and triplets, despite the much larger rewards available with more concentrated groups. There is no theory to reconcile the conflicting effects of group formation on individual outcomes.

This experiment explores whether internal structure will help or hinder groups in coordinating at larger scales. The complex experimental designs and large networked groups of most endogenous group experiments make it difficult to carefully distinguish hypotheses. I introduce a 4-player coordination game that elicits three types of coordination, depending on the value of an experimentally manipulated parameter. An experiment with only four players can be represented as a very small network. The design focuses on learning transfer from each of three coordination games.

Learning transfer is a growing area of behavioral game theory. Studies suggest that experiences of cooperation or coordination can transfer across very different types of games (Stahl, 2000; Devetag, 2005). In the most ambitious study, Woolley, Chabris, Pentland, & Hashmi (2010) give evidence for a general Collective

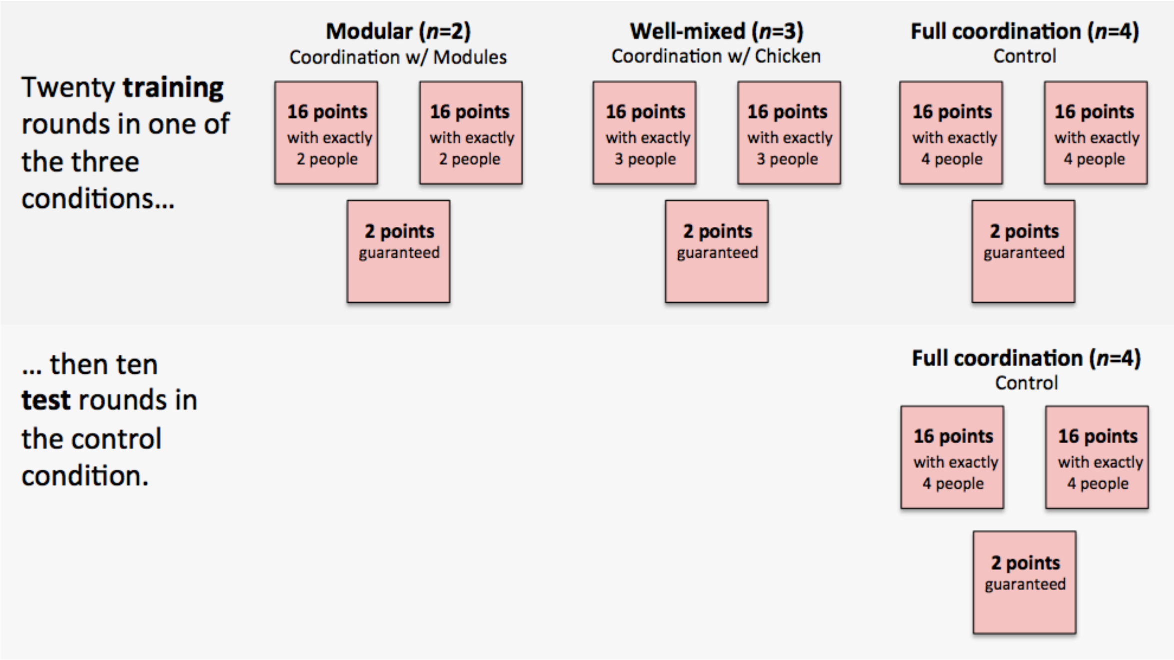

Figure: **Structure of the game, and design of the experiment**
Groups of four picked from three choices over thirty rounds of a Stag Hunt game, moving from twenty training rounds to ten identical test rounds. Two of the three choices (the top two) required coordination with exactly *n* other group members for 16 points (Stag), and the remaining choice guaranteed 2 *secure* points (Hare).

Intelligence factor by which certain groups seem to transfer easily across many unrelated collective tasks. But the processes of individual learning and transfer are complex, and we cannot cherry-pick concepts from the individual-level without acknowledging this complexity. For example, one individual-level phenomenon that complicates the idea of general intelligence is *negative transfer*, a type of learning transfer. In cases of negative transfer, a superficial similarity between two tasks will induce transfer of spurious concepts that actually hinder performance (Gagne, Baker, & Foster, 1950; Day & Goldstone, 2012). For example, tennis and badminton are superficially similar sports, but skills developed in one should not necessarily transfer to the other; Some tennis techniques, like maintaining firm wrists, will not improve performance in badminton. Negative transfer complicates general intelligence factors by introducing order effects, and generally by raising questions about what it means for two tasks to be similar or distant.

With the right design, a failure of internal structure to improve large-scale coordination implies negative transfer. Groups in this environment did in fact show negative transfer from their experience of a seemingly congruent coordination game. The consequence is that transfer is better from a less similar game—one that discouraged the slow, modular development of large-scale coordination.

Method

Participants played a novel multiple player generalization of the stag hunt, a classic two-player game. This paradigm was designed to explore the relationship between a group's internal patterns of behavior and their ability to coordinate at larger scales.

In the prototypical stag hunt, two players choose blindly to either hunt *Hare* or *Stag*. Hare offer little meat but can be caught without another's assistance. Stag reward both hunters with more food per person, but they cannot be successfully hunted by an individual alone. A decision to hunt hare instead of stag reflects an aversion to risk, because a lone stag hunter gets nothing while hare hunters are guaranteed a small but secure reward. The stag hunt captures many of the general incentives and pressures behind coordination, and the properties of agents in the stag hunt are well documented, both theoretically and empirically (Harsanyi & Selten, 1988; Camerer, 2003; Skyrms, 2004). However, upon expanding to multiple players, the number of generalizations explodes, and most extant research is in simulation.

In the multiple player stag hunt reported here—the *structured stag hunt*—players have three choices: they may hunt hare alone for a small payoff (2 points) or they may hunt either of two stag for a larger payoff (16 points). Group size in this game is fixed at four players.

The payoff structure of the two stag strategies depends on parameter *n*, which may equal 2, 3, or 4. At

$n=4$, the *Full coordination* condition, players who select one of the Stag strategies receive the large payoff only if all 4 players select it (See Figure). At this equilibrium, four hunters have successfully coordinated to hunt one of two large stag. At $n=4$, there are three pure strategy Nash equilibria, corresponding to the decision of all four players to all choose one of the three strategies. Previous work suggests that, as the game is iterated, players will settle into one of these three pure strategy equilibria (Camerer & Weber, 2007). The game also has many mixed-strategy equilibria—at all parameterizations—but I will attend only to the more salient pure equilibria. The Full coordination condition functioned as a control baseline condition for comparison with the other two conditions.

For $n=3$, the *Well-mixed* condition, only 3 players may hunt stag in order to receive a payoff. If all four players chose the same Stag strategy, then they each receive 0 points. In this condition, the proverbial stag has plenty of meat for three people, but is, perhaps, very likely to be startled by the stirrings of a larger crowd. At $n=3$, the structured stag hunt resembles the game of Chicken, in which the most profitable strategy for individual players gives the lowest payoff if all players select it.

Both theory and experiment suggest that coordination will be unstable in this condition of the game (Bornstein, Budescu, & Zamir, 1997). There are nine pure-strategy Nash equilibria in the Well-mixed condition but, unlike the other two conditions, there is no equilibrium in which all four players receive the largest payoff. Because the only symmetric equilibria involve selecting randomly from a distribution over the three strategies (mixed strategies), experience in the Well-mixed condition should select against the development of stable internal structure.

Finally, in the *Modular* condition, when $n=2$, an internal group structure becomes possible. When $n=2$ the same penalties apply if more than 2 players select the same stag strategy—players earn nothing. However, the $n=2$ condition is special because it is possible to split four players evenly between the two Stag such that all four players receive the higher payoff. The condition is called Modular because it requires division into two subgroups. With social learning, experience in the Modular condition should promote the development of an internal group structure. Based on results from previous work (Frey & Goldstone, 2010), my prediction is that groups in the Modular condition will naturally stratify between the two stag strategies over time. Whether this facilitated transfer to the Full coordination condition was an open question.

In all three conditions, Pareto dominance fails to select between the two pure equilibria involving Stag strategies, and there is an equilibrium selection problem on top of the traditional problem of selecting between Hare and a single Stag. The complexity of introducing two Stag was necessary to create the three nearly identical conditions.

Experiment

These three versions of the structured stag hunt provide the basic ingredients for distinguishing between two competing theories of how a group's internal structure influences its ability to coordinate.

Participants played the structured stag hunt in three conditions: a Full control condition and the Modular and Well-mixed conditions.

Participants played thirty rounds of the game. In all three conditions, the last ten rounds functioned to *test* performance in the Full coordination version of the game. In the control condition, the first 20 *training* rounds were also played with $n=4$. In the Well-mixed condition, groups played these first twenty rounds at $n=3$. In the Modular condition, groups played the first twenty rounds at $n=2$.

Subjects and procedure

52 psychology undergraduates played the game in 13 groups of four. Experiments were conducted over networked computers concealed in separate cubicles. Complete instructions were read aloud before participants were given the opportunity to review them individually. After the first round, participants saw their group's previous round's choices before the next round began. However, participant icons were made identical to make it more difficult to use reputation to form internal structure. Experimental sessions lasted just under five minutes on average, with about 10 seconds per round. Participants were paid a small bonus of 1¢ per point, and mean earnings were $1.25, or $15.00 an hour. The experiment was always run in the free time after other collective behavior experiments.

Measures

The main dependent variable in this experiment is the number of test rounds, out of ten, for which groups settled on one of the pure equilibria containing the Stag strategy. If internal group structure can improve higher-level coordination, then Modular groups will coordinate more successfully in test trials than the Well-mixed groups.

Other dependent variables were influenced by condition and number of rounds, including *group clustering* and *group internal structure*, *payoff*, *opting ou*t, and *fixation*.

Group clustering and *internal structure* were measured as the mean and standard deviation of the distances between participants. In each round, two participants shared distance 0 if they had made the same choice, and 1 otherwise. Summed over all rounds, two participants have distance 30 if they never selected the same choice, and distance 0 if they always selected the same choice. Using pairwise distances between group members, the structure of the group can be represented as a fully connected distance network. If the mean of these distances is low, participants are tending toward clustering on the same choice. For small groups, the standard deviation of distance is equivalent to closeness centrality (Frey & Goldstone, 2010), a measure of relational structure in networks. If the standard deviation is high, participants tend

Dependent measures	**Grand Mean**	**Full (*n*=4; control)**			**Well-mixed (*n*=3)**			**Modular (*n*=2)**		
		Train	**change**	**Test**	**Train**	**change**	**Test**	**Train**	**change**	**Test**
Performance	1.92	0.25		3	**3.5 ***	↑	*4.25*	1.25		*0*
Group distance	3.56	3.8	↓	1.0	3.81	↓	2.25	**4.6 ***		**4.25 ***
Group structure	2.82	3	↓	0.92	2.9	↓	2.25	**3.48 ***		**3.41 ***
Payoff	4.19	1.6		5.9	**4.8 ***		7.2	**5.56 ***		0.712
Opting out [0,1]	0.09	0.15		0.14	**0.074 ***		0.045	**0.045 ***		0.089
Fixation [$0.3\bar{3}$,1]	0.7	0.66	↑	0.93	0.71	↑	0.79	0.57	↑	0.72

Table: Summary measures of group performance
Distance is reported instead of clustering. Distance and clustering are inversely related.
bold* reports a significant effect ($p<0.01$). In a "Train" column, comparison is with respect to training in the control condition. In a "Test" column, comparison is with respect to tests in the control condition.
Arrows report significant effect directions of experience, within a condition, from Train to Test ($p<0.01$). All regressions report statistics distributed on F(5,30).
Italics in upper right Test columns represent one significant post-hoc test between Modular and Well-mixed test performance.

to be close to some group members and distant from others. By this definition, a modular arrangement of two groups of two will register as having the highest internal structure.

Payoff was the mean number of points per participant. *Opting out* was measured as the percentage of secure Hare choices, out of thirty. *Fixation* measured pure strategy play, the phenomenon of choosing the same strategy repeatedly. Fixation was defined as the maximum value in a participant's observed distribution of choices. By this, pure-strategy play will register a maximum fixation of 1.0, and random mixed-strategy play will register the minimum value of $0.3\bar{3}$.

Results

Two separate ANOVAs were used to compare the three conditions in the training trials separately from in the test trials. These analyses encoded three dummy variables, one for each condition. Additionally, a multiple regression tested the effects of experience within each condition. The adjusted R^2 of the regression over performance was 71%, and the model was significant ($F(6,30)=11.2$, $p<0.01$). To maintain the independence of observations, these analyses were conducted at the group-level. Means and significance values are summarized in the Table.

Looking first at the 20 training trials of the control condition, it is clear that Full coordination is difficult. Participants successfully coordinated on Stag in an average of 0.5 of the 20 training rounds. Groups performed much better during training in the Well-mixed condition, coordinating successfully on a Stag in 7 of the 20 training rounds (and significantly more often than groups in the Full coordination condition; $F(1,21)=24$, $p<0.01$).

During training in the Modular condition, participants settled upon the stable configuration (two subgroups of two) in only 2.5 of the 20 training rounds. This was not significantly higher than control. However, partial solutions were more common, with 21 instances (out of a possible 40, or two per round), of exactly two subjects successfully coordinating on a Stag.

Performance in the control condition increased (non-significantly) from 0.5/20 to 2.75/10 during the final ten test rounds. The first ten rounds of the Full condition may be understood as an alternative baseline, corresponding to an entirely untrained experience of the game. Across all sessions of the Full coordination condition, no groups successfully coordinated on Stag in the first ten rounds of training. Variance in performance was much higher in this condition than in the other two; Groups in the control condition tended either to converge stably on coordination success (10/10 test trials) or coordination failure (0/10 test trials), with little behavior in between these extremes.

Groups trained in Well-mixed trials showed improvement upon advancing to the test trials ($t(32)=3.16$, $p<0.01$). Mean performance on test was 4.25 out of 10 rounds. This was not significantly different than the test performance of the control group. However, a t-test showed that after training in the Well-mixed condition, groups exhibited better test performance than Modular groups ($t(3)=-5.67$, $p=0.010$), even though the Well-mixed game is less similar to the Full coordination game.

Across all test rounds of all groups in the Modular condition, no group successfully coordinated on Stag during test (0/20). Groups in the Modular condition did not show significantly different performance between training and test trials.

Group clustering, group internal structure, payoff, opting out, and fixation were modeled in the same manner as performance, with a linear model to establish the effects of increasing experience in the game, and separate ANOVAs for train and test trials to establish differences between the three conditions. These dependents were also modeled at the group level. Though many of these results may not become motivated until the discussion, means and significance values are summarized in the Table.

Groups exhibited significant internal structure. In the Well-mixed and Full coordination conditions, experience in the game (number of rounds played) predicted increased clustering ($t(32)=-5.86$; $t(32)=-7.6$, respectively—both p<0.01) and decreased internal structure (t(32)=-3.95; t(32)=-5.95, both p<0.01). Clustering and structure did not change for Modular groups, and during test trials, only Modular groups showed less clustering and more internal structure than control groups (F(1,33)=6.22, p<0.01; F(1,33)=6.76, p<0.01).

Payoffs in the training rounds were significantly higher in both the Modular and Well-mixed conditions than in the Full coordination condition (F(1,21)=14.9, p<0.01; F(1,21)=20.5, p<0.01). These differences did not persist between the test trials, and the change between train and test trials was not significant in the regression.

Opting out (choosing the secure payoff) showed the same pattern as payoffs. Opting out was significantly below control during the training of both Modular and Well-mixed groups (F(1,21)=13.2; F(1,21)=12.7, both p<0.01), but these changes did not persist in test and were not reflected in the model of experience. Over all trials and conditions, only 9% of choices were to the assured payoff.

Over all subjects, mean fixation was 70%; the most common strategy selected by a given subject was selected for 70% of the rounds. Fixation increased with experience in all three conditions, but did not differ significantly across conditions (Control: t(32)=6.06, p<0.01; Well-mixed: t(32)=4.83, p<0.01; Modular: t(32)=2.99, p<0.01)

Discussion

In the Full coordination control condition, groups face a more complex version of the already-difficult weakest-link game (Van Huyck, Battalio, & Beil, 1990). They performed moderately well in the test trials.

In the Well-mixed condition, groups showed moderate performance solving the n=3 coordination problem, and their performance on test was at least as good as that of groups trained in the control condition. Data support the prediction that these groups would not form modules or other manifestations of an internal structure, or at least not to the degree exhibited by groups in the Modular condition.

For groups trained in the Modular condition, there was a stable efficient outcome for two subgroups of two whereby all four players receive the largest payoff. Evidence supports the prediction that this environment promotes the emergence of stable subgroups; groups in the Modular condition did in fact exhibit high internal structure consistent with a modular group structure. However, while groups in this condition earned more during training than other groups, they were unable to settle consistently upon two groups of two simultaneously. Modular groups were also unable to use their experience within a structured group to coordinate upon stag during the test rounds.

Why did groups with internal structure test worse than groups without internal structure? I will reject a few possibilities. The first is that subgroups of two are small, while subgroups of three are almost as large as subgroups of four. Previous work has shown that incremental growth can aid coordination at higher scales (Camerer & Weber, 2008) while larger growth spurts can hinder it (Weber & Camerer, 2003). However, this perspective ignores that fact that coordination in all three conditions is coordination among four people. The structure of the Well-mixed condition, which creates conditions like those in the game of Chicken, makes successful coordination more than a matter of finding three willing risk-takers; it also involves coordinating with a fourth who will forgo the greatest payoff. Perhaps subjects in the structure condition learned to randomize. This would be consistent with the moderately efficient mixed strategies that exist in this condition. But mixed strategies are even more efficient in the well-mixed condition, which should have elicited randomized behavior most effectively. Subjects in the structure conditions could not have fixated too intently on specific strategies because fixation was not higher than in the other conditions. Poor performance can also not have been due to Modular groups opting out and selecting Hare; opting out was also not significantly higher than in any other condition during test, and it did not change with experience.

One more possible explanation is that internal structure itself caused the coordination failure at higher levels. The measures of group structure indicate that participants in the Modular condition overcame the difficulties of positively identifying each other and managed to form groups with internal structure. The structures that the Modular condition selected for were congruent with the demands of Stag in the Full coordination condition; subgroups need only merge into one larger group. However, the experience of stable subgroups seems to have transferred negatively to the Full coordination trials.

Conclusion

This work looks at the interaction of individual reasoning processes as group members interact and learn to coordinate. Some previous work suggests that building up small coordinating subgroups will aid growth to full-scale coordination. This work supports competing claims, that the spontaneous emergence of local stable patterns of coordination may interfere with large-scale coordination. While groups without stable internal structure performed as well as control groups, groups that adapted to match the modular structure of their problem found that this structure interfered with full-scale coordination in the test environment. While groups are certainly adaptive in an important sense, adaptability is not a universal, or even well defined property of group behavior. Similarly, not all experiences of coordination and cooperation are the same, and experience with one type of coordination can impair performance in others.

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